National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Mammoth Cave National Park

Natural Resource Report NPS/MACA/NRR—2021/2258





ON THIS PAGE
Mammoth Cave National Park protects at least 1,925 species, including this midland mud salamander (Pseudotriton diastictus). Photo by John MacGregor

ON THE COVER
Protecting Earth's most extensive known cave system, Mammoth Cave National Park's global significance has been codified through its designation by the United Nations as both a World Heritage Site and an International Biosphere Reserve.

Natural Resource Condition Assessment

Mammoth Cave National Park

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Executive Summary

The common feature of all America national parks is that they protect natural, and often cultural, resources. The National Park Service's Natural Resource Condition Program (NPS 2018a) provides a framework to evaluate the conditions of a park's natural resources as a "snapshot in time" by using credible science to report on conditions and trends, critical data gaps, and threats for a broad subset of a particular park's resources.

This document reports on the results of an analysis of such conditions for the natural resources of Kentucky's Mammoth Cave National Park (MACA). Established in 1941 with an area of 21,380 hectares, MACA protects a globally significant *karst* landscape—those that form on soluble rocks such as limestone in which caves, underground rivers, sinkholes and large springs are common. The centerpiece is the Mammoth Cave System, which has a current known length of more than 660 kilometers, by far the world's most extensive known cave system. The cave protects evidence of more than 4,000 years or human exploration, including artifacts showing that ancient explorers travelled up to eight kilometers from the nearest entrance, the deepest cave exploration of ancient people anywhere in world. A rigorous, sustained exploration effort has been underway for more than 60 years, and exploration continues with no end in sight. There are over 400 other known caves in the park, several of which are of major importance themselves. Because of the world-class nature of the hydrogeologic resources here, the area has attracted scientists, students and explorers from around the world and indeed what are now fundamental principles of karst science have been established through research efforts here. The NRCA project team collectively have more than 75 years of experience in working closely with park's resources, and its scientists, in research, teaching, conservation, and just exploring and enjoying the park itself.

Although Mammoth Cave served as the principal motivation for the establishment of the park, MACA also serves to protect many other important resources on the surface and underground. The Green River, which bisects the park flowing from east to west, has among the highest biodiversity of North American river systems, with a range of diverse habitats that support at least 150 species of fish and 70 mussels. In the park, there are at least 43 endemic species, those not found anywhere else in the world. The park is home to at least 1,925 species (Appendix A), a number of which are threatened or endangered.

Based on scoping meetings and close communication with the staff of MACA's Division of Science and Resource Management (S&RM) and the NPS Cumberland Piedmont Inventory and Monitoring Network (CUPN) we chose 13 focal natural resources to form the framework of the report. These include four physical/landscape topics (surface air, cave air, geology and soils, and hydrology/water

resources), six biological topics (bats, birds, herpetofauna, native communities, surface aquatic communities, and cave communities), and three that evaluate human influences on the resources (fire management, night skies, and human impacts).

There are a range of conditions and trends, and although many of the park's resources are in good condition and adequately protected, there are challenges. A major threat posed to many species of cave-dwelling bats in MACA and elsewhere is the deadly fungal disease known as White-nose Syndrome (WNS). Since discovery of the disease in the United States in 2006, and documentation in the park as of 2013, WNS in bats has been an important issue related to cave and bat management at MACA. Multiple bat species including the federally protected Indiana bat and northern long-eared bat have shown substantial declines in response to WNS. The declines observed in some winter-roosting species is as high as 93% (little brown bats at Colossal Cave since 2013). In response to the disease, monitoring and surveillance of bat populations has increased dramatically, colonial bat roosts were closed year-round except for approved research (although most have re-opened for normal cave research), researchers have been required to decontaminate all gear when going to caves that are not known to be WNS positive, and visitors leaving the cave are required to walk across cleaning mats to remove spores that may spread WNS. For now, there are no treatments or intervention other than monitoring but there is active research underway by a variety of laboratories.

Other major challenges include the threats to native plant communities, which are very diverse due to the range of habitats available in the park, from invasive plants and exotic pests and diseases. There are at least 174 species of non-native plants in the park (Appendix B) including 31 each of species designated as severe and significant, respectively, by the Kentucky Invasive Plant Council. The park continues to invest a significant effort in eradication of these plants, including creative leveraging to utilize the assistance of student and intern groups but it is an overwhelming, labor-intensive task, and if future resources permitted, developing a full-time crew for this work would be an important investment. The emerald ash borer (*Agrilus planipennis*), which has killed millions of ash trees since being accidentally introduced into the US in 2002 (USDA 2018a), was confirmed at MACA just prior to this writing. Another exotic pest that has seriously impacted eastern hemlock trees (*Tsuga Canadensis*) through the Appalachian Mountains, the hemlock wooly adelgid (*Adelges tsugae*) has not reached the park but is throughout eastern Kentucky. The beautiful and relatively remote stands of hemlocks tucked in the valleys of Bylew Creek and Cubby Cove in the park's northwest sandstone areas are to some degree isolated from the current range of the pest, but time will tell.

There are also bright spots where resources are in good condition or even improving. Although MACA continues to have significant air pollution problems, the situation has improved in the last ten years in some parameters, including rainfall acidity, sulfate, visibility, ozone, and wet deposition with amelioration of the impacts of regional coal combustion. These include technological improvements at the plant level, use of cleaner coal from Wyoming's Powder River Basin, and increased use of natural gas to replace coal for largely economic reasons. While regional air pollution is obviously a resource threat largely out of the control of NPS land managers, these improvements have been significantly influenced by legislation and other legal activities of environmental groups including the National Parks Conservation Association. Related to this, and also getting better as

visibility improves, are MACA's night skies. Many cavers who have explored and mapped the Mammoth Cave System have memories of coming out of the cave at 3 am after a long cave trip on some winter night and walking back to the car through the cold, wholly exhausted but still staring up at a stunning Milky Way streaming across a beautiful dark sky. This is another special MACA feature, increasingly rare for the eastern US, and an example of how our assessments are based on quantitative data: most of the park has a Class 4 rating on the Bortle Scale as well as consistent Unihedron Sky Quality Meter (SQM) readings over 21.0, which qualifies it for Silver Tier Status from the International Dark Skies Association for "exemplary nighttime landscapes."

Conditions of the natural resources of MACA are described in detail below. In general, the authors of this report are in full agreement that this is a well understood, well cared for, and carefully protected national park. In cycles of waxing and waning resources to do so, through our work we more fully than ever appreciate and laud the scientists, administrators, support staff and partners—largely volunteers—who have made this happen over more than seven decades as a national park.

Acknowledgments

The authors have enjoyed a long and rich history of collaborations with the staff of MACA as well as the NPS Cumberland Piedmont Inventory and Monitoring Program. We appreciate the two Superintendents who have spanned the project, Sarah Craighead and Barclay Trimble, along with Deputy Superintendent Bruce Powell, for making this and many other opportunities possible. Much of our knowledge of the park comes from interactions with MACA's S&RM Division, including Division Chiefs Bobby Carson and later Tim Pinion, and their staff including Larry Johnson, Brice Leech, Rick Olson, Rick Toomey, Shannon Trimboli, Liz Thomas, and Eddie Wells. CUPN staff on whom we have relied on include Network Manager Teresa Leibfreid as well as Clare Bledsoe, Sammi Jo Eubank, Kurt Helf, Johnathan Jernigan, Joe Meiman, Bill Moore, Lillian Scoggins, Steve Thomas, and Brenda Wells. Lora Peppers of the Law Enforcement Division and Dave Spence, Chuck Decroix, and Johnny Merideth of the Interpretive Division provided useful information.

We appreciate the efforts and support of Dale McPherson, Acting Region 2 Coordinator for the NPS Natural Resource Condition Assessment Program for his patient support and guidance in the administration of this project.

We especially acknowledge, and have drawn heavily upon, the work of Joe Meiman. He has made great contributions to the understanding of MACA's water resources, and wrote the outstanding *Mammoth Cave National Park Water Resources Management Plan* (Meiman 2006). Water could be thought of as the "glue" that ties virtually all MACA's resources together, in both the surface and subsurface, and it is possible that few national parks have as thorough an accounting of water resources as this document has provided. Other scientists who provided information and/or photos included Art Palmer, John MacGregor, Monte MacGregor, Blaine Ferrell, Kate Slankard, and Mike Hensley. Ouida Meier and Katie Losekamp made important contributions through their efforts to organize water quality data and other tasks, and we thank Lillian Groves and Rhylea Lawson for assistance with cave photography.

WKU students Matthew Riggle and Justin Cave also helped produce maps that appear in the report.

We cannot protect what we don't understand, and a great challenge exists at MACA because many of the park's most important natural resources are hidden underground. Many parts of the park's underground world have only been visited by a small handful of people and much of what is known about even the basic geography of the cave exists because of a great volunteer partnership over more than six decades between the National Park Service and the Cave Research Foundation (CRF) and the Central Kentucky Karst Coalition (CKKC). CRF kindly provided cave maps for this report and the associated GIS database and in particular we thank Pat Kambesis, Bob Osborn, Dave West, and Charles Fox. Numerous other cave explorers have contributed to this effort, and among them we'd like to especially acknowledge Jim Borden, Jim Currens and their colleagues with the CKKC, as well as Joel Despain and Pat Kambesis and their colleagues who are exploring and provided the data for Whigpistle Cave.

Prologue

Publisher's Note: Changes in publishing requirements, and in some cases scientific delays, resulted in several NRCA reports not being published in a timely manner. These publications reported on studies initiated in the 2013–16 timeframe. Since Natural Resource Condition Assessments provide a snapshot-in-time evaluation of park resource conditions, it is important to note that data discovery and analyses for this study was conducted a few years prior to publication. Thus, park conditions reported in this document pertain to that time period. Please see the Publisher's Note at the beginning of the Executive Summary or Chapter 2 for dates specific to this report.

List of Acronyms

CAM Network – Cave Atmospheric Monitoring Network

CRF – Cave Research Foundation

CUPN – Cumberland Piedmont Network Inventory and Monitoring Program

EPA – US Environmental Protection Agency

GIS – Geographic Information Systems

KDEP – Kentucky Department of Environmental Protection

I & M – Inventory and Monitoring

IRMA – the NPS Integrated Resource Management Applications Portal

MACA – Mammoth Cave National Park

MACA WRMP – 2006 MACA Water Resources Management Plan

MHSA – Mine Health and Safety Administration

NADP – National Atmospheric Deposition Program

NEH – National Endowment for the Humanities

NPS – National Park Service

NPSTORET – NPS version of STORET Data Warehouse

NRCA – Natural Resources Condition Assessment

NRR – Natural Resource Reports

PI – Principal Investigator

S&RM – MACA's Division of Science and Resource Management

STORET – the US EPA STOrage and RETrieval (STORET) Data Warehouse for water quality

UN – United Nations

UNESCO – United Nations Educational, Scientific, and Cultural Organization

USFWS – US Fish and Wildlife Service

USGS – US Geological Survey

WKU – Western Kentucky University

WNS – White-nose Syndrome

A Note on Measurement Units

Many quantitative measurements described by values requiring units are presented in this report. We have chosen to use metric units throughout. In a relatively few cases, however, English (feet, miles etc.) appear. This includes where these occur in direct quotes, and in the use of navigational markers that identify specific locations along the Green River, shown as, for example “Green River Mile 207.5” or “river mile 207.5.” These locations are well known to researchers and others familiar with the park and are shown on maps, and it was felt that changing these to kilometers would add more confusion than clarity.

Chapter 1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs Strive to Provide…

- *Credible condition reporting for a subset of important park natural resources and indicators*
- *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement—not replace—traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs:

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and GIS (map) products; [4]
- Summarize key findings by park areas; and [5]
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

[1] The breadth of natural resources and number/type of indicators evaluated will vary by park.

[2] Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

[3] NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

[4] As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

[5] In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ⇨ indicators ⇨ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management

targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

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Chapter 2. Introduction and Resource Setting



Much of what is known about the resources of MACA is due to cave explorers and scientists who have spent decades exploring, mapping, and studying the park's caves. Many have been both. Rick Olson, here at a small waterfall of Mammoth Cave's Gallows Avenue, has for many years both explored and mapped the cave on weekend expeditions as a member of the Cave Research Foundation (see Appendix C) and studied the cave and park as an Ecologist with MACA's Division of Science and Resource Management. Photo by Art Palmer.

2.1. Introduction

2.1.1. Enabling Legislation

On May 25, 1926, Congress approved an Act to provide for the establishment of the Mammoth Cave National Park in the State of Kentucky, and for other purposes (44 Stat. 635), which read:

> Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That when title to lands within the area hereinafter

> referred to shall have been vested in the United States in fee simple, there shall be, and there is hereby, established, dedicated, and set apart as a park for the benefit and enjoyment of the people, the tract of land in the Mammoth Cave region in the State of Kentucky, being approximately seventy thousand six hundred and eighteen acres, recommended as a National Park by the Southern Appalachian National Park Commission to the Secretary of the Interior, in its report of April 8, 1926, and made under authority of the Act of February 21, 1925; which area, or any part or parts thereof as may be accepted on behalf of the United States in accordance with the provisions hereof, shall be known as the Mammoth Cave National Park: Provided, That the United States shall not purchase by appropriation of public moneys any land within the aforesaid area, but such lands shall be secured by the United States only by public or private donation. (U.S.C., 6th supp., title 16, sec. 404.)

A long and relatively complicated period of land acquisition through federal, state and private partnerships followed, which eventually did include appropriation of public funds (NPS 1970, Goode 1986, Algeo 2004, WKU 2011). On July 1, 1941, after the required 18,336 hectares had been acquired by purchase or condemnation, Mammoth Cave National Park, which now also goes by its NPS designation MACA, was established.

In 1905 members of the Kentucky Congressional delegation first suggested the idea of a national park in the southcentral Kentucky cave area to the Secretary of the Interior (NPS 1970). While over the next few decades several unsuccessful bills were written, it was only in April of 1926 that the Southern Appalachian National Park Commission recommended national park status for the Mammoth Cave Region. The report (NPS 1970) cited:

> limestone caverns which contain “beautiful and wonderful formations,” the “great underground labyrinth” of passageways “of remarkable geological and recreational interest perhaps unparalleled elsewhere,” and the “thousands of curious sinkholes of varying sizes through which much of the drainage is carried to underground streams, there being few surface brooks or creeks;”
>
> The rugged topography and “areas of apparently original forests which, though comparatively small in extent, are of prime value from an ecological and scientific standpoint, and should be preserved for all time in its virgin state for study and enjoyment;”
>
> The “beautiful and navigable Green River and its branch, the Nolin River,” which flow through the forests of the area; and “All of this offers exceptional opportunity for developing a great national recreational park of outstanding service in the very heart of our Nation’s densest population and at a time when the need is increasingly urgent and most inadequately provided for.”

According to Algeo (2004) the motivations for the movement to establish the park and to “nationalize” the cave area were based on a mix of strategic economic development, boosterism,

sectional pride, and conservation. The L&N Railroad had acquired large land holdings including about 1,725 ha, with cave rights, acquired as a wholly owned subsidiary established in 1898 called the Colossal Cave Company. L&N officials encouraged local businessmen and civic leaders to form the Mammoth Cave National Park Association, a non-governmental organization charged with raising funds to purchase land for donation to the federal government, which was organized in Bowling Green in October 1924 (WKU 2011).

There were conservation motivations, as exploitation of stalactites, cave crystals, and other associated items offered for sale as souvenirs to tourists provided a conservation rationale for nationalizing the cave system. Federal ownership could also help to eliminate sometimes destructive economic competition among cave operators that along with mining of mineral formations, threatened to destroy the underground landscape that was the very basis for economic development through tourism.

2.1.2. Geographic Setting

MACA, which covers 213.7 square kilometers, lies within parts of Kentucky's Edmonson, Hart, and Barren Counties (Figure 2.1). It is about midway between Nashville, Tennessee to the south and Louisville, Kentucky to the north, lying just to the west of Interstate Highway 65. Outside of the park this is a rural, agricultural area. In terms of the landscape, MACA lies within the dissected Mammoth Cave Plateau, just to the north of, and influenced by, the Pennyroyal Plateau. The name for the Pennyroyal region has been reported to originate from the Pennyrile mint plant (*Mentha pulegium*), which was discovered by early settlers. The Pennyroyal region is characterized by warm, yet moist conditions. Summers are usually humid and warm, and winters cool. In the winter, wind currents are commonly from the north and in the summer, the weather patterns are influenced by air from the Gulf of Mexico. Table 2.1 provides the monthly temperature normals for MACA (NPS 2015).

Table 2.1. 30-year climate normals (1981–2010) for MACA (NPS 2015).

Climatic Measure	Measure Descriptor	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Temperature (°C)	Max	7.8	10.6	16.1	21.7	26.1	30.0	31.7	31.1	28.3	22.2	15.6	8.9	20.8
	Min	−2.2	0.0	3.9	8.3	12.8	15.6	20.0	19.4	15.0	9.4	4.4	−0.6	9.1
Average Precipitation (cm)	Total	8.8	10.0	11.7	11.2	13.8	11.2	11.6	10.4	10.2	9.7	11.0	13.1	132.7

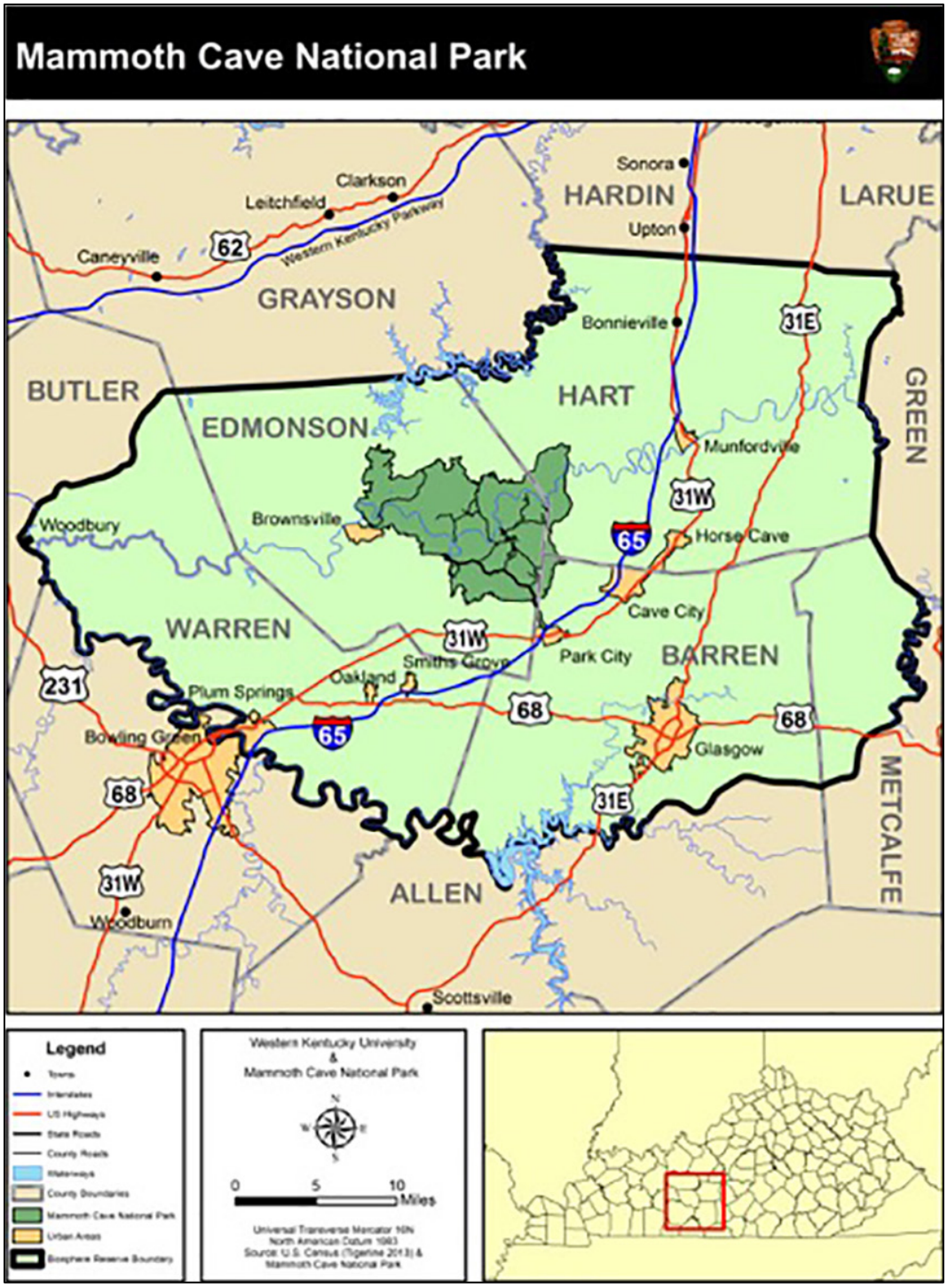


Figure 2.1. Location of MACA. Map by Katie Algeo.

Prior to MACA becoming a National Park, as families were resettled to other locations outside of the park's boundaries, the Civilian Conservation Corps (CCC) coordinated four camps within the future boundaries of the park. To facilitate the transition of home sites and farm fields to National Park condition requirements, removal of buildings and fences was considered essential. The CCC also

began planting trees to facilitate reforestation of the landscape. An inventory of wildlife was also important. Claude Hibbard, the pre-park resident wildlife technician, conducted the first bird and mammal surveys of the area.

Understanding the habitats that Hibbard observed while conducting surveys is informative. In the mid 1930s, the majority of the park's landscape was still open farm fields with many small roads connecting family home sites to their neighbors. Indeed, some landowners had not completely moved out of the area. The Civilian Conservation Corps (CCC) was charged with initial restoration of the appearance of the landscape to that of mature forest.

Aerial photographs in the same vicinity from 1951 and 2010 highlight the substantial land-type shift towards forest. Hibbard noted more prairie and woodland edge species compared to the more recent surveys. Of the 160 bird species found in 1934 and 1935, 41 were not found in the 2005 survey. Interestingly, while the wild turkey (*Meleagris gallopavo*) was labeled extinct in Hibbard's survey, wild turkeys are frequently observed along the roadways and throughout the park today.

2.1.3. Visitation Statistics

MACA had 566,895 recreation visitors in 2015 (NPS 2016a; Figure 2.2). The apparent precipitous drop in visitation statistics in 2007 due to an NPS policy decision to remove consideration of local vehicles simply transitioning through the park from being considered as visitors. Under the new guidelines, the average visitation has been around 500,000. Summer months are the busiest. Most MACA visitors come to participate in the cave tours. However, some utilize the 128 km (70 mi) of hiking trails at the park to watch birds, view wildflowers, or go hiking. Park staff also offer interpretive talks and various educational programs.

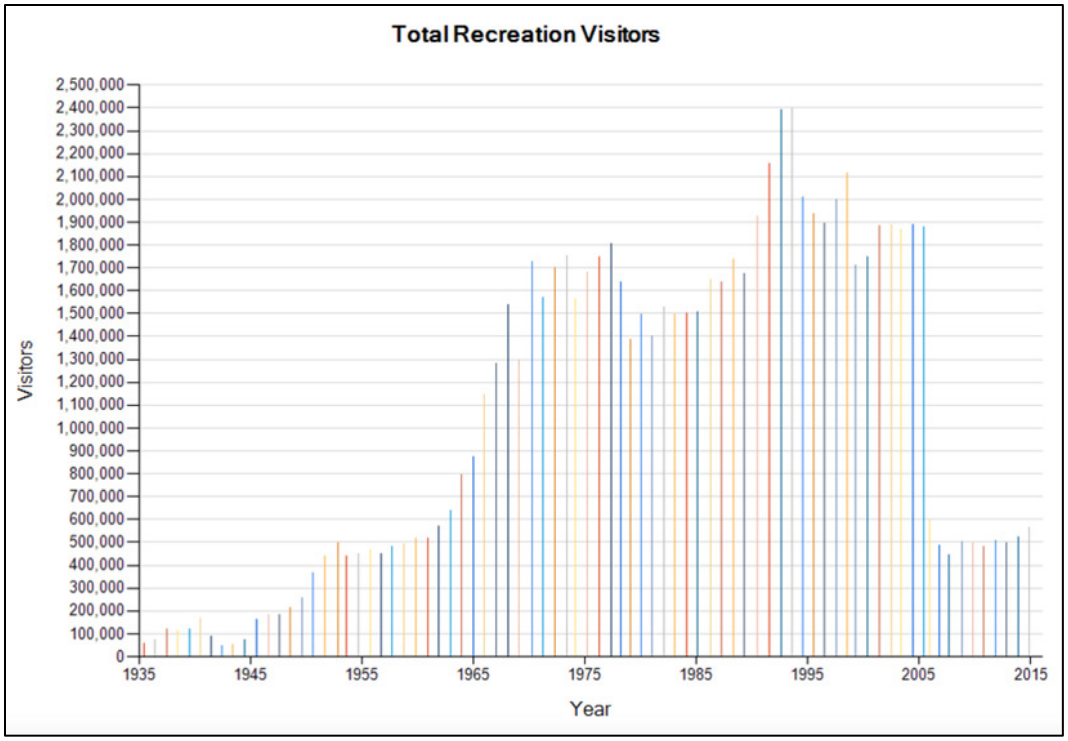


Figure 2.2. Recreation visitor usage at MACA. Source NPS 2016a.

2.2. Natural Resources

2.2.1. Physical Resources

The Green River watershed in the Commonwealth of Kentucky extends over 27,400 mi^2 and is divided into two hydrologic units—The Upper Green River Basin, which is the part of the watershed upstream from the confluence of the Barren River and the Green River and the downstream portion or the Lower Green River basin. The Upper Green River basin encompasses MACA, with the Green River flowing from east to west through the park. The Upper Green River supports a great biodiversity of fish, macroinvertebrates and freshwater mussels, many of which exist only in this part of the watershed. The headwaters of the Green River are characterized by bedrock of limestones, sandstones and shales. The limestone areas have well-developed karst topography and are characterized by vast sinkhole plains which take in virtually all surface drainage and channel the water through caves and other underground passages. The sinkhole plain in central Kentucky has approximately 5.4 sinkholes per km^2 over a 153 km^2 area.

MACA has approximately 1,300 flowering species in a relatively compact area, and is located in the transitional zone between the open grasslands and drier oak-hickory forests to the west, and the moister mixed mesophytic forests to the east. It is likewise located transitionally between the sub-tropical climates to the south and the colder climates to the north. Many of the plant species found in the park are at the northern, southern, eastern, or western limits of their natural range.

Contributing even more to the diversity of the flora is the wide variety of habitats supporting differing plant communities. There are dry upland flats and sandstone-capped ridges, limestone

exposed slopes, ravines and karst valleys, broad alluvial bottoms along the Green River, gorge-like hemlock ravines, deep sinks with exposed subterranean streams, old-growth timber, successional growth forests, barrens and savannah habitats, and wetlands, including ponds, forest swamps, springs, seasonal wet woodlands, and cobble bars and banks along the Green River.

While as in all national parks there is a wide variety of resources that are protected, the Mammoth Cave System is the dominant resource around which the park owes its existence. In contrast to many natural resources, however, the cave is essentially hidden away from sight, and its geography and nature have only been revealed through a remarkable program of exploration and survey. This stretches back thousands of years to the Native Americans, and a modern, sustained effort underway for the last 70 years. In Appendix C, we summarize the exploration and survey of the cave system.

2.2.2. Biological Resources

Even though MACA is known for its subsurface resources, it also contains forests, springs, prairie, and pleasant vistas. In central and western Kentucky, the "Barrens" was an extensive one to two million hectare region of tallgrass prairie and savannah that covered the area that includes MACA prior to Euro-American settlement. Today, barrens (or prairies) in the park are limited to small areas, none greater than 16 hectares. Although very few of these barrens have actual remnant prairies from the 1700s, several are in areas where there were prior barrens and some remaining native seed bank. Other small prairies have been planted by the park using local seed to preserve this rare habitat in the park. The park is home to the principal prairie grasses such as big bluestem (*Andropogon gerardii*), Indian grass (*Sorghastrum nutans)*, and little bluestem (*Schizachyrium scoparium)*. Associated flowering plants such as prairie dock (*Silphium terebinthinaceum*), purple coneflower (*Echinacea purpurea)*, Culver's root (*Veronicastrum virginicum)*, and tall coreopsis (*Coreopsis tripteris)* are also present.

MACA is transitional between the drier Oak-Hickory Forest Region to the west and the mixed Mesophytic (medium moisture) Forest Region to the east and north. More than 1,300 species of flowering plants, including 84 species of trees can be found. Past botanical surveys in the park have found 38 species listed as Endangered, Threatened, or of Special Concern by the Kentucky State Nature Preserves Commission. The diverse habitats of MACA are under threat by a variety of invasive plants.

In the broad uplands, oak-hickory forest covers relatively large areas of acid mesic-subxeric and calcareous sub-xeric habitat types. North of the river, sandstone capped uplands with similar habitats support oak-hickory forest. Moist ravines connected with the major river valleys support beech (*Fagus grandifolia)*, maple, and tulip poplar (*Liriodendron tulipifera)* in largely calcareous mesic habitats. On the floodplain alluvium, boxelder (*Acer negundo)*, sycamore (*Platanus occidentalis*), and river birch (*Betula nigra*) complement beech and maple. These habitats receive limited sunlight to dry fuels, and are watered by runoff. In the driest limestone habitat types (calcareous xeric and subxeric), especially on south to west facing slopes, cedar-oak glades prevail. The inherent dryness of the site favors the growth of drought tolerant species such as blue ash (*Fraxinus quadrangulata)*. Acid xeric habitats support nearly pure but narrow stands of Virginia pine (*Pinus virginiana)* and chestnut oak (*Quercus prinus*) along sandstone cliffs facing south to west.

The Mammoth Cave Big Woods consists of 120 hectares of forest and is considered one of the largest tracts of forest in Kentucky that was never clear-cut or farmed. This area is listed as a Natural Heritage Site by the Kentucky State Nature Preserves Commission. The forest includes a large number of oak species, including white (*Quercus alba*), northern red (*Q. rubra*), blackjack (*Q. marilandica*), post (*Q. stellata*), and black oak (*Q. velutina*). It also includes various hickories, Virginia pine, butternut (*Juglans cinerea*), and even some small American chestnut (*Castanea dentata*). Recent field work at Mammoth Cave Big Woods suggests that much of the area is not "virgin" old-growth, but instead appears to be of a mix of old-growth and second-growth forest. Many very old and large trees are present. Approximately 45 percent of park land was used for agricultural purposes prior to park establishment. These areas are largely dominated by eastern red cedar (*Juniperus virginiana*) and Virginia pine mixed with deciduous trees along the outer margins. Surface animals are typical of an eastern hardwood forest.

Larger mammals include white-tailed deer (*Odocoileus virginianus*), fox, raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), woodchuck (*Marmota monax*), beaver (*Castor Canadensis*), rabbit (*Sylvilagus floridanus*), and squirrel. Smaller mammals, such as bats, mice and chipmunks are also common. Birds such as mourning doves (*Zenaida macroura*), whippoorwills (*Caprimulgus vociferous*), owls, hawks, woodpeckers, warblers and bald eagles (*Haliaeetus leucocephalus)* are routinely observed. Wild turkeys, reintroduced in 1983, are now regularly seen by visitors.

The Green River supports a high diversity of fish and three species of cavefish live within the park's aquifers. Of particular note are the over 50 species of mussels, including seven on the endangered species list, that live in the park.

More than 160 animal species are regular inhabitants within the Mammoth Cave system. These species are divided almost equally among three classes: obligate cave dwellers (troglobites), facultative species which can complete their life cycle in or out of caves (troglophiles), and those that use caves for refuge (trogloxenes). Because of the region's unique history, the tremendous variety of abiotic conditions, and the presence of key trogloxene species, the south-central Kentucky karst has cave species and biotic cave communities that are among the most diverse in the world. Although Mammoth Cave is not currently used by large numbers of bats, eight species, including two that are federally listed and one that is threatened, do live in the cave. Like bats, crickets are trogloxenes as well. They spend much of their life in the cave but depend on night-time forays on the surface to gather food. Crickets are extremely important in delivering energy, in the form of droppings, eggs and carcasses, to other animals in the cave.

Since Mammoth Cave was formed millions of years ago, many types of speleothems, or cave formations, have developed throughout the cave system such as stalactites, stalagmites, columns travertine dams, and helictites. Stalactites form on ceilings and overhangs over long periods of time as water seeps through limestone leaving thin, hollow calcite soda straws. Continual water over time transforms the straws to thicker formations that resemble icicles. Water drips on the floors of the cave from overhead. The water leaves calcite deposits which build up making a mound. Continued dripping water causes the mound to grow upward, forming stalagmites. When stalactites and stalagmites meet and grow together, they form columns. Mammoth Cave has other formations that

occur when stalactites blend together to form sheets or drapes. Curly, tangled-looking spaghetti calcite formations called helictites can be seen on some of Mammoth Cave's ceilings and walls. Mammoth is also home to gypsum formations known as "gypsum flowers." Gypsum flowers are curved accumulations of fibrous crystals that resemble flowers. Delicate gypsum needles occur in the cave. Mammoth Cave is a living cave as formations continue to grow.

Mammoth Cave features a complex network of underground conduits, cracks, fissures and underground rivers, streams and springs, all of which are common in karst systems. Numerous underground streams, which form Mammoth Cave, flow through the cave system to emerge at the Green River. Echo River, in the Historic area of the cave, was once used for tours by boat but was discontinued in the early 1990s due to negative effects on the aquatic life. The flow of water through Mammoth Cave can vary greatly on a daily basis as can the water level.

MACA provides suitable habitat for 13 species of bats (NPS 2018i) including the gray bat (*Myotis grisescens*), as the forests and wetlands provide bats with proper foraging areas within the park. Over 200 species of birds have been confirmed in MACA (NPS 2018i). The documented herpetofauna of MACA includes 14 kinds of frogs and toads, 16 salamanders, 8 lizards, 22 snakes, and 9 turtles for a total of 75 species. Inventory and monitoring surveys for amphibians and reptiles have been conducted regularly since 2003. Most amphibian and reptile species known historically from the park appear to be doing well. Six reptiles documented from the park during early surveys in the 1930s appear to have been extirpated, undoubtedly due to habitat conversion. Amphibians in general have fared better but the eastern tiger salamander (*Ambystoma tigrinum*) seems gone from the park and eastern narrowmouth toads (*Gastrophryne carolinensis*) have become quite rare. Both also seem to require open habitats. In addition, northern dusky salamanders (*Desmognathus fuscus*), abundant at several sites at Mammoth Cave as recently as the mid-1960s, are now known from only two locations even though other semiaquatic salamanders with similar habitat requirements are doing quite well.

In the MACA reach of the Green River, there is a highly diverse population of fish, with fish such as largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and sauger (*Sander canadensis*) occasionally observed.

Common breeding birds in the park include the prothonotary warbler (*Protonotaria citrea*) and yellow-breasted chat (*Icteria virens*). Raptor species are also common in MACA, and can be observed foraging. The bald eagle utilizes both the riparian habitat along the Green River within MACA and has been found breeding on park land.

2.3. Resource Issues Overview

The overall purpose of this assessment to provide a snapshot of the current health of the natural resources of MACA, and where there are ongoing or anticipated challenges to describe the nature of those threats. While we introduce those resources here, Chapter 4 provides the detailed evaluations. This is organized by resource classes such as air quality, bats, and the like, and the conditions of these resources are determined by evaluation of specific indicators. Indicators of hydrology/water resources, for example, include rainfall, surface water, and groundwater. The conditions of these indicators, in turn, are evaluated in terms of specific measures. For surface water, for example,

measures include concentrations of nitrate, fecal bacteria, and dissolved oxygen along with pH and specific conductance. All resources, indicators, and measures are shown in section 3.2.3.

2.3.1. Physical Landscape Resources

The physical landscape resources and features in the park are surface and cave air, geology, and hydrology. Surface air and surface air quality includes on-going concerns with pollution and visibility. Cave air and monitoring of cave air quality and meteorology reflects efforts to minimize any impacts from tourism. Protection issues for the geology of the park, an extraordinarily important natural resource, include possible threats to sediments from regional pollution sources and to cave minerals from vandalism. Hydrology (surface water and groundwater) is under continual pressure from external influences such as fecal bacteria and nitrates. Several power plants located in the region can influence both wet and dry deposition in the park. Agricultural activities in the surrounding communities as well as motor vehicles may make modest contributions to the air pollution in the park (NPS 2015).

2.3.2. Human Impacts on Resources

The resources that most illustrate human impacts include human use, night sky and fire management. Human use can be assessed by examining graffiti, impacts of entrance and passage modifications, roadwork, and tourism. Analysis of night sky quality is complex and reflects concern for light pollution. Fire management is included in this section because the resource indicator is the effects of prescribed burning.

2.3.3. Biological and Ecological Resources

The biological and ecological resources in the park are native and plant communities, bats, birds, herps, and surface aquatic and cave communities. Freshwater mussel habitat and species diversity is of exceptional importance in the park. Cave shrimp, crickets and microorganisms are important indicators of the biological cave resources. Foliar injury caused by ozone pollution has been confirmed in a number of plant species at MACA (Jernigan et al. 2010). Of the 411 native plant species found in the park, 1.4% are non-native and may pose a threat to the native ecological communities because of their ability to outcompete and replace native species (NPS 2017b).

2.4. Resource Stewardship

2.4.1. Management Directives and Planning Guidance

In the 1983 MACA general management plan, priorities were put in place to help with guiding the park's decision making in the proper direction (NPS 1983). The Foundation Document was completed in 2014. The Foundation Document provides for planning and management and restates the purpose, significance, fundamental resources and values, and interpretive themes. It establishes an assessment of planning and data needs for the park to focus on in the future (NPS 2014).

2.4.2. Status of Supporting Science

The CUPN identifies key resources network-wide and for each of its parks that can be used to determine the overall health of the parks. These key resources are called Vital Signs. The NPS Vital Signs Monitoring Program addresses five goals for all parks with significant natural resources:

- Determine the status and trends in selected indicators of the condition of park ecosystem,

- Provide early warning of abnormal conditions,
- Provide data to better understand the dynamic nature and condition of park ecosystems,
- Provide data to meet certain legal and congressional mandates, and
- Provide a means of measuring progress towards performance goals.

The Network monitoring program at MACA includes nine vital signs that involve repeated visits to established sites. Vital signs include five cave vital signs (aquatic biota, bats, crickets, meteorology, woodrats), forest vegetation community invasive species early detection, ozone/foliar injury, and water quality. Water quality monitoring follows a schedule for two years "on", five years "off", at 13 sites. Forest monitoring began in 2011 and continues with 60 long-term monitoring plots rotated on a five-year panel, consisting of 12 site visits each September. This park has a continuous ozone monitor and foliar injury is assessed on-site every year, beginning in 2008. The Invasive Species Early Detection protocol was completed in 2012.

Chapter 3. Study Scoping and Design

This NRCA is a collaborative project between the NPS and Western Kentucky University (WKU). Project stakeholders include the MACA resource management team, CUPN Inventory and Monitoring Program staff, and Southeast Regional Office staff. Before embarking on the project, it was necessary to identify the specific roles of the NPS and WKU. Preliminary scoping meetings were held, and a task agreement and a scope of work document were created cooperatively between the NPS and WKU.

3.1. Preliminary Scoping

NPS Regional NRCA Coordinator Dale McPherson travelled to MACA to present the objectives and guidance during a January 2014 scoping session. A second scoping meeting was held from 12–13 March 2015. At this meeting, WKU and NPS staff agreed that the purpose of the MACA NRCA was to evaluate and report on current conditions, critical data and knowledge gaps, and selected existing and emerging resource condition influences of concern to MACA managers. Certain constraints were placed on this NRCA, including the following:

- Condition assessments are conducted using existing data and information;
- Identification of data needs and gaps is driven by the project framework categories;
- The analysis of natural resource conditions includes a strong geospatial component;
- Resource focus and priorities are primarily driven by MACA resource management.

This condition assessment provides a "snapshot-in-time" evaluation of the condition of a select set of park natural resources that were identified and agreed upon by the project team. Project findings will aid MACA resource managers in the following objectives:

- Develop near-term management priorities (how to allocate limited staff and funding resources);
- Engage in watershed or landscape scale partnership and education efforts;
- Consider new park planning goals and take steps to further these;
- Report program performance (e.g., Department of Interior Strategic Plan "land health" goals, Government Performance and Results Act [GPRA]).

Specific project expectations and outcomes included the following:

- For key natural resource components, consolidate available data, reports, and spatial information from appropriate sources including: MACA resource staff, the NPS Integrated Resource Management Application (IRMA) website, Inventory and Monitoring Vital Signs program, and available third-party sources. The NRCA report will provide a resource assessment and summary of pertinent data evaluated through this project.

- When appropriate, define a reference condition so that statements of current condition may be developed. The statements will describe the current state of a particular resource with respect to an agreed upon reference point.

- Clearly identify "management critical" data (i.e., those data relevant to the key resources). This will drive the data mining and gap definition process.

- Where applicable, develop GIS products that provide spatial representation of resource data, ecological processes, resource stressors, trends, or other valuable information that can be better interpreted visually.

- Utilize "gray literature" and reports from third party research to the extent practicable.

3.2. Study Design

3.2.1. Selection of Resources and Measures

As part of the NRCA process, a "framework" is developed for a park or preserve. This framework is a way of organizing, in a hierarchical fashion, bio-geophysical resource topics considered important in park management efforts. The primary features in the framework are key resource components, measures, stressors, and reference conditions.

"Components" in this process are defined as natural resources (e.g., birds, plant communities), ecological processes or patterns (e.g., natural fire regime), or specific natural features or values (e.g., geological formations) that are considered important to current park management. Each key resource component has one or more "measures" that best define the current condition of a component being assessed in the NRCA. Measures are defined as those values or characterizations that evaluate and quantify the state of ecological health or integrity of a component. In addition to measures, current condition of components may be influenced by certain "stressors," which are also considered during assessment. A "stressor" is defined as any agent that imposes adverse changes upon a component.

These typically refer to anthropogenic factors that adversely affect natural ecosystems, but may also include natural processes or disturbances such as floods, fires, or predation.

During the MACA NRCA scoping process, key resource components were identified by NPS staff and are represented as "components" in the NRCA framework. While this list of components is not a comprehensive list of all the resources in the park, it includes resources and processes that are unique to MACA in some way, or are of greatest concern or highest management priority in MACA. Several measures for each component, as well as known or potential stressors, were also identified in collaboration with NPS resource staff.

3.2.2. Selection of Reference Conditions

A "reference condition" is a benchmark to which current values of a given component's measures can be compared to determine the condition of that component. A reference condition may be a historical condition (e.g., flood frequency prior to dam construction on a river), an established ecological threshold (e.g., EPA standards for air quality), or a targeted management goal/objective (e.g., a bison herd of at least 200 individuals) (adapted from Stoddard et al. 2006).

Reference conditions in this project were identified during the scoping process using input from NPS resource staff. In some cases, reference conditions represent a historical reference before human activity and disturbance was a major driver of ecological populations and processes, such as "pre-fire suppression." In other cases, peer-reviewed literature and ecological thresholds helped to define appropriate reference conditions.

3.2.3. Finalizing the Framework

An initial framework was adapted from the organizational framework outlined by the H. John Heinz III Center for Science's "State of Our Nation's Ecosystems 2008" (Heinz Center 2008). Many of the key resources for MACA were adapted from the CUPN Vital Signs monitoring plan (Leibfreid et al. 2005). This initial framework was presented to park resource staff to stimulate meaningful dialogue about key resources that should be assessed. Significant collaboration between WKU analysts and NPS staff was needed to focus the scope of the NRCA project and finalize the framework of key resources to be assessed.

The initial NRCA framework was finalized in May 2015 and modified several times through May 2018 following acceptance from NPS resource staff. This framework (Table 3.1) outlines the components (resources), most appropriate measures, known or perceived stressors and threats to the resources, and the reference conditions for each component for comparison to current conditions.

3.3. General Approach and Methods

This study involved gathering and reviewing existing literature and data relevant to each of the key resource components included in the framework. No new data were collected for this study; however, where appropriate, existing data were further analyzed to provide summaries of resource condition or to create new spatial representations. After all data and literature relevant to the measures of each component were reviewed and considered, a qualitative statement of overall current condition was created and compared to the reference condition when possible.

3.3.1. Data Mining

The data mining process (acquiring as much relevant data about key resources as possible) began at the initial scoping meeting, at which time MACA staff provided data and literature in multiple forms, including: NPS reports and monitoring plans, reports from various state and federal agencies, published and unpublished research documents, databases, tabular data, and charts. GIS data were also provided by NPS staff. Additional data and literature were acquired through online bibliographic literature searches and inquiries on various state and federal government websites. Data and literature acquired throughout the data mining process were inventoried and analyzed for thoroughness, relevancy, and quality regarding the resource components identified at the scoping meeting.

3.3.2. Data Development and Analysis

Data development and analysis was highly specific to each component in the framework and depended largely on the amount of information and data available for the component, as well as recommendations from NPS reviewers and sources of expertise including NPS staff from MACA and the CUPN. Specific approaches to data development and analysis can be found within the respective component assessment sections located in Chapter 4 of this report.

Table 3.1. MACA Natural Resource Condition Assessment framework.

Framework Category	Resource	Indicator	Measure
Landscapes (ecosystem pattern and processes)	Surface air	Air quality	• Visibility • Particulates • Ozone • NOx • Mercury
	Cave air	Air quality	• Radon • CO2 • Cave meteorology
	Geology and soils	Bedrock units	Threats to bedrock
	Geology and soils	Alluvial sediments	Sediment quality
	Geology and soils	Cave minerals	Threats to minerals
	Geology and soils	Cave sediments	Sediment quality
	Geology and soils	Economic mineral resources	Threats from mineral exploitation
	Geology and soils	Soil	Soil conditions
	Hydrology/water resources	Rainfall	• pH • SO_4 • SpC
	Hydrology/water resources	Surface water	• Fecal bacteria • Nitrate • Dissolved oxygen • pH • SpC
	Hydrology/water resources	Groundwater	• Fecal bacteria • Nitrate • Dissolved oxygen • pH • SpC
	Human use	Graffiti	Impacts and threats
	Human use	Entrance modifications	Impacts of modifications
	Human use	Passage modifications	Impacts of modifications
	Human use	Roadwork	Impacts and threats
	Human use	Development of tourism	Resource threats
	Human use	Surface trail conditions	Condition and ongoing impacts
	Night sky	Light pollution	Bortle Scale and SQL

Table 3.1 (continued). MACA Natural Resource Condition Assessment framework.

Framework Category	Resource	Indicator	Measure
Land use and biological integrity of vegetation	Native communities	Native plant communities	Species richness and diversity
	Native communities	Native animal communities	Species richness and diversity
	Fire management	Fire effects (prescribed burning)	• Density of shade-tolerant species, other woody species, and shrubs • % Native herbaceous cover and preferred tree species • % Cover of exotic plants • Mortality of over-story trees • Total fuel load
Biological integrity of wildlife	Bats	Bats	• Diversity • Impacts of White-nose Syndrome • Distribution • Changing Dynamics of Habitat and Roosts • Reproductive success • Threatened and Endangered Species
	Avian	Birds	• Species diversity • Productivity and survivorship
	Herps	Amphibians	• Diversity • Distribution • Species changes
	Herps	Reptiles	• Diversity • Distribution • Species changes
	Surface aquatic communities	Fish	• Diversity • Distribution • Species changes
	Surface aquatic communities	Freshwater mussels	• Diversity • Distribution • Species changes

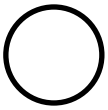
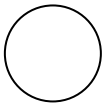
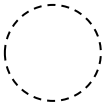
Table 3.1 (continued). MACA Natural Resource Condition Assessment framework.

Framework Category	Resource	Indicator	Measure
Biological integrity of wildlife (continued)	Cave communities	Kentucky cave shrimp	• Population • Distribution
	Cave communities	Cave microorganisms	• Abundance (# of species) • Community composition (bacteria only) • Distribution
	Cave communities	Allegheny woodrats	• Population • Distribution
	Cave communities	Cave crickets	• Population • Distribution

3.3.3. Assigning Conditions

Table 3.2 summarizes the potential graphical symbols used to represent a component's condition in this assessment. The colored circles represent the level of concern: red circles signify a significant concern, yellow circles a moderate concern and green circles that a resource is in good condition. White circles are used to represent situations in which WKU analysts, park staff, and network staff felt there were currently insufficient data to make a statement about the condition of a component. For example, condition is not assessed when no recent data or information are available, as the purpose of an NRCA is to provide a "snapshot-in-time" of current resource conditions. The arrows inside the circles indicate the trend of the condition of a resource component, based on data and literature from the past 5–10 years, as well as expert opinion. An upward pointing arrow indicates the condition of the component has been improving in recent time or there are data to expect improvement moving forward. A horizontal arrow indicates a stable condition or trend, and an arrow pointing down indicates deterioration in the condition of a component in recent times. These are only used when it is appropriate to comment on the trend of condition of a component. In general, trends area assigned to components only when time series data, or data from recent times are available. In situations where the trend of the component's condition is currently unknown, no arrow is given.

Table 3.2. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

The preparation of draft assessments for each component was a highly cooperative process among WKU analysts and MACA and CUPN staff. Though WKU analysts rely heavily on peer-reviewed literature and existing data in conducting the assessment, the expertise of NPS resource staff also plays a significant and invaluable role in providing insights into the appropriate direction for analysis and assessment of each component. This step is especially important when data or literature are limited for a resource component.

The process of developing draft documents for each component began with a detailed phone or email conversation with an individual or multiple individuals considered local experts on the resource components under examination. These conversations were a way for analysts to verify the most relevant data and literature sources that should be used and also to formulate ideas about current conditions with respect to the NPS staff opinions. Upon completion, draft assessments were forwarded to component experts for initial review and comments.

Following review of the component draft assessments, analysts used the review feedback from resource experts to compile the final component assessments. As a result of this process, and based on the recommendations and insights provided by CUPN resource staff and other experts, the final component assessments represent the most relevant and current data available for each component and the sentiments of park resource staff and outside resource experts.

3.3.4. Measures and Reference Conditions/Values

Resource component measures were defined in the scoping process and refined through dialogue with resource experts. Those measures deemed most appropriate for assessing the current condition of a component are listed in this section, typically as bulleted items.

Reference Conditions and Values

This section explains the reference condition determined for each resource component as it is defined in the framework. Explanation is provided as to why specific reference conditions are appropriate or logical to use. Also included in this section is a discussion of any available data and literature that explain and elaborate on the designated reference conditions. If these conditions or values originated with the NPS experts or WKU analysts, an explanation of how they were developed is provided.

Current Condition and Trend

This section presents and discusses in-depth key findings regarding the current condition of the resource component and trends (when available). The information is presented primarily with text but is often accompanied by detailed maps or plates that display different analyses, as well as graphs, charts, and/or tables that summarize relevant data or show interesting relationships. All relevant data and information for a component are presented and interpreted in this section. This section provides a summary of the threats and stressors that may impact the resource and influence to varying degrees the current condition of a resource component. Relevant stressors were described in the scoping process and are outlined in the NRCA framework. However, these are elaborated on in this section to create a summary of threats and stressors based on a combination of available data and literature, and discussions with resource experts and NPS natural resources staff.

Data Needs/Gaps

This section outlines critical data needs or gaps for the resource component. Specifically, what is discussed is how these data needs/gaps, if addressed, would provide further insight in determining the current condition or trend of a given component in future assessments. In some cases, the data needs/gaps are significant enough to make it inappropriate or impossible to determine condition of the resource component. In these cases, stating the data needs/gaps is useful to natural resources staff seeking to prioritize monitoring or data gathering efforts.

Overall Condition

This section provides a qualitative summary statement of the current condition that was determined for the resource component using the WCS method. Condition is determined after thoughtful review of available literature, data, and any insights from NPS staff and experts, which are presented in the Current Condition and Trend section. The Overall Condition section summarizes the key findings and highlights the key elements used in determining and justifying the level of concern, if any, that analysts attribute to the condition of the resource component. Also included in this section are the graphics used to represent the component condition.

Sources of Expertise

This is a listing of the individuals (including their title and affiliation with offices or programs) who had a primary role in providing expertise, insight, and interpretation to determine current condition (and trend when appropriate) for each resource component.

Literature Cited

One list of references has been made for the entire document.

Chapter 4. Natural Resource Conditions

4.1. Surface Air Quality

Negative impacts to the natural composition of the atmosphere come from a variety of human activities. This is quantified as air quality by measuring the composition and concentrations of pollutants that have direct impacts by changing the chemistry of the air, as well as indirect impacts on visibility as well as human and ecological health. Degradation of air quality can have significant impacts on the resources of national parks, and this has certainly been the case at MACA. For the purposes of this resource condition analysis, we divide discussion of air quality into two sections: 1) Surface Air Quality and 2) Cave Air Quality as the information comes from different data sets. This section conforms with the NPS guidance document Guidance for Evaluating Air Quality in Natural Resource Conditions Assessments (NPS 2015) and uses data and analysis from the park Conditions and Trends (NPS 2017a). In the sections on visibility, ozone, nitrogen deposition and sulfur deposition, information in the Conditions and Trends, Level of Confidence, and Condition Summaries sections is drawn on verbatim from the park Conditions and Trends (NPS 2017a) data.

The atmosphere has been one of the most heavily influenced resources at MACA with direct major pollution sources including operation of coal-fired power plants, industrial and mobile emissions as well as secondary sources that can form through chemical reactions in the atmosphere (NPS 2002). National parks such as MACA can also have minor impacts from smoke from wood and pellet stoves, campfires, prescribed burning, and industrial and mobile emissions (NPS 2006a).

The impacts of impaired air quality include damage to human and ecological health as well as to visibility. In a review of the air quality for the national park system, the NPS (2002) wrote:

> Among the experiences that visitors to national parks treasure is the breathtaking scenery—majestic mountains contrasted against a pure blue sky or the form, color, and texture of unique landscapes and geologic features. Spectacular scenic views need to be seen to be appreciated. In 1977, Congress specifically recognized this by establishing a national goal of remedying any existing and preventing any future human-caused visibility impairment in most of our largest national parks. Unfortunately, air pollution currently impairs visibility to some degree in every national park.

Air quality at MACA has been among the worst of the nation's parks. It was ranked in 2015 as the 10th worst (NPCA 2015) with grades of D for "healthy air" and F for "seeing clearly."

Though there have been and are a number of air monitoring facilities in and around MACA, most of the data for this assessment comes from the Houchin Meadow Air Quality Monitoring Site just southwest from MACA (Figures 4.1 and 4.2). The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. For current air quality data and information for this park, please visit the NPS Air Resources Division website at www.nps.gov/subjects/air/index.htm.

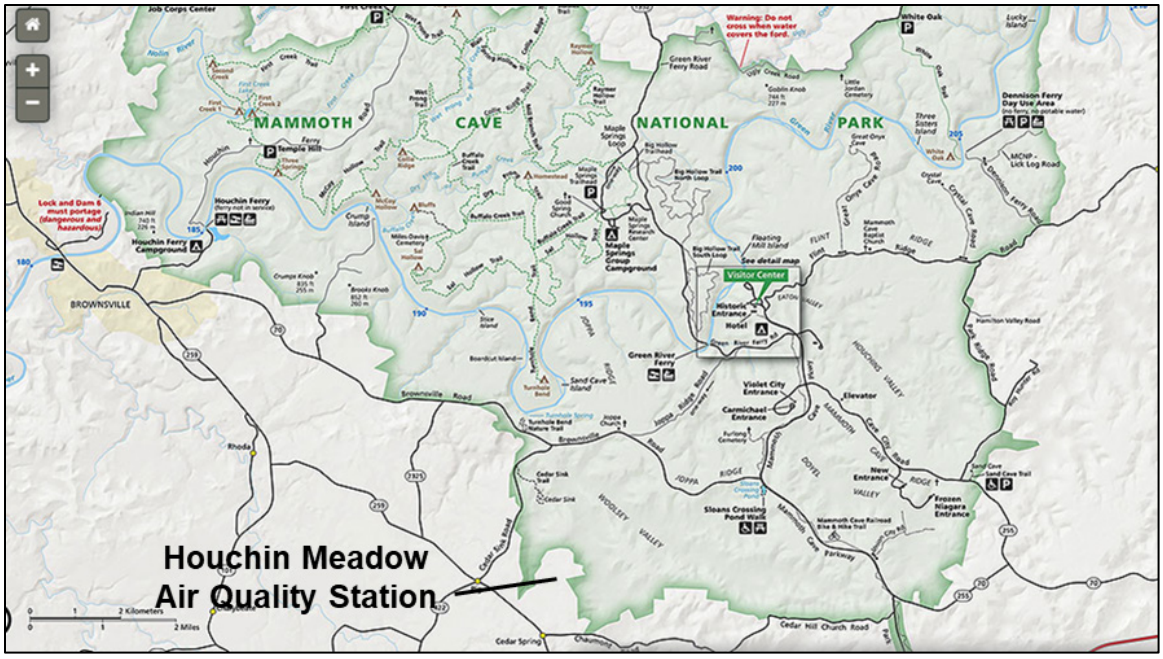


Figure 4.1. Location of the Houchin Meadow Air Quality Monitoring Station. Figure modified from NPS (2018b).



Figure 4.2. The Houchin Meadow Air Quality Monitoring Station. NPS photo by Johnathan Jernigan.

We have split out data such that nitrogen and sulfur wet deposition are reported in the air quality section while dissolved constituents (pH, SO_4, specific conductance, and mercury) are reported in the precipitation water quality section.

Surface air quality is evaluated through a description of the following indicators:

- 4.1.1. Visibility
- 4.1.2. Ozone
- 4.1.3. Nitrogen deposition
- 4.1.4. Sulfur deposition

4.1.1. Visibility

There has been sustained, significant improvement in both the clearest and haziest days, though visibility conditions are still in the region of "significant concern." Data for the last two years suggest that, if trends continue, MACA may move into a condition of "moderate concern" over the next few years.

Description

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets that become suspended in the atmosphere. It is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. Two categories are routinely measured: fine particles (PM2.5), which are 2.5-micrometers in diameter or smaller and inhalable coarse particles (PM10), which are smaller than 10-micrometers (the width of a single human hair) (EPA 2009). The size of particles is directly linked to their potential for causing human health and landscape visibility problems. Both PM10 and PM2.5 are a concern to human health as these particles can easily pass through the throat and nose and enter the lungs. Short-term exposure to these particles can cause shortness of breath, fatigue, and lung irritation, while long-term exposure can cause more serious health effects, including heart and lung diseases (EPA 2009).

Air quality in parks and wilderness areas is regulated through the 1916 Organic Act and the Clean Air Act of 1977 (CAA) and the subsequent amendments (NPS 2004a). The CAA establishes authority in protecting both the natural and cultural resources of parks. Two classes (Class I and II) of air sheds were established. Class I areas include national parks greater than 2,428 hectares in size and which were in existence or authorized by 1977. They receive the highest degree of air quality protection under the Clean Air Act and only a small amount of additional air pollution is permitted in the air shed above the accepted baseline levels. Areas designated as Class I and II (which include all other national park units (Johnathan Jernigan, Physical Scientist, CUPN, August 2018, personal communication) air sheds typically use the EPA National Ambient Air Quality Standards (NAAQS) as criteria for air pollutants. The NAAQS are the standards for allowable levels of air pollution that provide for human health and the health of natural resources (EPA 2014a). The CAA also addresses visibility by mandating any current visibility impairment be remedied and a management plan designed to prevent future impairment (EPA 2014a). EPA is currently developing secondary NAAQS for ozone and nitrogen and sulfur compounds to protect sensitive plants, lakes, streams, and soils.

National Parks and other natural areas are also impacted by EPA's Regional Haze Program which implemented the Regional Haze Rule in 1999, designed to facilitate efforts of federal agencies to work together to improve visibility in 156 national parks and wilderness areas (EPA 2017). With the establishment of the program, EPA developed a timeline for states to implement the rule leading up to 2018, with states providing periodic reviews and completing revised haze plans every ten years thereafter. In December 2016 EPA finalized revisions to the Rule to guide development of these plans moving forward (EPA 2017). There is as of this writing, however, uncertainty as the EPA has published a *Decision to Revisit Aspects of the 2017 Regional Haze Rule Revisions* in response to petitions from several energy companies and utilities, as well as the state of Alaska (EPA 2018a).

In response to the mandates of the CAA of 1977, federal and regional organizations established the program for Interagency Monitoring of Protected Visual Environments (IMPROVE) in 1985 to aid in monitoring of visibility conditions in Class I air sheds (Pohlman and Maniero 2005). The goals of the program are to 1) establish current visibility conditions in Class I air sheds; 2) identify pollutants and emission sources causing the existing visibility problems; and 3) document long-term trends in visibility. Based on aerosol data collected in MACA, Pohlman and Maniero (2005) indicate that the primary sources of visibility impairment are sulfates from coal combustion, light absorbing particulates (likely from wood smoke and fires), and nitrates from coal and natural gas combustion as well as vehicle emissions. These particles and gases impair visibility when they scatter or absorb light; the net effect is called "light extinction": a reduction in the amount of light from a scene that is returned to an observer (Malm 2017).

Data here (Figures 4.3–4.5) come from the IMPROVE program, with visibility reported in unitless deciviews (*dv*) (Richards 1999). There are different scales for measuring visibility, a complex phenomenon to quantify (Malm 2017), because this can be related both to the physical interactions of light energy with the different atmospheric contaminants, as well as human visual perception. The deciview scale is related to light extinction, but scaled in a way such that the difference in visibility perceived by an observer given a one *dv* change is the same regardless of the haze conditions. A dv value of zero corresponds to a visual range of about 380 kilometers, while 45 dv would correspond to a range of about 4 kilometers.

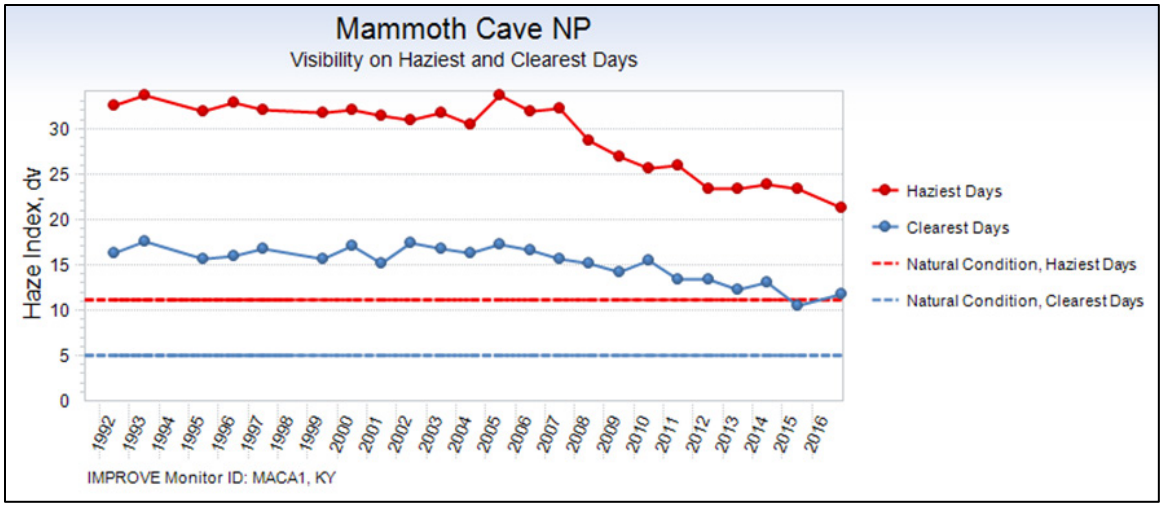


Figure 4.3. Visibility data for Houchin Meadow Site near MACA park (IMPROVE 2018) showing annual haziest and clearest days from 1992 through 2017.

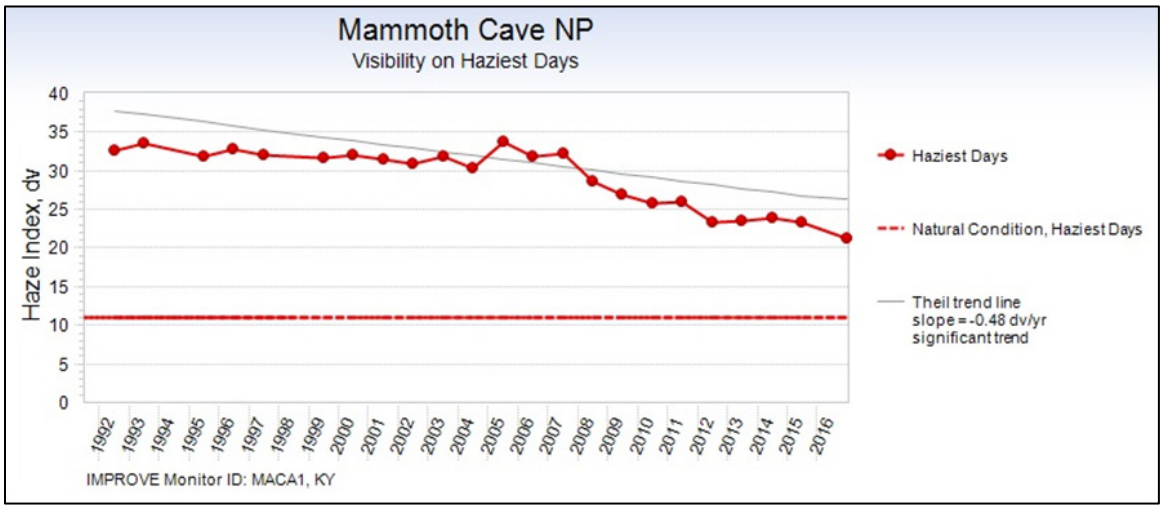


Figure 4.4. Visibility data for Houchin Meadow Site near MACA (IMPROVE 2018) showing annual haziest days from 1992 through 2017.

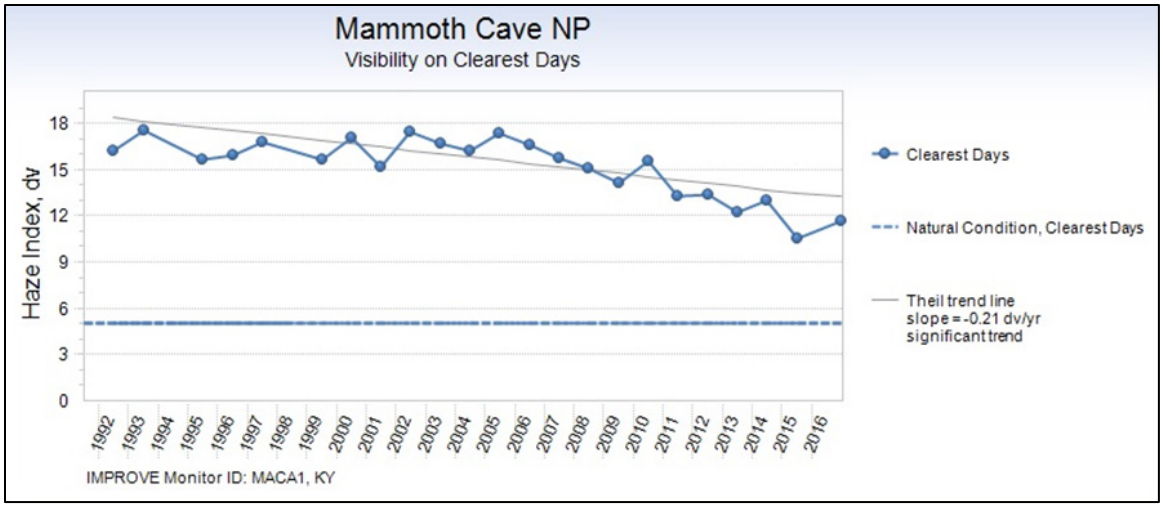


Figure 4.5. Visibility data for Houchin Meadow Site near MACA (IMPROVE 2018) showing annual clearest days from 1992 through 2017.

Reference Conditions/Values

In the long term, EPA's Regional Haze Rule (IMPROVE 2018) calls for state and federal agencies to work together to improve visibility in all 156 federal Class I national parks and wilderness areas. States are to develop long-term strategies for reducing air pollutant emissions that cause visibility impairment. This regulation also has had additional benefits of improving visibility outside of Class I areas and reducing pollutants that contribute to ozone, fine particles, and acid deposition. Because pollutants can be transported hundreds of kilometers, each of the 50 states must evaluate its contribution to haze in Class I areas and must implement emission control strategies that demonstrate reasonable progress toward the goal of no "man-made impairment" in Class I areas by 2064. The rules require states to establish goals for each affected Class I area that improve visibility on the haziest days and ensure no degradation occurs on the clearest days.

We can use existing trend data and recent values to evaluate progress towards that goal (NPS 2010a). The visibility condition is defined as the average current visibility minus the estimated average annual conditions (Table 4.1).

Table 4.1. Criteria for visibility conditions (NPS 2010a).

Visibility Condition	Average visibility – estimated average natural conditions (*dv*)
Warrants Significant Concern	>8
Warrants Moderate Concern	2–8
Resource is in Good Condition	<2

Condition and Trend

Parts of the information in this, the Level of Confidence, and the Condition Summaries sections is drawn verbatim from the park *Conditions and Trends* (NPS 2017a) data. Visibility warrants

significant concern at Mammoth Cave NP. This status is based on NPS Air Resources Division benchmarks (NPS 2010a) and the 2011–2015 estimated visibility on mid-range days of 10.5 *dv* above estimated natural conditions. Visibility trends and conditions are both expressed in terms of a Haze Index in deciviews (*dv*); however, the benchmark metrics are different. Condition assessments are based on estimated five-year average visibility on mid-range days (40th to 60th percentile) minus the estimated natural visibility condition on mid-range days. Visibility trends (Table 4.2) are computed from the haze index values on the 20% haziest days and the 20% clearest days. For 2006–2015, the trend in visibility at MACA improved on the 20% clearest days and improved on the 20% haziest days. The Clean Air Act visibility goal requires visibility improvement on the 20% haziest days, with no degradation on the 20% clearest days. However, the 2016 and 2017 values are lower (Figure 4.3), and while this is not yet low enough to bring the five-year average down from the zone of significant concern, this is an encouraging trend. If this continues, the assessment may change in 2020 or 2021 to the region of moderate concern.

Level of Confidence and Data Gaps

These long term, high-quality data come from the Houchin Meadow station adjacent to MACA, and therefore there is a high level of confidence and there are no data gaps.

Condition Summary

Table 4.2. Graphical summary of status and trends for visibility.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Visibility	Haze index		Although there are statistically significant improving trends in both best and worst haze conditions, conditions remain in the area of significant concern.

Sources of Expertise

Bobby Carson (Chief of MACA Division of S&RM, retired), and Johnathan Jernigan (MACA Division of S&RM/Physical Scientist, CUPN) provided expertise for this section.

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. Note that the measures and methods used for assessing the condition of viewshed in this report predate current measures and methods recommended by the NPS. For current information and methodology, please visit the NPS Air Resources Division website at www.nps.gov/subjects/air/ or contact the NPS at visual_resources@nps.gov.

4.1.2. Ozone

Impacts to both human and vegetation health remain in the area of moderate concern at MACA, though the situation is improving as a result of EPA NOx regulations in place since 1998.

Description

Ozone (O_3) gas is found in two different regions of the atmosphere where it plays two different roles with respect to environmental conditions. Stratospheric ozone forms high in the atmosphere from chemical reactions associated with ultraviolet radiation (UV), and serves to block much of the UV coming into the earth system. As unfiltered UV would have serious human health and ecological impacts, this is often called "good ozone."

More relevant to the current discussion is the tropospheric or ground level ozone—sometimes referred to as "bad ozone" that at higher concentrations, is harmful to plants and human health (NPS 2005). Ground-level ozone is created by a chemical reaction between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of heat and sunlight. Some major sources of ozone-forming chemicals include vehicle and industrial emissions, gasoline vapors, and chemical solvents (NPS 2005, Pohlman and Maniero 2005). Breathing air containing ozone can aggravate asthma, reduce lung function, inflame lung tissue, cause acute respiratory problems, or impair the body's immune system (NPS 2005). At high concentrations, ozone has been linked to increased susceptibility to respiratory infections in humans. Parks must address this potential effect on human health aspect seriously as visitors to the park are often physically active by hiking, canoeing, and biking or other outdoor pursuits (Pohlman and Maniero 2005).

Ozone is also one of the most widespread pollutants affecting vegetation in the U.S. (NPS 2005). In 2005, Pohlman and Maniero (2005) completed an air quality monitoring considerations assessment for the national park units served by CUPN. Part of this assessment focused on ozone concentrations in parks and the risk of injury to plant species that are sensitive to sustained ozone exposure. Analyzing ozone data from 1995–1999, Pohlman and Maniero (2005) found that ozone concentrations in MACA frequently exceeded 60–80 ppb for a few hours each year and sometimes, though very rarely, exceeded 100 ppb. Sensitive plant species begin to experience foliar injury when exposed to ozone concentrations of 80–120 ppb/hour for extended periods of time (8 hours or more) (Pohlman and Maniero 2005). The authors determined periodic peaks in concentration to be intermittent and occasional; thus, overall risk of injury to sensitive vegetation is quite low. However, if ozone concentrations should increase in the future, the authors suggested an on-site monitoring program that assesses foliar injury and growth progress may be necessary.

A number of MACA plant species are highly sensitive to ozone, with documentable physical impacts at levels well below the current EPA standard (NPS 2005, Pohlman and Maniero 2005; Kohut 2004, 2007) (Figure 4.6). Long-term exposures are associated with possible shifts in species composition from increased vulnerability to insects and diseases and shifts in species composition (NPS 2005). A summary of ozone damage sensitive plants at MACA listed 30 species of 27 genera (NPS 2019).



Figure 4.6. Example comparison of healthy (left) and ozone damaged (right) leaves of tall milkweed (*Asclepias extalta L.*) from Great Smoky Mountains National Park, which has faced similar ozone impacts to MACA (Bingham and Porter 2015).

Data and Methods

Ozone is measured with a UV absorption analyzer along with relevant meteorological parameters at the Houchins Meadow Air Quality Station (Figure 4.1) (NPS 2016b) through the Gaseous Pollutant Monitoring Program (GPMP). Data are expressed in two ways related to the primary (human health) standard and the secondary (related to vegetation health): in parts per billion (PPB) and as the W126 index. This is an index that evaluates risk to vegetation based on ozone exposure (Ray 2004, NPS 2009 and 2017b). It is a sigmoidal function that weights higher ozone concentrations that are more prone to do damage, and is calculated by

$$W126 = O_3 * (\frac{1}{1+(4403*e^{-126O_3})}) \qquad (4.1)$$

with O_3 concentrations in parts per million (PPM).

Reference Conditions/Values

Regarding human health and vegetation, the EPA has set the human health standard at 70 PPB for the fourth-highest daily maximum 8-hour ozone concentration. W126 reference conditions are shown in Table 4.3 (NPS 2017b). The W126 metric relates plant response to ozone exposure. A risk assessment concluded that plants in at Mammoth Cave NP were at high risk for ozone damage (Kohut 2004, 2007).

Table 4.3. Criteria for ozone conditions with respect to vegetation risk (NPS 2010a).

Ozone W126 Condition	W126 in ppm-hours
Warrants Significant Concern	>13
Warrants Moderate Concern	7–13
Resource is in Good Condition	<7

Condition and Trend

Ozone concentrations from 2006 through 2015 are shown in Figure 4.7 with the human health standard of 70 PPB shown in red. The trend line shows a statistically improving trend (Table 4.4). This improvement has been ascribed to the 1998 State Implementation Plan known as the NO_x SIP Call (NPS 2010a). NO_x includes both NO and NO_2, both of which are precursors to ground level ozone. From *Park Condition and Trends* (NPS 2017a), the human health risk from ground-level ozone warrants moderate concern at MACA. This status is based on 2011–2015 estimated ozone of 68.6 parts per billion (ppb). The trend in ozone concentration at MACA shows improvement. Vegetation health risk from ground-level ozone warrants moderate concern at MACA based on the 2011–2015 estimated W126 metric of 10.0 parts per million-hours (ppm-hrs) (Figure 4.8; Table 4.3). Over the same period, the trend in the W126 metric at MACA improved.

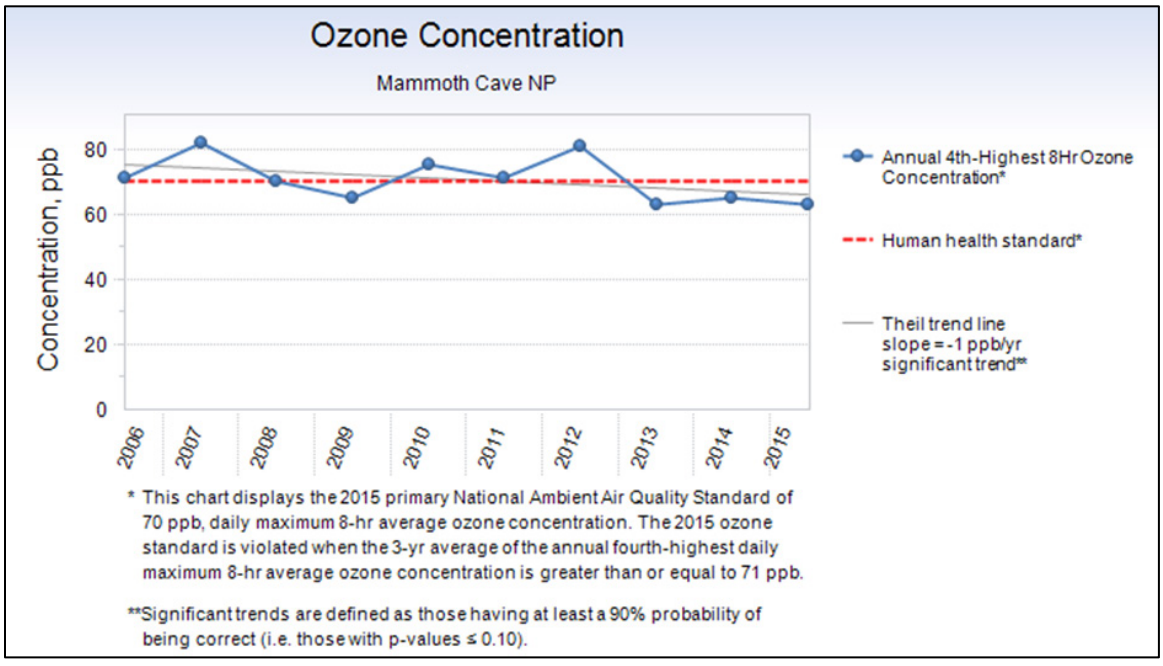


Figure 4.7. Ozone data for Houchin Meadow Site near MACA (NPS 2017b) showing annual values from 2006 through 2015.

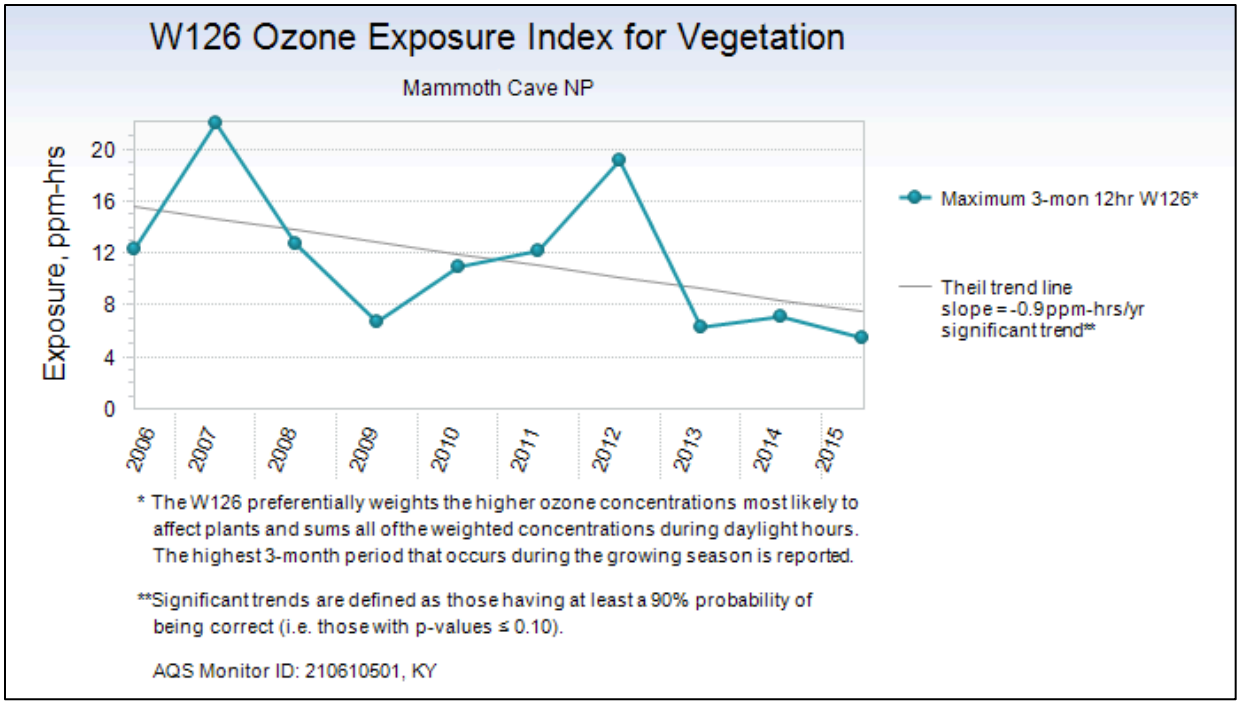


Figure 4.8. Ozone data for Houchin Meadow Site near MACA (NPS 2017b) showing annual values of the W126 metric from 2006 through 2015.

Level of Confidence and Data Gaps

These long-term, high-quality data come from the Houchin Meadow station adjacent to MACA (Figure 4.1) collected and analyzed with the protocols of several high-quality programs with which MACA has cooperated, and there is a high level of confidence. There are no significant data gaps.

Condition Summary

Table 4.4. Graphical summary of status and trends for ozone (NPS 2017a).

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Ozone	Human health: Annual 4th-highest 8hr concentration		Human health risk from ground-level ozone warrants moderate concern at MACA, based on the 2011–2015 estimated ozone of 68.6 parts per billion (ppb), and the trend in ozone concentration improved
	Vegetation health: 3-month maximum 12hr W126		Vegetation health risk from ground-level ozone warrants moderate concern at MACA based on the 2011–2015 estimated W126 metric of 10.0 parts per million-hours (ppm-hrs). A risk assessment concluded that plants in at Mammoth Cave NP were at high risk for ozone damage, though the trend in the W126 metric improved.

Sources of Expertise
Bobby Carson (Chief of MACA Division of S&RM, retired), and Johnathan Jernigan (MACA Division of S&RM/Physical Scientist, CUPN) provided expertise for this section.

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. For current air quality data and information for this park, please visit the NPS Air Resources Division website at www.nps.gov/subjects/air/index.htm.

4.1.3. Nitrogen Deposition

Nitrogen deposition levels, as indicated by wet deposition or the amount of nitrogen in precipitation, are a source of significant concern at MACA.

Description
Atmospheric deposition describes a set of processes by which particles and gasses delivered from the atmosphere to the earth's surface, either in precipitation (wet deposition) or by the settling of various constituents directly from the air (dry deposition). Although both are important in understanding the quantities of these materials making their way to the surface, it is much more common for atmospheric monitoring sites to measure wet deposition, so that the evaluation of the environmental concerns can be based on wet deposition only. For both nitrogen and sulfur, the Houchin Meadow Atmospheric Monitoring Station (Figure 4.1) measures both wet deposition through the National Atmospheric Deposition Program National Trends Network (NADP NTN) and dry deposition in cooperation with EPA's Clean Air and Status and Trends Network (CASTnet).

This section describes the conditions with respect to nitrogen deposition at MACA, considering wet deposition. Nitrogen is a complex element and there are several forms, or species that make up atmospheric deposition the most abundant are NO_3^- (nitrate) and ammonium (NH_4^-). MACA has highly detailed data showing that these, along with smaller amounts of nitric acid (HNO_3^-) make up the bulk of total nitrogen reaching the surface (Figure 4.9).

Nitrogen deposition can cause changes in the water chemistry, including acidity that can negatively affect terrestrial and aquatic vegetation, fish, amphibians and aquatic invertebrates (NPS 2002). Although MACA has been assigned a Very High ranking with respect to nitrogen pollution exposure (Sullivan et al. 2011a), it simultaneously has a Very Low ranking for ecosystem sensitivity. This is related to the geology of MACA (see section 4.4) with extensive limestone exposures that have a high buffering (acid neutralization) capacity. However, there are also areas of sandstone bedrock underlying the flat ridges in the park's northern reaches including highly susceptible upland ponds that don't have the same buffering ability, and there is also concern about periods of intense precipitation that could cause temporary flushes of acidity (Meiman 2006). These water chemistry changes can also create changes in both plant community structure and nutrient cycling.

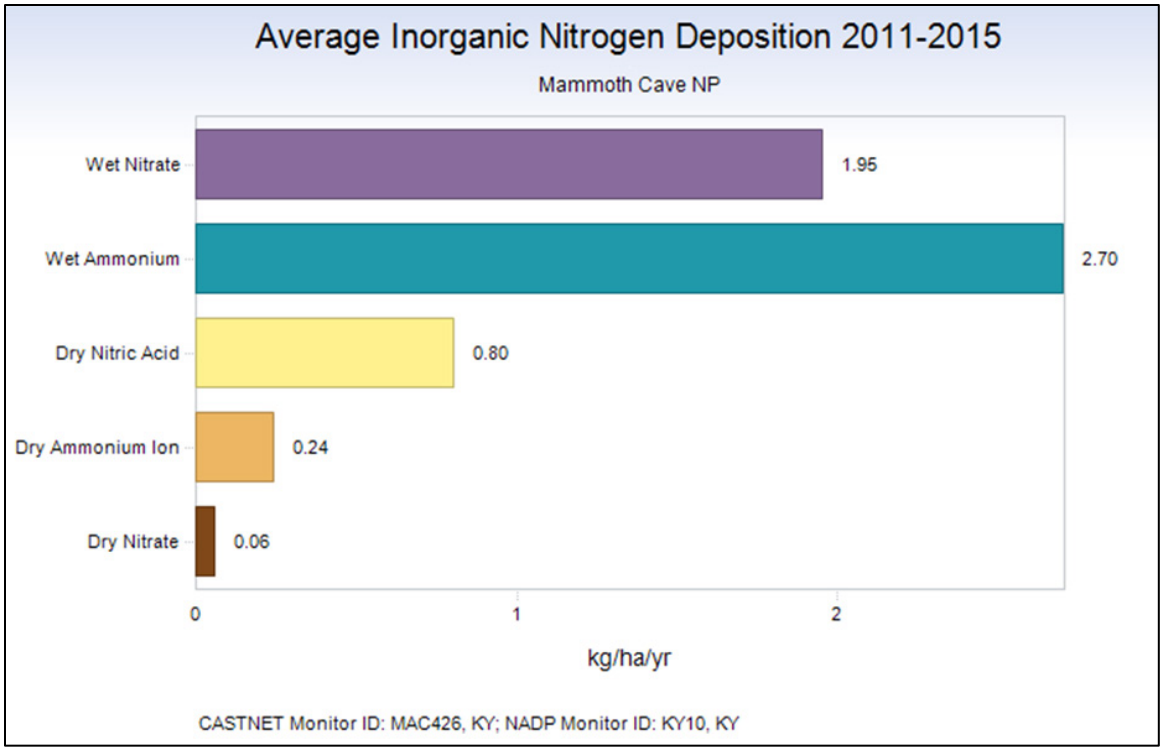


Figure 4.9. Distribution of nitrogen sources from Houchin Meadow Site near MACA (NPS 2017b) from 2011 through 2015.

Data and Methods

Houchin Meadow Atmospheric Monitoring Station (Figure 4.1) has provided both wet deposition through the National Atmospheric Deposition Program National Trends Network (NADP NTN) and dry deposition in cooperation with EPA's Clean Air and Status and Trends Network (CASTnet) using methods described in publications by NADP (Malm 2017) and EPA (2018b). Data used in the analyses here focus on total wet nitrogen deposition and were obtained from the *2017 Park Conditions and Trends* (NPS 2017b). The condition levels are based on a five-year average from 2011–2015, and trends are based on ten years of data.

There are several different units used in relevant sources to report nitrogen data. The criteria establishing the levels of concern (see Table 4.5) are in kilograms of nitrogen deposited per hectare per year (kg/ha/yr), where a hectare is 10,000 m^2. The graphs (Figures 4.10–4.12) splitting out the different nitrogen species are expressed as microequivalents per liter (µeq/l) to make the concentrations comparable to one another, as NO_3^- and NH_4^+ have different masses but are univalent. Figure 4.13 shows the spatial distribution of nitrogen deposition.

Table 4.5. Criteria for nitrogen and sulfur deposition (NPS 2010a).

Status Category	Wet Deposition (kg/ha/yr)
Warrants Significant Concern	>3
Warrants Moderate Concern	1–3
Resource is in Good Condition	<1

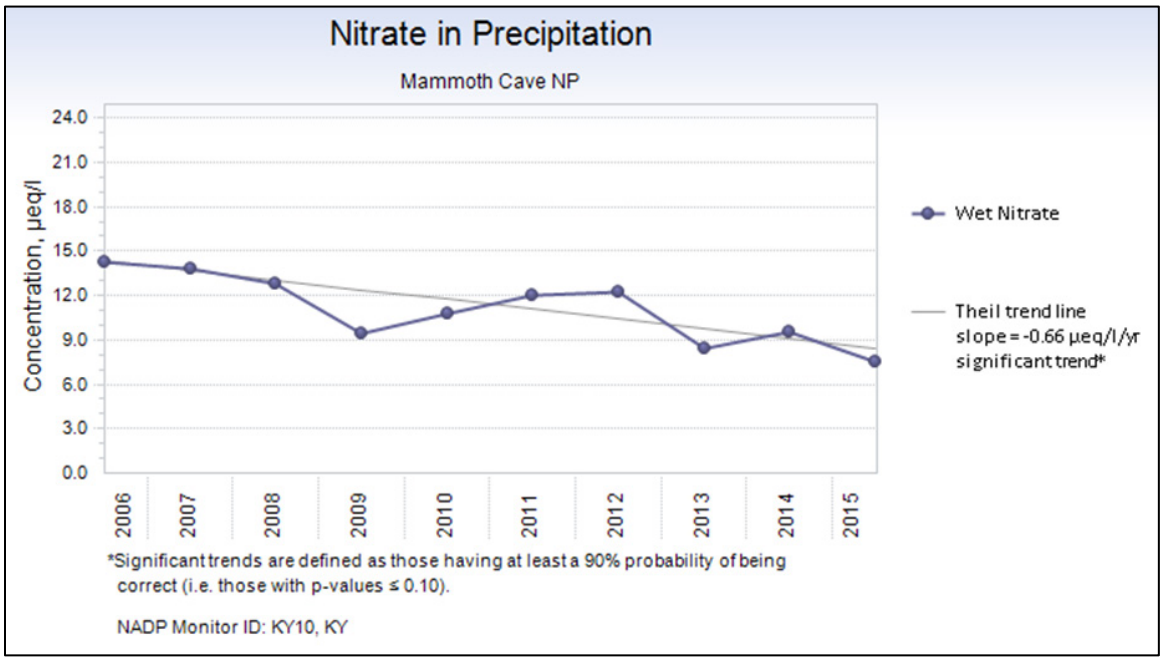


Figure 4.10. Nitrate in precipitation data for Houchin Meadow Site near MACA (NPS 2017b) showing annual values from 2006 through 2015. Data are concentrations shown in µeq/L.

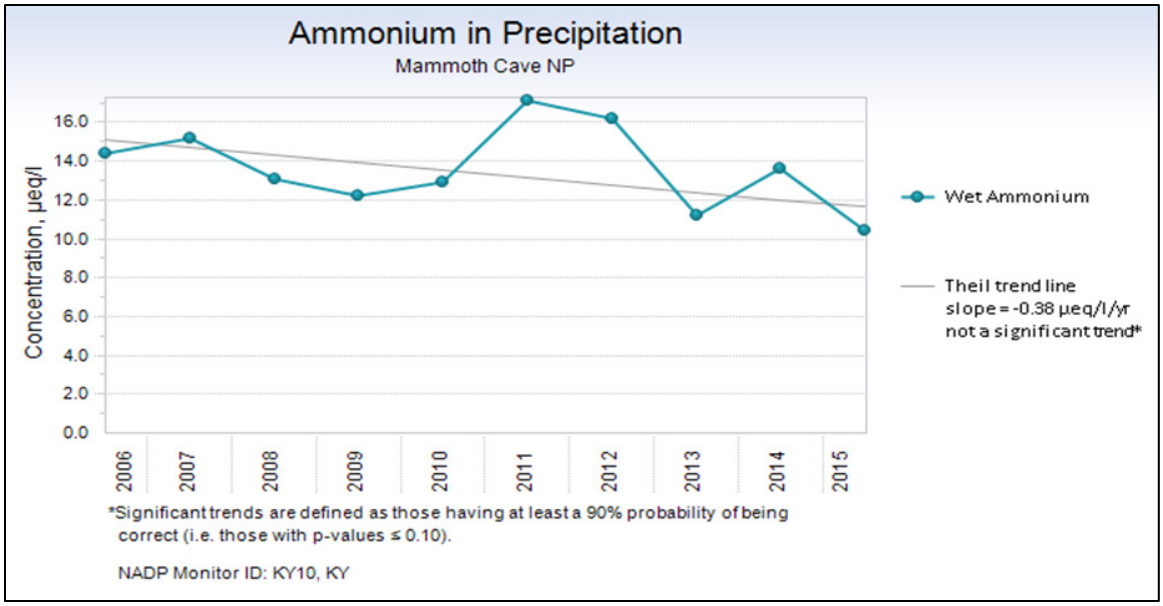


Figure 4.11. Ammonium in precipitation data for Houchin Meadow Site near MACA (NPS 2017b) showing annual values from 2006 through 2015. Data are concentrations shown in µeq/L.

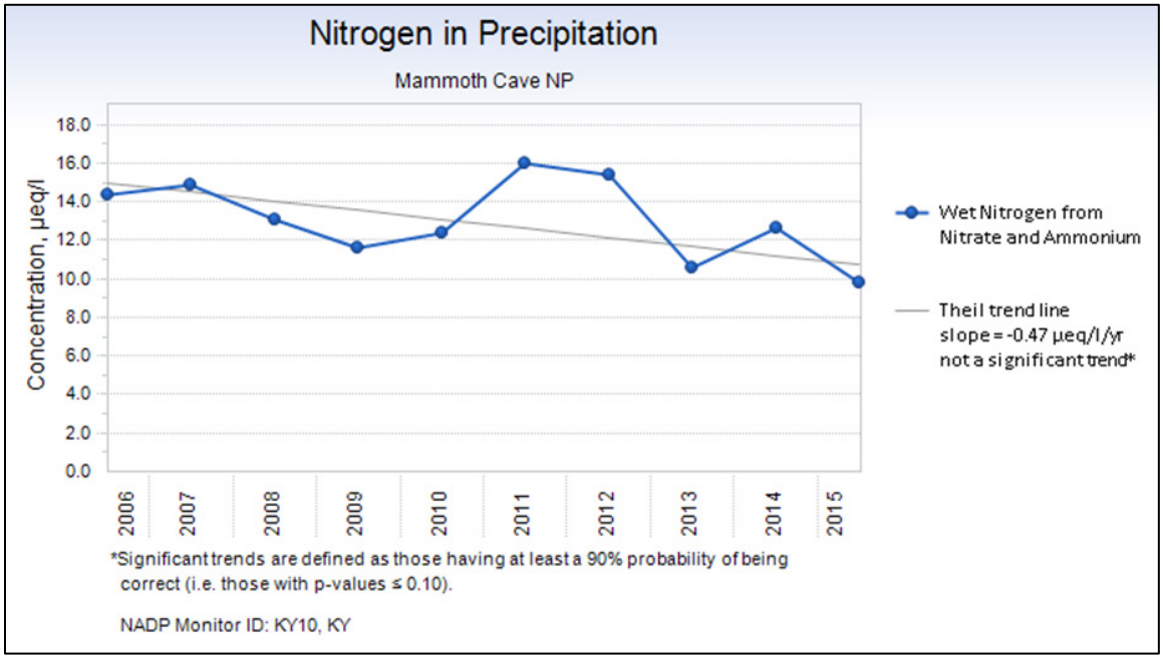


Figure 4.12. Nitrogen in precipitation data for Houchin Meadow Site near MACA (NPS 2017b) showing annual values from 2006 through 2015. Data are concentrations shown in µeq/L for the different nitrogen species to be comparable.

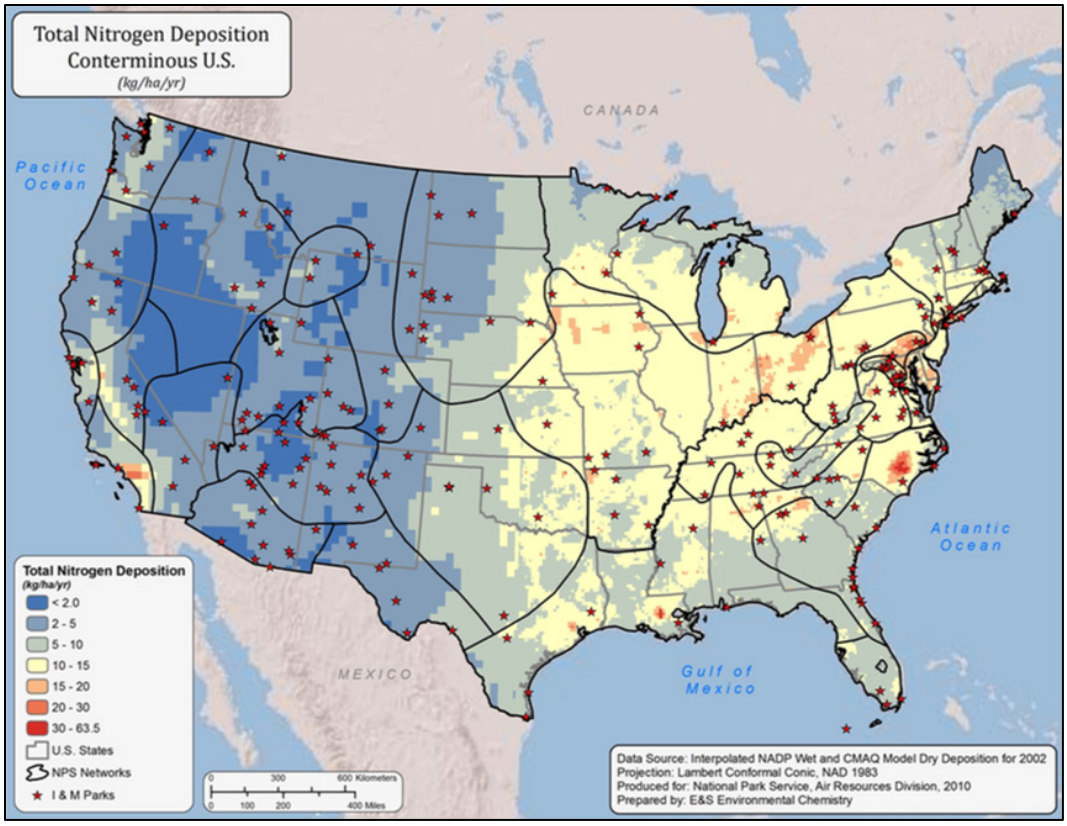


Figure 4.13. Total nitrogen deposition 2002. From Sullivan et al. 2011.

Reference Conditions/Values

Benchmark conditions for nitrogen and sulfur wet deposition are shown in Table 4.5 (NPS 2010a). Wet nitrogen deposition (Table 4.6) warrants significant concern at MACA based on the 2011–2015 estimated wet nitrogen deposition of 4.3 kilograms per hectare per year (kg/ha/yr) (Table 4.5). Although MACA receives high levels of nitrogen deposition, ecosystems in the park are not typical of nitrogen-sensitive systems and were rated as having very low sensitivity to nutrient-enrichment effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011a, 2011b). For 2006–2015, the trend in total wet nitrogen concentrations remained relatively unchanged (NPS 2017a).

Level of Confidence and Data Gaps

These long term, high-quality data were collected and analyzed with the protocols of the NADP NTN and CASTnet programs, and therefore there is a high level of confidence. There are no data gaps.

Condition Summary

Table 4.6. Graphical summary of status and trends for nitrogen deposition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Nitrogen	Wet deposition		Wet nitrogen deposition warrants significant concern at Mammoth Cave NP based on the 2011–2015 estimated wet nitrogen deposition of 4.3 kilograms per hectare per year (kg/ha/yr).

Sources of Expertise

Bobby Carson (Chief of MACA Division of S&RM, retired), and Johnathan Jernigan (MACA Division of S&RM/Physical Scientist, CUPN) provided expertise for this section.

4.1.4. Sulfur Deposition

Wet sulfur deposition warrants moderate concern at MACA based on estimated wet sulfur deposition of 3.0 kg/ha/yr (NPS 2017a), though the trend in total wet sulfur deposition has improved.

Description

Sulfur deposition can lead to acidification of surface water and soils, which in turn can have negative impacts on a wide range of organisms including microorganisms, aquatic organisms and plants. Along with direct ecological impacts, impacts to ecosystem services—direct human benefits that follow from healthy ecosystems—have been documented (Irvine et al. 2017).

The southeastern U.S. has been significantly impacted for decades by sulfate deposition because of extensive coal burning in the region for electricity production. Coal often contains the mineral pyrite, or FeS_2 (iron sulfide) that when burnt can become oxidized and end up as SO_4^{2-} (sulfate) in the atmosphere. In turn this mixes with rainwater or snow to form H_2SO_4, or sulfuric acid. This was particularly a problem because locally derived coal from the Western Kentucky Coalfield just to the north of MACA commonly has relatively high concentrations of pyrite. The situation has improved in recent years, as highlighted in the analysis below, through regulations that include more use of cleaner Wyoming coals, improved combustion technology, and conversion of important regional coal facilities to natural gas.

Data and Methods

The Houchin Meadow Atmospheric Monitoring Station (Figure 4.1) has provided data for both wet deposition through the National Atmospheric Deposition Program National Trends Network (NADP NTN) and dry deposition in cooperation with EPA's Clean Air and Status and Trends Network (CASTnet) using methods described in publications by NADP (Malm 2017) and EPA (2018b). Data used in the analyses here focus on total wet sulfur deposition and were obtained from the 2017 *Park Conditions and Trends* (NPS 2017a). The condition levels are based on a five-year average from 2011–2015, and trends are based on ten years or data.

As with nitrogen deposition, sulfate data are shown there are several different units, with the condition criteria expressed at kg/ha/yr and the trend graph shown in concentrations in □eq/l.

Reference Conditions/Values

Benchmark conditions for nitrogen and sulfur wet deposition are shown in Table 4.5 (NPS 2010a).

Condition and Trend

Wet sulfate precipitation over the period from 2006 through 2015 are shown in Figure 4.14 (NPS 2017a). From the Park Condition and Trends (NPS 2017a) wet sulfur deposition warrants moderate concern at MACA based on NPS Air Resources Division benchmarks and the 2011–2015 estimated wet sulfur deposition of 3.0 kilograms per hectare per year (kg/ha/yr). Ecosystems in the park were rated as having high sensitivity to acidification effects relative to all Inventory & Monitoring parks (Sullivan et al. 2011c, 2011d). Some plants are sensitive to the effects of acidification in the park, include sugar maple (*Acer saccharum*) trees, even though much of the surface and groundwater in the park is readily neutralized by limestone buffering.

Overall there were contributions to sulfur deposition from both wet and dry deposition (Figure 4.15). Wet sulfate provides the highest contribution, followed by dry sulfur dioxide and dry sulfate. As the total sulfur has varied from year to year, the proportional contributions stay relatively constant.

For 2006–2015, the trend in total wet sulfur concentrations in rain and snow at MACA improved (Figure 4.14; Table 4.7), following changes in regional coal burning technology.

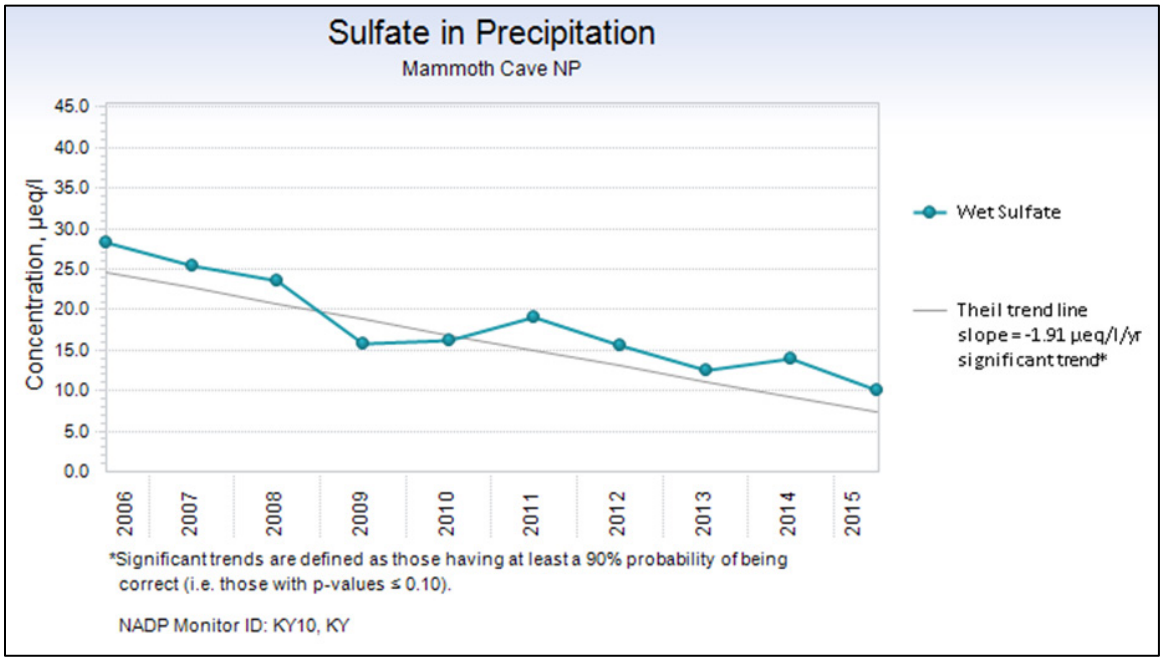


Figure 4.14. Wet sulfur deposition data for Houchin Meadow Site near MACA showing annual values from 2006 through 2015 (NPS 2017b).

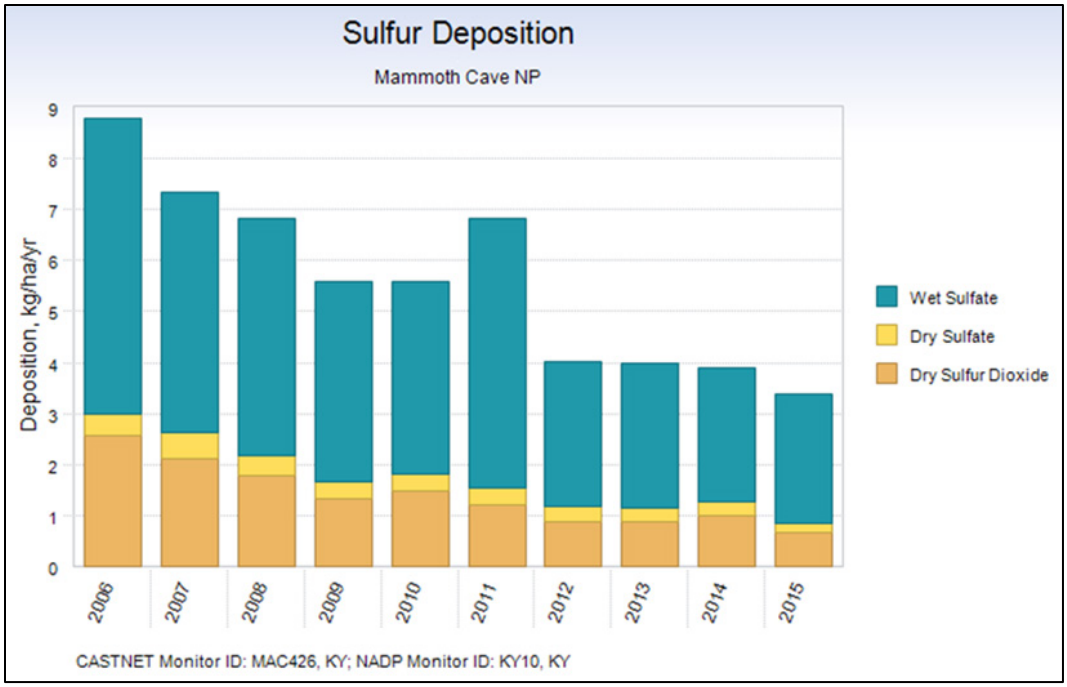


Figure 4.15. Distribution of the contributions to sulfur deposition at Houchin Meadow Site near MACA from 2006 through 2015 (NPS 2017b).

Table 4.7. Graphical summary of status and trends for sulfur deposition.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Sulfur	Wet deposition		Wet sulfur deposition warrants moderate concern at MACA based on estimated wet sulfur deposition of 3.0 kilograms per hectare per year (kg/ha/yr) (NPS 2017a). For 2006–2015, the trend in total wet sulfur concentrations in rain and snow at MACA improved.

Level of Confidence and Data Gaps

These long term, high-quality data come from the Houchin Meadow station adjacent to MACA (Figure 4.1) collected and analyzed with the protocols of the NADP NTN and CASTnet programs, and therefore there is a high level of confidence. There are no significant data gaps.

Sources of Expertise

Bobby Carson (Chief of MACA Division of S&RM, retired), and Johnathan Jernigan (MACA Division of S&RM/Physical Scientist, CUPN) provided expertise for this section.

4.2. Cave Air Quality

Atmospheric conditions within the Mammoth Cave and other caves of MACA are fundamentally different from those above ground, and for this reason we include this as a separate resource indicator. Of course, while it is the same air that circulates between the outside atmosphere and the cave, conditions in some ways are very different (Olson 2017a). There is no sunlight, for example, which plays an important role in atmospheric chemistry above ground (see section 4.1.2 on ozone), and in the absence of such diurnal changes conditions such as temperature and relative humidity are typically much more constant than outside. There are also differences because of interactions with the water, rock and sediment in caves that affect air chemistry, especially with respect to carbon dioxide, but may include other gasses (Toomey 2009) such as hydrogen sulfide, carbon monoxide, and methane that can get concentrated in areas with restricted ventilation.

The cave passages themselves along with smaller fractures and conduits allow gasses to move readily through the otherwise solid rock of karst aquifers. For this reason, in some areas—including MACA—harmful radon gas can move upward from deeper geologic sources towards the surface where it can accumulate in caves and upwards from there into homes and other structures (Webster 1990, USGS 1993). Sources of radon also exist within the cave passages, as it is also emanating from the surrounding rock of the cave walls as well as deposited sediments. The Mammoth Cave System has significant radon concentrations relative to human exposure guidelines (see discussion below), with the potential that employees' time could be limited in the cave in a given year (Carson 1981, Eheman et al. 1991).

Fumes from pollution releases at the surface can also thus move readily through the typically permeable unsaturated zones of karst aquifers to accumulate in caves, sometimes creating dangerous conditions. Serious, documented cases have included contamination by gasoline and TCE (trichloroethylene) and in at least two cases cave explorers were killed by accidentally igniting explosive vapors (Groves and Crawford 2017). There is some potential of this occurring at MACA as a result of spills along I65 or the CSX railroad and flowing through the aquifer. In 2001 3,800 gallons of diesel fuel spilled along I65 near Park City, although transport of the material through the aquifer was apparently impeded by sumps, which are places that a cave ceiling comes down to water surface of a cave stream so that that passage beyond is full flooded (Meiman 2006). At those locations, floating chemicals such as hydrocarbons are trapped up against the ceiling, and neither liquid chemicals nor fumes were ever detected from that spill. In this assessment impacts of such spills are discussed in the section on water quality (4.4.3) rather than air quality.

Because the conditions in the cave are relatively stable they are more sensitive to perturbations by smaller, more localized changes in air quality (Olson 2017a) from activities such as the use of gas lanterns for tours and formerly "torch throwing" (Figure 4.16), in which for more than a century small knots of cotton soaked in kerosene were lit on fire and flung in high arcs across the passage to land on small, high ledges to provide lighting in large rooms that were otherwise hard to see. Although spectacular to see, the burnt kerosene impacted the otherwise stable air quality of the cave and the practice was ended in 1991. An early study of tour impacts on air (Kaletsky 1992) showed

that cooking food for tours in the underground restaurant of the Snowball Dining Room created clear microclimate changes and eventually this was also discontinued.

The indicators with which we assess the condition of cave air quality include:

- 4.2.1. Radon
- 4.2.2. Carbon Dioxide
- 4.3.3. Cave Meteorology

4.2.1. Radon

Radon, a naturally occurring radioactive gas that causes elevated risk for lung cancer, occurs in MACA caves. There is a significant concern for radon concentrations in the cave, but a moderate concern for employee exposures as this can be controlled by monitoring and limiting underground hours. Both measures are stable.

Description

Radon is a colorless, odorless radioactive gas produced by geologic materials that contain small amounts of uranium. Uranium decays through a complex series of steps to form thorium, which decays into radium, and from there into radon. Under near-earth surface conditions radon exists as a gas and is therefore relatively mobile (USGS 1993). Because of the radiation produced as radon subsequently decomposes, exposure to the gas presents an elevated risk of lung cancer when people frequent places where it can build up such as homes, mines, and caves (Field 2007).

MACA lies within a broad swath of Kentucky counties that have relatively high levels of radon (Figure 4.17). Several hundred meters below the karst-forming rocks of the MACA area lies the Devonian-aged Chattanooga Shale, which has relatively high concentrations of uranium (Stockdale and Klepser 1959). The red swath of Zone 1 counties shown in Figure 4.16 roughly corresponds to the axis of the Cincinnati Arch, a large structural upwarping of the sedimentary rocks that underlie Kentucky. This has brought the underlying layers of rock, including the Chattanooga Shale (see Figure 4.24), closer to the surface. In turn, especially in the highly karstified Mississippian rocks that lie between the shale and the surface, the high permeability allows the gas to easily move through the otherwise solid ground into caves as well as through the soil into homes and other structures.



Figure 4.16. Because of the stable conditions in Mammoth Cave, activities can have measurable impacts on temperature, relative humidity, and air chemistry (Olson 2017a). Top: a century of “torch throwing” was discontinued in 1991 due to air quality impacts (NPS photo). Bottom: Gas lanterns, along with hundreds of candles, are concentrated in the Methodist Church during the annual Cave Sing, this one in 2012. This event is held once each year (photo by Chris Groves).

In 1975, the NPS initiated a study of radon and thoron levels in all NPS administered caves that offered tours to the public (Yarborough 1980). The survey at MACA was performed in March and August of 1975 to obtain winter and summer levels. By the next year is became apparent that the ventilation shaft that had been constructed at the park to provide cool air from the cave to air condition the administrative offices and Visitor Center was allowing radon to get into those buildings, and the shaft was sealed. The subsequent events were described by Bobby Carson of MACA's Division of S&RM:

> The vent shaft was constructed somewhere between 1958–1962 as part of Mission 66. Radon was discovered in 1975 as part of a service-wide effort to assess radon levels at NPS operated caves after being discovered in Carlsbad Caverns. The now defunct Mine Enforcement and Safety Administration (MESA) and NPS Scientist Dr. Keith Yarborough made survey trips to MACA in January and May 1976. Following these trips MESA recommended that the ventilation shaft be sealed due to radon levels in the Visitor Center and administrative offices being equal to levels found in the Historic Tour (in summer). MESA also recommended establishing a routine radon monitoring program and employee exposure monitoring/recordkeeping. The park responded to the recommendations by sealing the shaft in July 1976 and establishing a radon monitoring and employee exposure recordkeeping program.

EPA determined in about 1978 that due to the relatively short exposure time experienced by visitors it would not be necessary to inform the public or post radiation area signs. Employee exposure limits were set at 4 Working Level Months (WLM) per year which was equal to the occupational exposure allowed by underground miners. Additional studies of the potential for radon hazards in caves (Baier 1976, Yarborough 1980, Field 2007) and at MACA in particular (Carson 1981, Eheman et al. 1991) have taken place since that time and the monitoring program continues.

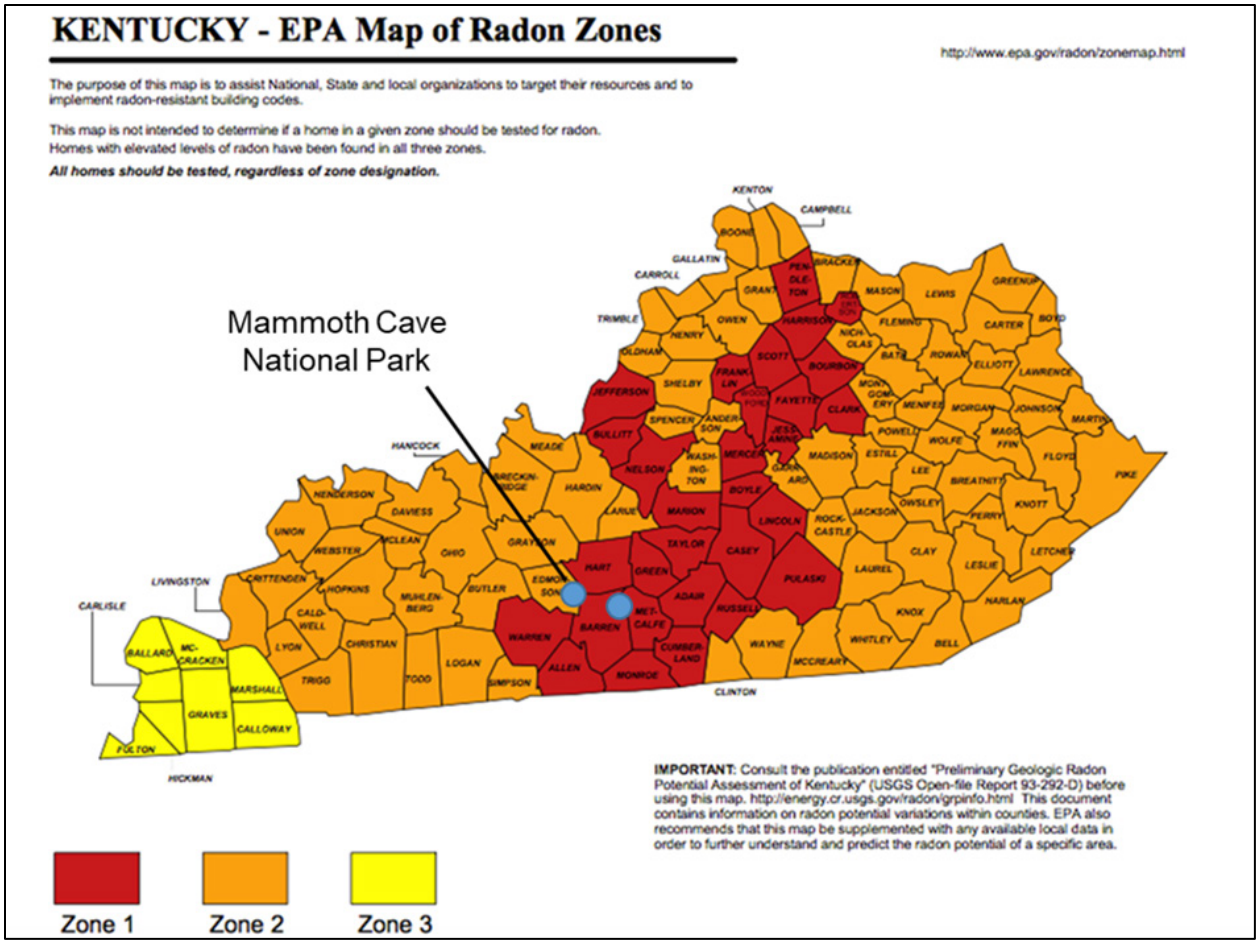


Figure 4.17. Map of highest (Zone 1) concentrations in Kentucky by county. Note that MACA and the cave system is within parts of Hart, Barren and Edmonson Counties (EPA 2014b). This band of high values roughly corresponds to the axis of the Cincinnati Arch (USGS 2001).

Data and Methods

There are several types of units that are used to describe radon (chemical symbol Rn) levels. The principal relevant form of radon is the isotope ^{222}Rn. A complication is that it is not sufficient to measure simple concentrations, because what is relevant is the rate at which the decay of a nucleus produces one of several particles. Those particles create the relevant health effects. While these occur from the decay of radon, that decay also forms a suite of short-lived radioactive *progeny*, or decay products which are also radioactive and emit their own dangerous particles. These include polonium 218 (^{218}Po), lead 214 (^{214}Pb), bismuth 214 (^{214}Bi) and polonium 214 (^{214}Po). For understanding potential health impacts, the individual concentrations don't matter as much as the total number of particle disintegrations. The unit of a *Bequerel* (abbreviated Bq, with units of 1/s) was developed, corresponding to the activity of a quantity of material such that one nucleus disintegrates per second, and the cumulative exposure for people in a work environment that contains radon such as a mine or cave is measured in *working level months* (WLM) which as the name implies determines the total exposure of the employees considering both the concentration of radon progenies and the

accumulated time of exposure. The allowable level, in turn, for employee work exposure would be expressed in WLM per year, or WLM yr−1. The federal exposure limit is 4 WLM yr−1 (EPA 1971).

The method for analysis of radon concentrations and human impacts are governed by NPS-14 (National Park Service 1980), and the techniques described by Eheman et al. (1991) are still in use:

Guidelines established by the NPS and approved by [the Mine Health and Safety Administration] MSHA require weekly sampling when the average ^{222}Rn progeny concentration meets or exceeds 1.12 kBq m−3 (0.30 WL) (NPS-14 1980). Radon-222 progeny measurements in Mammoth Cave are made using the Kusnetz method developed for use in underground mines (Kusnetz 1956). Measurements are taken by drawing a minimum of 2.0 L m−1 of air for 5 min through a 25-mm fiberglass filter utilizing a calibrated sampling pump[1]. The ^{222}Rn progeny concentrations are determined using an α-scintillation counter and an α detector[2]. The scintillation counter and detector are calibrated at 6-mo intervals using procedures described by the Mine Safety and Health Administration (Beckman 1975) and are checked daily with a calibrated ^{230}Th source. Measurements are made in all toured sections of the cave once a week. Each "room" or trail on a cave tour is sampled so that the number of samples taken depends on the length of the tour.

The NPS calculates the exposure of employees to ^{222}Rn progeny by assessing the time spent in each area and the Working Level measured in that area for that week. Exposure records are maintained for each employee who works in the cave. An employee's record contains exposure history, occupation category, sex, and date of birth. Records also indicate whether an employee was exposed prior to 1976, if he or she smokes, and the result of any sputum cytology tests. NPS staff review exposure records on a weekly basis. If an employee's cumulative exposure reaches 3.5 WLM in a year, that person is assigned to duties outside the cave.

Reference Conditions/Values

There is not a specific reference condition of radon concentration that signifies a threshold for dangerous conditions from exposure to radon. Exposure depends both on concentrations and the length of time that a person is breathing that air. However, the U.S. Occupational Safety and Health Administration (OSHA 2016) defines the exposure limits for workers exposed to radioactive materials as an Annual Limit of Intake (ALI), defined as the "derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year" as 4 WLM yr−1. The same regulations define the threshold Derived Air Concentration (DAC) or 0.3 WL, referring to the concentration of a given radioactive element in air which, if breathed for a working year of 2,000 hours under conditions of light work results in an intake of one ALI. Weekly monitoring and employee record keeping are required at 25% of 0.3 WL, or 0.75 WL (Bobby Carson, MACA Division of S&RM, Division Chief, June 2016, personal communication). Based on

[1] Model S monitaire sampling pump, Mine Safety Appliance Company, Pittsburgh, PA 15230.

[2] Model 2200 a-scintillation counter and model 439 01 detector, Ludlurn Instrument Company, Sweetwater, TX 79556.

these regulations and through discussion with MACA S&RM staff we define reference conditions here for radon progeny exposure in Table 4.8.

Table 4.8. Criteria for radon progeny exposures (OSHA 2016; USNRC 2017; Bobby Carson, MACA Division of S&RM, Division Chief, June 2016, personal communication).

^{222}Rn Condition	Derived Air Concentration (WL)	Annual Limit on Intake (WLM)
Warrants Significant Concern	>.3	>4
Warrants Moderate Concern	0.074–0.3	1–4
Resource is in Good Condition	<0.074	<1

Condition and Trend

Jernigan (1999, 2001) undertook an analysis of the large quantity of radon monitoring data up to that time. For the purpose of this assessment, two analysis are highlighted based on data from 1989 through 2001, using a typical data set from the Historic Tour area of the cave, location H5 taken between River Hall and Mammoth Dome. Figure 4.18 (left) shows the mean concentrations in working levels shown monthly using 1989 through 2001 data, and Figure 4.18 (right) shows the trend through time over the same period. In the context of the current resource assessment, the principal conclusion is that, while there are seasonal variations with higher levels in the warmer months (Figure 4.18 [left]), most values are below 1.0 WL, and there is no discernable upward or downward trend over the twelve years of data in Figure 4.18 (right). These are typical for data from other parts of the toured areas of the cave, which include sampling from the Historic, Cleveland Avenue, Frozen Niagara/Travertine, Violet City Lantern, Gothic Avenue, and Great Onyx tours.

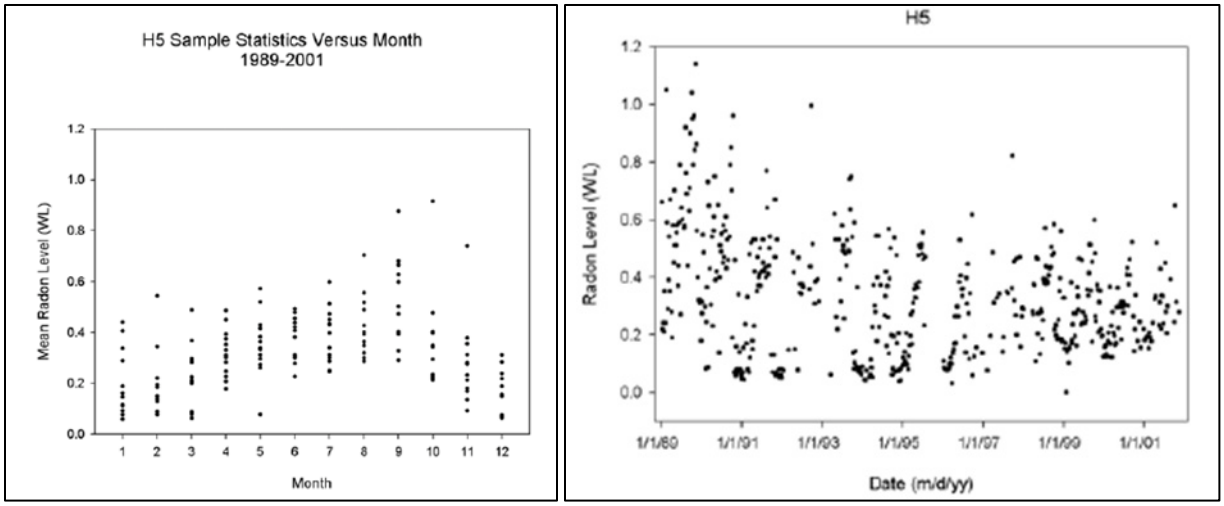


Figure 4.18. Example radon data along the Historic Tour between River Hall and Mammoth Dome for 1989 through 2001 (left; Jernigan 1999, 2001). These are typical of data from other areas of the toured parts of the cave. Most values are under 1.0 working levels, and there is no discernable upward or downward trend over the twelve years of data (right).

Radon data have been collected since, but have not been analyzed (Johnathan Jernigan, MACA S&RM/CUPN, Physical Scientist, June 2016, personal communication). Since there was not a clear upward or downward trend in the twelve-year 1989–2001 data, and since there have not been changes to airflow by manipulation of the gate at the Historic entrance, there is not an indication that radon levels would be higher in that part of the cave. See discussion in the section on data gaps, below.

Employee radon exposure at MACA is stable (Table 4.9), because in recent years, employee scheduling has been such that staff are not regularly spending long periods of time in the cave. This had especially been a concern when there were full-time cave maintenance crews, but due to staffing limitations it has been years since that has been the case (Bobby Carson, MACA Division of S&RM, June 2016, personal communication). In this case the cave guides would be the staff members spending the most hours in the cave, but with scheduling in recent years, it has been at least as far back as the early 1990s since any guide staff have had to alter their schedule due to radon exposure (Kathy Profitt, Supervisory Park Ranger, MACA Division of Interpretation and Visitor's Services, October 2018, personal communication).

Level of Confidence and Data Gaps

There are two conclusions made here: 1) that there is no evidence that radon levels have had an upward or downward trend since they were last analyzed in 2002, and 2) that employee exposure is below the recommended threshold. Both are made with only medium confidence given the long term, data monitoring program in place at MACA since the 1970s, but the fact that there have not been detailed analysis and interpretation of the data since 2002. We regard the uncertainties with regard to these questions to constitute a very significant data gap, especially with regard to fully implementing and updating the system for tracking employee cave time and exposure.

In the 1970s–1990s research was done at MACA to develop a more detailed understanding of radioactivity exposure through investigation of research on radon which, in addition to measuring radon gas and radon progeny, determined unattached fractions of radon and radon decay products, measured the various radon progeny concentrations using the more robust Tsivoglou method as opposed to the simplified Kusnez method to speciate radon byproducts, and determined equilibrium ratios between radon and radon decay products (Bobby Carson, MACA Division of S&RM, Division Chief, June 2016, personal communication). If resources would permit in the future, such continued work could be useful, but significantly less important than addressing the major data gaps of regularly analyzing radon level data collected to be sure that levels have not changed and more importantly addressing the shortcomings of the existing exposure tracking system to be sure we adequately track each employee's exposure. Data collection of radon has continued, so resources to conduct regular data analysis, and application of these levels to employee time in the cave would solve this issue.

Sources of Expertise

Bobby Carson and Liz Thomas of MACA S&RM, and Johnathan Jernigan (MACA S&RM/CUPN) provided expertise for this section.

Condition Summary

Table 4.9. Graphical summary of status and trends for ^{222}Rn progeny.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
^{222}Rn progeny	Derived air concentration (WL)		Levels commonly exceed 0.3 WL which requires continuous monitoring of air and record keeping for staff exposure levels. There are no long-term upward or downward trends.
^{222}Rn progeny	Annual limit on intake (WLM)		Exposure commonly exceeds 1 WLM but employees are monitored and assigned surface duties at 3.5 WLM. This has not happened for at least 25 years.

4.2.2. Carbon Dioxide

Although in confined areas such as buildings, mines, or caves carbon dioxide can be harmful at high enough concentrations by replacing needed oxygen, this is not the case on the tours at MACA and there are known no negative impacts from cave CO_2 on human health. Elevated CO_2 concentrations can also have negative impacts, including corrosion of speleothems and cave walls (e.g., Mulec and Kosi 2009, Sanchez-Moral et al. 1999, Pulido-Bosch et al. 1997), impacts on cave organisms (e.g., Howarth and Stone 1990, Miedema 2009), and impacts on plant growth and species of lampenflora (Lamprinou et al. 2014) (see section 4.13).

Description

Carbon dioxide (CO_2) is an important gas in the Earth's near surface systems although it occurs in very small concentrations in the atmosphere, currently about 400 parts per million (ppm). Steadily rising atmospheric CO_2 concentrations since the onset of the industrial revolution have been shown to be changing rates of climate change (IPCC 2013). Carbon dioxide is also a key component in photosynthesis.

Carbon dioxide is a critical component of karst landscape aquifer development. While the details are complex (e.g., Drever 1982, White 1988) the basic idea is that CO_2 from the atmosphere, along with larger amounts in soil gas that come from root respiration and microbial degradation of organic material, mixes with water to form carbonic acid (H_2CO_3). While limestone is only slightly soluble in pure water, its solubility and the rates at which it dissolves increase dramatically in carbonic acid. Dissolution is the key landscape-forming process responsible for the distinctive surface and subsurface features of karst regions, including the world's most extensive known cave here at MACA.

While climate change related to changes in atmospheric CO_2 concentrations is likely to have significant impact on future resource conditions at MACA, the purpose of this section is to evaluate conditions with respect to CO_2 within the air of MACA's caves. CO_2 is elevated in caves compared to the surface due to outgassing from water as carbonate minerals precipitate, production by bacteria, fungus, and animals, and elevation in tourist caves due to visitors.

Data and Methods

Five (2003–2007) years of continuous CO_2 concentrations were measured at three cave sites within the toured areas of Mammoth Cave (Wright's Rotunda on the Lantern Tour, Little Bat Avenue on the Historic Tour, and Showerbath Spring on the Frozen Niagara Tour) and for reference outside air at the Houchin Meadow monitoring site (Jernigan 2007; Figure 4.1).

Reference Conditions/Values

The EPA does not have reference standards for CO_2 as it is very unusual to have concentrations that can lead to either acute or chronic health problems in either indoor or outdoor environments. CO_2 when measured in buildings is highly correlated with, and used as a proxy for, human bioeffluents (body odor) and so CO_2 measurements can be useful to determine whether there is adequate ventilation in a particular setting to keep the bioeffluent load sufficiently low (Apte et al. 2000). However, there are circumstances where CO_2 can build up in caves to uncomfortable or even dangerous conditions (e.g., Elliot 1997). A list of potential effects of higher concentrations is given in Table 4.10, and we use these for the evaluation of health concerns related to CO_2. There is also potential for environmental impacts, and New Zealand's Waitomo Cave has set 2,400 ppm as a threshold for concern (Miedema, 2009), and at Spain's Candamo Cave, 5,000 ppm is considered to be the lower limit for human safety (Hoyos et al. 1998). Although levels over 1,000 ppm indicate the possibility of mild health effects, concentrations between 1,000 and 2,000 ppm (elevated 3–5 times atmospheric background) are very common levels in caves including the tours of Mammoth Cave (Figure 4.19). MACA interpretive staff do not report recollection of any otherwise healthy tourists complaining about or having problems with bad air, over years of visitation that has typically been just under 500,000 visitors per year (Chuck Decroix, MACA Division of Interpretation and Visitor Services, Park Ranger, July 2018, personal communication). Mindful of these considerations, we assign a threshold for moderate concern at 2,000 ppm at which point the effects typically become more pronounced.

Table 4.10. Potential Health Effects of various CO_2 concentrations (Wisconsin Department of Health Services 2019).

CO_2 concentration (ppm)	**Potential Health Effects**	**CO_2 Condition**
250–350	Background outside air*	Resource is in good condition
350–1,000	typical level found in occupied spaces with good air exchange	Resource is in good condition
1,000–2,000	possible complaints of drowsiness and poor air	Resource is in good condition
2,000–5,000	possible headaches, sleepiness, and stagnant, stale, stuffy air	Warrants moderate concern
5,000	toxicity or oxygen deprivation could occur. This is the permissible exposure limit for daily workplace exposures	Warrants significant concern
40,000	immediately harmful due to oxygen deprivation	Warrants significant concern

* These data are used verbatim from the cited source, though with rising atmospheric background CO2 concentrations now around 400 ppm, typical current values are likely higher.

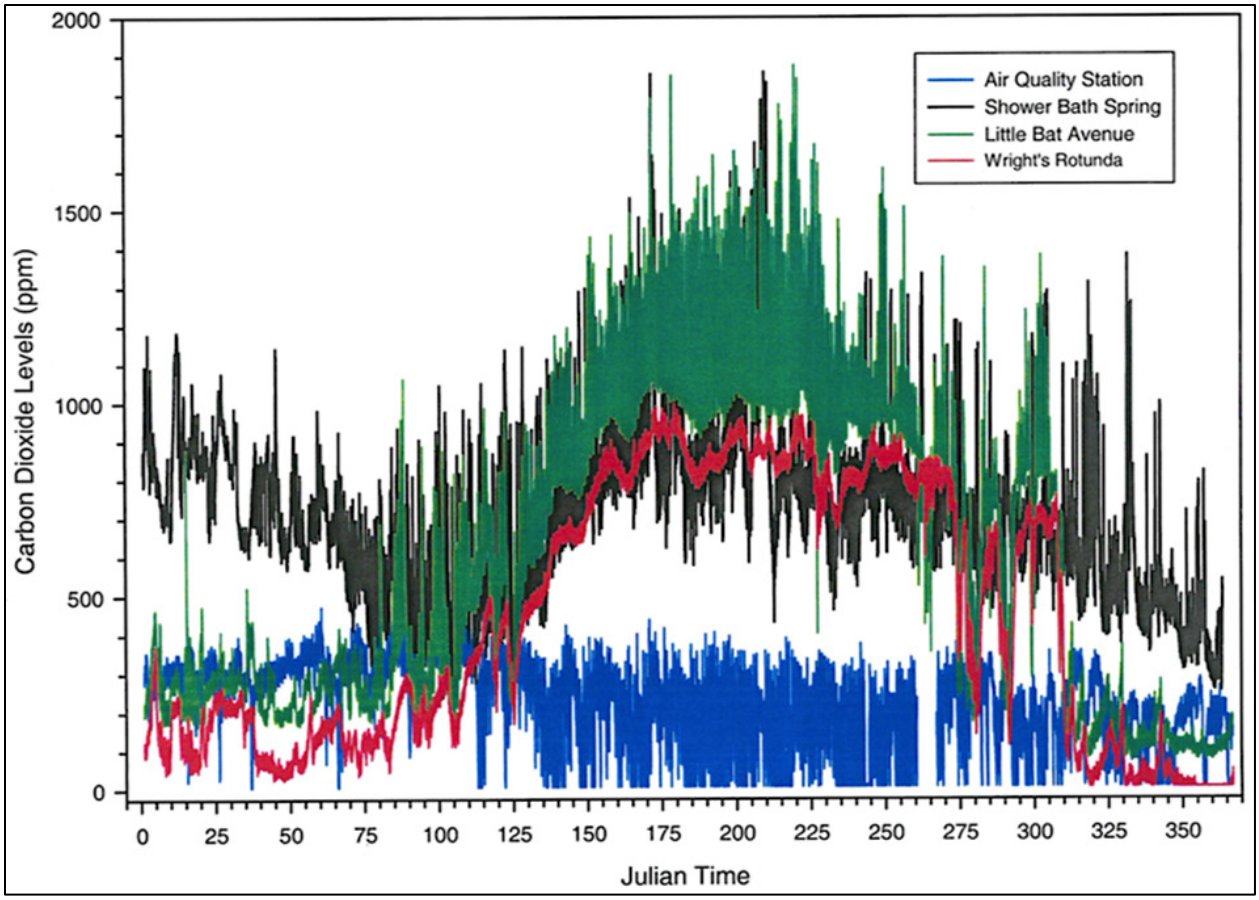


Figure 4.19. Example (2004) CO_2 data from several locations along tours in Mammoth Cave as well as outside background air (Jernigan 2007). The cave levels are all below 2,000 ppm, which is about 5 times the atmospheric background level. Julian time refers to days of the year starting on January 1.

Condition and Trend

The conditions are assessed through analysis of a five-year data set (2003–2007; Jernigan 2007) described above. An example year (2004) is shown in Figure 4.19. These are highly detailed data that represent conditions at three different locations within the cave, and as these are as a result of natural conditions, there is no expectation there should be an increasing or decreasing trend through to the present. All levels are under 2,000 parts per million so there does not seem to be a reason to be concerned about these concentrations for human health (Table 4.11). While in some parts of caves, particularly dead-end passages, CO_2 concentrations can reach concentrations of at least 9,000 ppm (Kozel et al. 2018), to a large degree this is a function of ventilation and the accessible cave tour paths at MACA are in general well ventilated.

In terms of other environmental impacts, from the authors' experience there is not much evidence that water in contact with cave walls or spelethems had high enough CO_2 pressures that problems exits from corrosion at the levels of CO_2 that we see in MACA's caves. While there are places in the cave that localized corrosion of walls or speleothems can be seen, the fact that these are localized suggests this is from geochemical effects other than exposures to regular CO2 concentrations (see

Palmer and Palmer (1995) for an example). The elevated (from atmospheric) concentrations of CO2 do exacerbate lampenflora growth, due to the fact that algae grows better in the elevated CO2 that we see in the cave. However, we do not see (non-transitory) tourist related increases and managing CO2 levels is not an effective way to reduce lampenflora growth.

Condition Summary

Table 4.11. Graphical summary of status and trends for CO_2 data.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
CO_2	Concentration in parts per million (ppm)		All high-resolution data from a five-year study of representative Mammoth Cave air were below 2,000 parts per million. Park staff reported no known cases of visitors complaining about air quality.

Level of Confidence and Data Gaps

These are high quality data directly from MACA, and are consistent with the observations from park staff about visitor experiences, so there is high confidence in these interpretations.

Sources of Expertise

Johnathan Jernigan (MACA S&RM/CUPN), Rick Toomey (MACA S&RM) and Chuck Decroix (MACA Interpretation and Visitor Services) provided expertise for this section of the analysis.

4.2.3. Cave Meteorology

Description

There are not standardized reference conditions for cave meteorology conditions but the movement of air and water vapor within the caves of MACA has important application for a variety of sensitive resources so we consider some of these within the scope of this NRCA. Indeed, while significant meteorological data collection had begun earlier in the cave, the remarkable rock fall of January 1994 near the Historic Entrance ushered in a new age of sustained data collection and analysis that continues today. A period of unusually cold temperatures that month was followed by a warm front that came through Kentucky, raising the region's temperatures just above freeing and producing rain that froze on contact with the cold ground surface and left about a centimeter of solid ice over the whole park and surrounding region. This was followed shortly after by a strong cold front that brought several cm of snow on top of the ice and a rare, frigid polar air mass that caused temperatures to fall far below zero. Under these conditions the state interstate highway system was shut down, closing MACA for several days as no one could get in or out of the park. One night that week the air temperature dropped to minus 16ºF, and during the whole period freezing air was roaring into the cave through the Historic Entrance into the first big room, the Rotunda. When the tours reopened after a few days, the first tour down into the Historic area quickly realized that a huge slab of rock—about 20 m long and 6 m wide—had fallen onto the tourist trail, destroying a handrail

and part of the remains of the 1800s saltpeter mining operation. A check showed that no significant seismic activity had occurred, and so the cold temperatures were the overwhelmingly likely cause.

Data and Methods

There is a large quantity of data that have been collected in caves of MACA, most of which was been air temperature and relative humidity, but in some cases this has included wind speed and direction. Although only a portion of these have been subject to analyses, what has been processed has used interpretation of graphical time series or statistical summaries (e.g., Jernigan and Carson 2010, 2011, in review) as well as mathematical modelling (e.g., Jernigan 1997). These have been under auspices of both MACA and CUPN. Olson (2017a) listed the principal efforts and describe sporadic earlier efforts, which go back at least as far as descriptions of the seasonal air flow of the Historic Entrance described in 1824 (Blane 1824). Modern measurements have had a range of sophistication ranging from measurements of air flow using soap bubbles in the late 1980s by Bobby Carson and balloons by Rick Olson in 2003 (Figure 4.20) to a "lift station" (Figure 4.21) designed and built by engineers.

Important programs have been the Cave Atmospheric Monitoring (CAM) program which measured conditions at 11 stations that operated over different from 1994 to 1998 or 1999 to quantify impacts of a program underway at that time to reseal the artificial entrances with airlocks to revert them back their original impact on airflow, or lack thereof. Subsequently CUPN developed a monitoring protocol (Woodman et al. 2012) and maintained during a developmental program beginning during 2002 and a monitoring program from 2008–2015 with observations at 18 locations within 6 caves (11 in Mammoth Cave, two each in Blood and Haunted Caves, and one each in Blight, Luna, and Saucer Cave). Details of the program and methodology were given by Woodman et al. (2012).

Reference Conditions/Values

There are no particular reference conditions for cave meteorological conditions similar to those for, say, water quality. We use existing data and professional judgement here to determine whether sensitive natural or cultural resources in the cave are being impacted by meteorological conditions in the cave as they are understood. It should be noted that these are naturally occurring processes in places where entrances or passages may or may not have been modified, and so it would seem reasonable to focus on modifications that may have caused problematic conditions, and whether these should or can be ameliorated.



Figure 4.20. Simple equipment can be used to gather useful data. In this 2003 experiment airflow was mapped flowing along the ceilings of both Broadway and Audobon Avenue towards the Rotunda (Photo by Rick Olson).

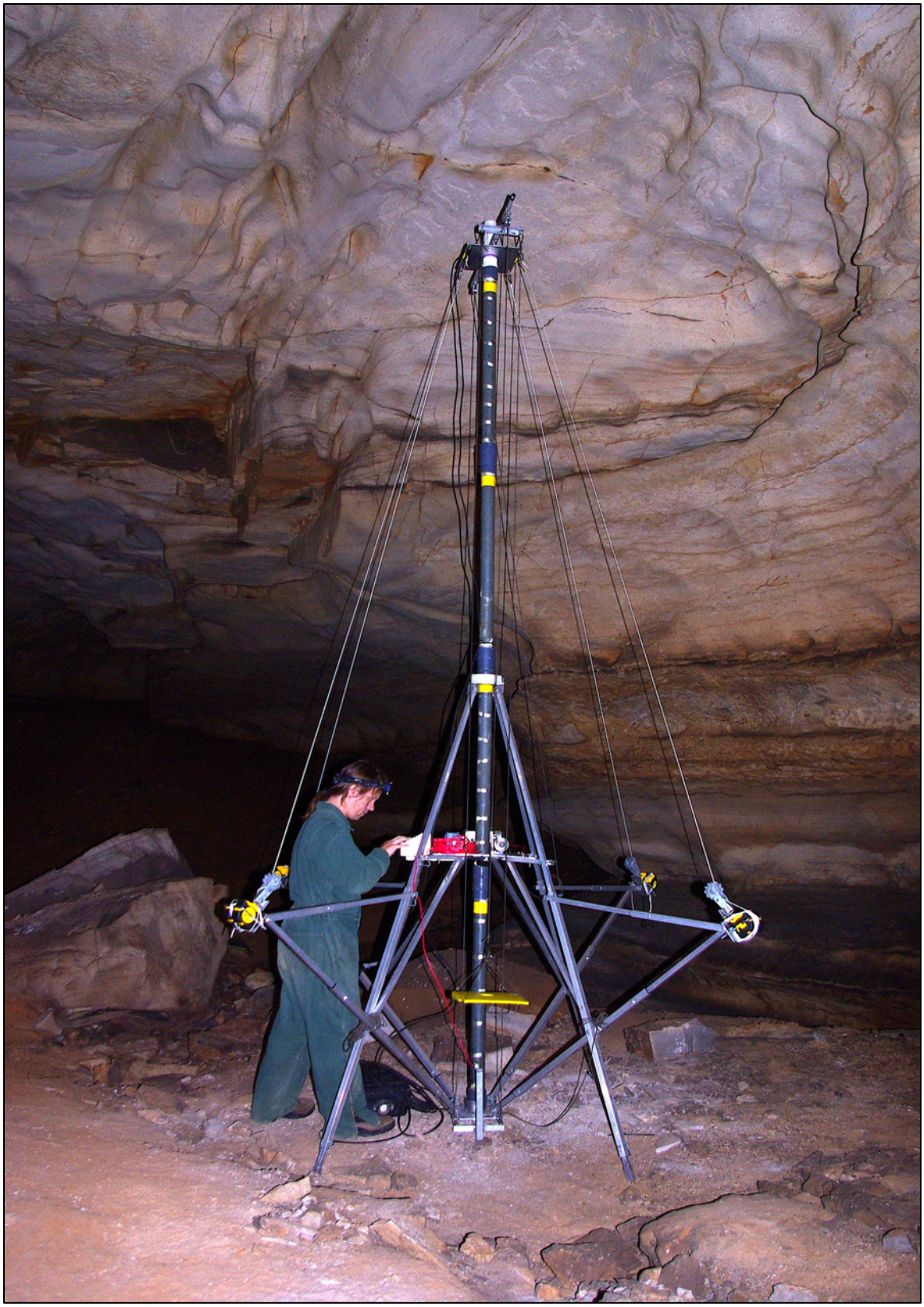


Figure 4.21. CUPN scientist Johnathan Jernigan at a “lift station” in Mammoth Cave that can move sensors to different vertical positions to measure stratification (NPS photo by Kurt Helf).

Condition and Trend

Although a very large quantity of high-quality cave meteorological data has been collected, only a subset has been quantitatively evaluated. This may provide insights into the processes associated with these conditions for future scientists. As it is, they have been useful to evaluate the results of various management practices like modification of entrances.

In the context of this assessment, to evaluate the health of MACA resources, the data suggest only limited current impact of meteorological conditions on park resources (Table 4.12). In one vexing case that has received considerable attention (Olson 2017a) air near the ceiling coming from Gothic Avenue into Broadway (Figure 4.20) under some conditions forms drops of condensation that then fall on irreplaceable historic structures from the 1800s saltpeter mining operation.

An important conclusion that has become apparent (see Jernigan 1997 for details) is that air movement in Mammoth Cave is almost wholly driven by temperature-dependent density differences and largely independent of changes in outside barometric pressure.

Condition Summary

Table 4.12. Graphical summary of status and trends for cave meteorology.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Cave meteorology	Temperature, relative humidity and air flow		There are no standardized reference conditions for cave meteorological conditions. There is no threat to human health, but moderate concern due to significant, if localized, to historic artifacts from War of 1812 saltpeter mining

Sources of Expertise

Bobby Carson, Rick Olson, and Rick Toomey of MACA's S&RM Division and Johnathan Jernigan (MACA S&RM/CUPN) provided expertise for this section.

The National Park Service's Air Resources Division oversees the national air resource management program for the NPS. Together with parks and NPS regional offices, they monitor air quality in park units, and provide air quality analysis and expertise related to all air quality topics. For current air quality data and information for this park, please visit the NPS Air Resources Division website at www.nps.gov/subjects/air/index.htm.

4.3. Geology and Soils

In this part of the report, to avoid considerable redundancy, with some exceptions the "Data and Methods" and "Sources of Expertise" information is given just once in the first section below, to cover the entire section 4.3 Geology and Soils.

The geological conditions within Hart, Barren and Edmonson Counties, interacting with climate and hydrology, have created the unique situation that has led to formation of MACA's unique landscape. MACA lies within the Interior Low Plateaus physiographic province (Fenneman 1928) formed by gently dipping rocks of Paleozoic age. Landscapes depend on the varying resistance and solubility of different rock types with sandstone being the most resistant, shale the least and limestone being the most soluble. The park is developed within the dissected Mammoth Cave Plateau (Figures 4.22, 4.23, and 4.24). Just south of the park, the Dripping Springs Escarpment forms the southern edge of the Mammoth Cave Plateau. As is apparent along the southern part of Figure 4.24, the landscape drops off about 100 m at the edge of the plateau, forming the boundary with the Pennyroyal Plateau to the south. Although it is outside of the park, the Pennyroyal Plateau serves an important function for both the hydrology and geomorphology of the park, as this is the principal headwaters area that collects the rainfall that forms the cave systems beneath the Mammoth Cave Plateau.

The geological resources that are included in this analysis include:

- 4.3.1. Bedrock units
- 4.3.2. Alluvial sediments
- 4.3.3. Cave mineral features such as speleothems and other crystals
- 4.3.4. Cave sediments
- 4.3.5. Economic mineral resources
- 4.3.6. Soils

4.3.1. Bedrock Units

Bedrock in MACA is adequately protected by land management practices and there is no mining of bedrock in the park.

Description

There are excellent summaries of the geological conditions in and around MACA (e.g., e.g., Livesay and McGrain 1962, Palmer 1981, White 1988, Granger et al. 2001, Meiman 2006, Groves and Meiman 2005, Toomey and Olson 2008, Thornberry-Ehrlich 2011, Palmer 2017a, 2017b, White 2017). The three principal limestone layers in which Mammoth Cave and the other major caves have formed are, in ascending order from oldest to youngest, the St. Louis Limestone, the Ste. Genevieve Limestone, and the Girkin Limestone (Figures 4.22, 4.23 and 4.24). The upper two formations, along with the upper half of the St. Louis below, are largely made of very pure limestones which are excellent karst-forming rocks due to their high solubility and the relatively high rates at which they dissolve in the abundant rainfall of this humid subtropical climate (Köppen-Geiger Cfa) (Peel et al. 2007). MACA has a mean annual precipitation of 1,300 mm and temperature of 14.7ºC (Kentucky Climate Center 2018).

Although the geology shown in Figures 4.23 and 4.24 appears to be very complex, in fact it is relatively simple once the patterns become apparent. These are nearly horizontal layers of sedimentary rock, tilted very slightly to the north, analogous to layers of a layer cake. The layer that is exposed at a particular location, and the color shown on the map that represents that layer, is simply the highest one at that point that has not been removed by erosion. Deeper layers are exposed where the overlying layers have been removed. Above the principal karst-forming limestone units are a series of thinner, heterogeneous, upper Mississippian sedimentary rocks.

Capping the Girkin Formation, in ascending order, are the Big Clifty Sandstone, the Haney Limestone, the Hardinsburg Sandstone, the Glen Dean Limestone, the Lietchfield Formation (mixed clastic rocks).

In the north and northwestern areas of the park these beds are overlain by the cliff-forming sandstones and conglomerates of the Pennsylvanian-aged Caseyville Formation (Figures 4.23, 4.24, and section 5.6). The Caseyville thickens in the northwestern part of the park where an ancient river valley formed the Sharon-Brownsville Paleovalley System (Pryor and Potter 1979) early in the Pennsylvanian Period that was eventually filled in with thick clastic sediments, resulting in a major unconformity at the base. At places, as can be clearly seen at Dismal Rock on the eastern bank of the Nolin River just downstream from the Nolin dam a few kilometers north of the park boundary, the Caseyville rests directly on the Haney Limestone, with the intervening formations having been removed by erosion. Because these relative thick clastic rocks tend to form steep cliffs, this is the most rugged area of the park, particularly along the Nolin River just downstream from the Nolin River Dam and its eastern tributary Bylew Creek. The conglomerate beds, containing white quartz pebbles that are sometimes several cm in diameter, formed from the filling of localized stream channels, representing sources of clastic sediments from as far east as Pennsylvania and West Virginia (Johnson and Schwalb 2010). At least some of the quartz may have been derived from schists in the Piedmont of Virginia (Wanless 1975). The landscape characteristics of this area are very different from the rest of the park, to some degree reminiscent of natural areas along the Cumberland Plateau Escarpment to the east, albeit with about one-third of the local relief. Tucked up along the steep cliffs in the ends of the various tributary creeks along the eastern side of the Nolin in the park are numerous rock shelters (see section 5.6), waterfalls, and in places natural bridges. This area is in places very steep and lacks roads and trails, requiring good backcountry hiking skills to access.

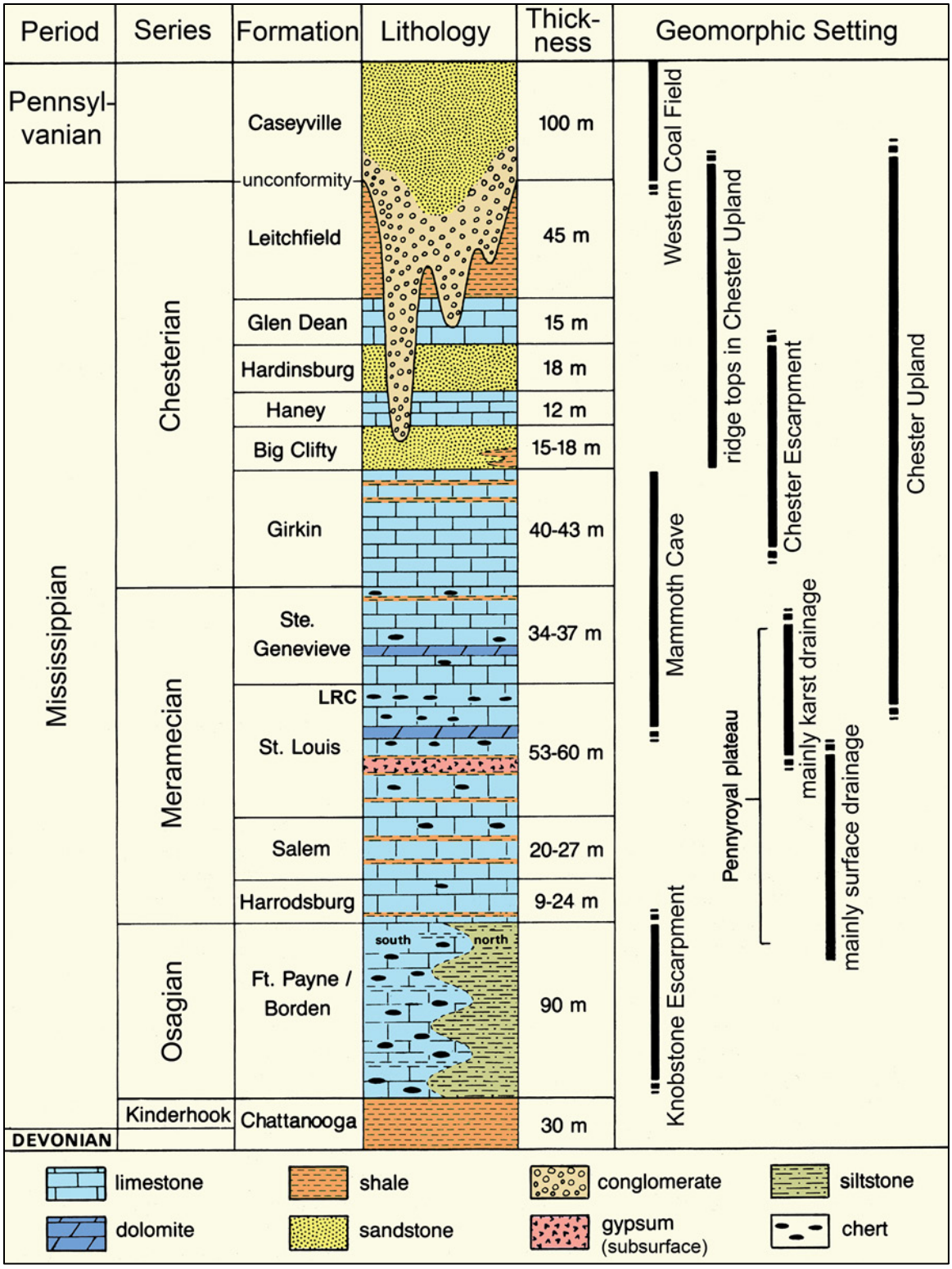


Figure 4.22. Geologic section in the vicinity of MACA (Palmer 2017a).

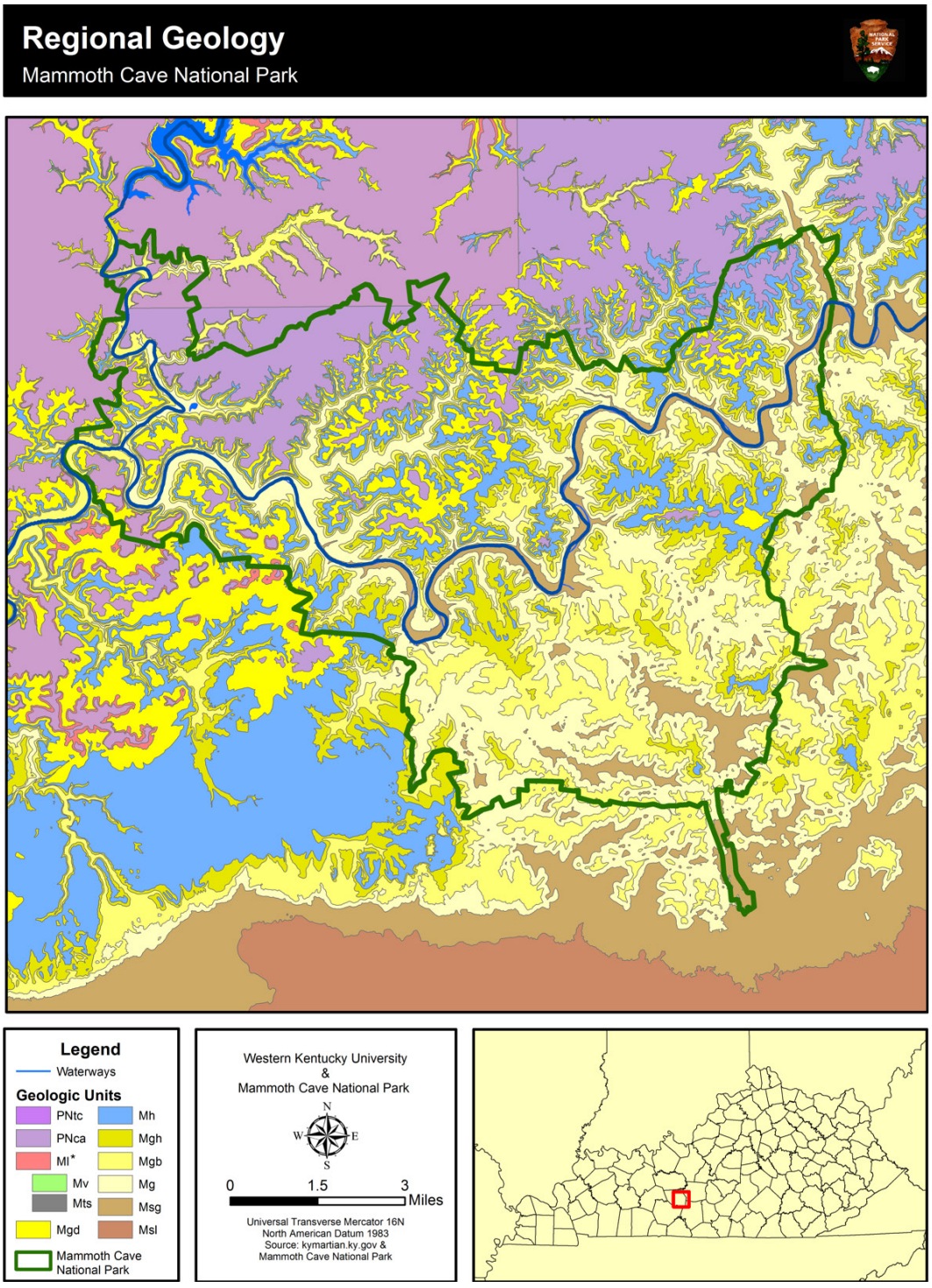


Figure 4.23. Geology of MACA and Vicinity. Map by Katie Algeo and Matthew Riggle using data from the Kentucky Geological Survey. From youngest (top) to oldest, the formations are PNtc (Tradewater/Caseyville), PNca (Caseyville), Mv (Vienna Limestone), Mts (Tradewater Sandstone), Ml (Lietchfield Formation), Mgd (Glen Dean Limestone), Mh (Hardensburg Sandstone), Mgh (Haney Limestone), Mgb (Big Clifty Sandstone), Mg (Girkin Limestone), Msg (Ste. Genevieve Limestone) MSl (St. Louis Limestone).

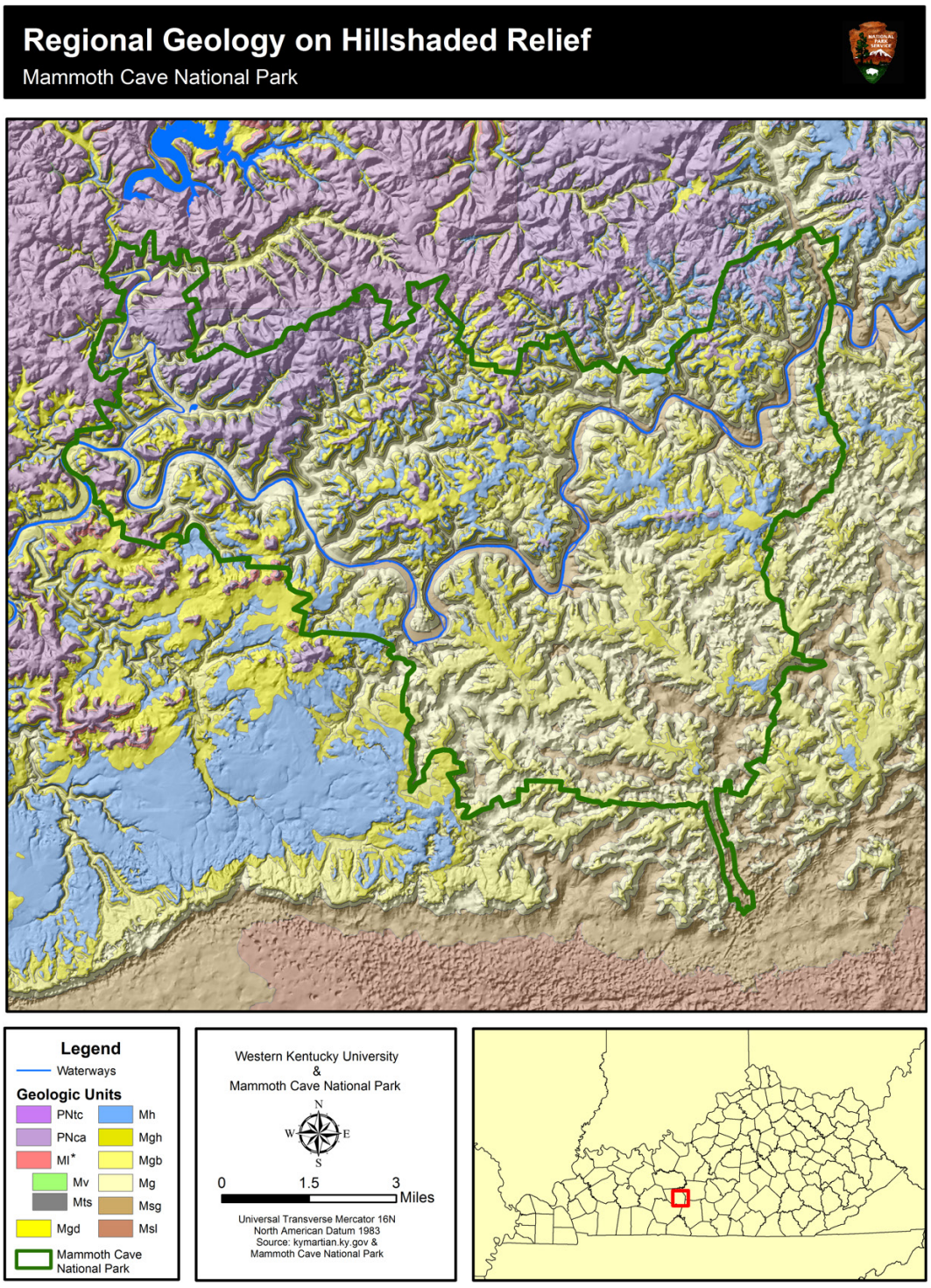


Figure 4.24. Geology draped on hillshade relief. The southern edge of the Mammoth Cave Plateau where the Dripping Springs Escarpment drops down to the Pennyroyal Plateau “sinkhole plain” is apparent. Map by Katie Algeo and Matthew Riggle with data from the Kentucky Geological Survey. See Figure 4.23 for formation legend.

Data and Methods (Covers all of Section 4.3)

The information collected in this section was based on a review of internal NPS reports and external literature from scientific papers, Kentucky Geological Survey reports and maps, Master's theses as cited above, as well as discussions with CUPN and MACA S&RM staff. Particularly useful have been the *Geologic Resource Evaluation Scoping Summary Mammoth Cave National Park* (NPS 2006b) and the resulting *Mammoth Cave National Park Geologic Resources Inventory Report* (Thornberry-Ehrlich 2011), as well as Meiman's (2006) *Mammoth Cave National Park Kentucky Water Resources Management Plan.*

In all cases the relevant available information on each resource was reviewed and the information synthesized to draw conclusions about the status and trends of the evaluated resources. As there is, with exceptions noted below, a paucity of quantifiable reference standards in this section, the evaluations in places relied on the experience and judgement of the authors in determining the nature of degradation that has occurred previously and whether there is a threat of new or continued degradation into the future.

Reference Conditions/Values

In general, there are not standard, quantifiable reference values for the bedrock resources considered in the section, but we can evaluate the conditions of these resources by considering their present status, whether some amount of degradation has occurred previously and whether there is a threat of new or continued degradation into the future.

Condition and Trend

These resources are in a good condition (Table 4.13). There is no identifiable potential for processes of resource degradation for MACA's bedrock.

Level of Confidence and Data Gaps

In general, although there is a lack of standard reference conditions, there is a high level of confidence for the evaluations in the bedrock geology section.

A collection of other recommended areas for additional research was identified in a June 15–16, 2006 scoping meeting held at MACA (NPS 2006b, Thornberry-Ehrlich 2011). Rather than parcel these out across the various indicators all that are relevant to the geology section of the report are listed here. Progress has been made in a number of these areas.

1. Identify long-term geologic information needs.
2. Perform comprehensive park-wide fault mapping on the land surface, within sinkholes, and in caves.
3. Inventory, map, and describe the more than 300 small caves within park boundaries. Obtain baseline biological, geological, hydrological, and hazard information for each in order to set up routine monitoring.
4. Perform mapping of Quaternary floodplain and river terrace deposits.
5. Research fluvial geomorphology in cave streams as well as the Green River.

6. Continue to inventory paleontological resources within the cave and extend inventory to the surface at the park. Excavations, if deemed appropriate by expert consultation, and inventories should include dating and identifying all fossil remains (distinguishing between extinct vs. extirpated species as well as the number of individuals for comparison with current population lists and ranges), collecting pollen and 14C samples from each natural level. Exercise care in collecting any charcoal deposits. Store and catalogue samples.
7. Identify correlations between biology and geology such as the presence of sandstone controlling the distribution of chestnuts, or the chinquapin oaks (Quercus muehlenbergii) preference for limestone soils.
8. Develop a karst sensitivity and vulnerability map.
9. Continue to research speleogenesis, paleoclimatology, and cave sediments for interpretation and management purposes.
10. Work to refine the speleogenesis model employed at the park.
11. Perform a mineralogical inventory of the caves, focusing on pre-cave mineralogy.
12. Map dust dispersion in the cave system and relate to trails and airflow.
13. Use cave spatial information and digital geologic map to predict locations of new caves based on known relationships (i.e., small caves along certain geologic contacts, etc.).
14. Continue cave mapping along survey lines for incorporation into a GIS environment.

Condition Summary

Table 4.13. Graphical summary of status and trends for bedrock units.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Bedrock units	Threats from mining or other source of deterioration		There is not a standard reference condition for the condition of bedrock units. Bedrock in MACA is adequately protected by land management practices and there is no mining in the park.

Sources of Expertise (Covers all of Section 4.1 Geology and Soils except where noted)
Bobby Carson (Chief of MACA Division of S&RM, retired), Rick Toomey (Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM), Rick Olson (Park Ecologist, MACA Division of S&RM), Brice Leech (Resource Management Specialist, MACA Division of S&RM), and Joe Meiman (Hydrologist, CUPN). The authors also have extensive experience in studying and interpreting geologic resources of the park.

4.3.2. Alluvial Sediments

Although Meiman (2006) concluded that in general MACA alluvial sediments were well protected compared to other regional karst drainage systems, there are sources of contaminated sediments upstream of MACA. There is uncertainty with regard to the potential threat posed by a known source of dioxin upstream from MACA on the Green River.

Description

Much of the drainage at MACA is underground, and so surface alluvial sediments are missing in large parts of the park compared to what would be found in a non-karst landscape. The two principal base level rivers, the Green River and its tributary the Nolin, store and transport alluvial sediments along their channels and flood plains. For the Green River, these have been derived primarily from Mississippian clastic rocks of the Pennyroyal Plateau to the east of the park as far as Casey County (see section 4.4.2 Surface Water). A twelve-year (1950–1963) study of sediment transport in the Green River at Munfordville (about 27 kilometers upstream from MACA but broadly representative of conditions at MACA, Cushman et al. 1965) found that sediment was generally fine, as there is relatively little bedload. Measured distributions of the sediments are shown in Table 4.14.

Table 4.14. Suspended sediment size distributions for the Green River, 1950–63 (Cushman et al. 1965).

Particle		Approximate % of total amount
Class	**Size (mm)**	
Clay	<0.0039	50–65
Very Fine Silt	0.0039–0.0078	15
Fine Silt	0.0078–0.0156	15
Medium Silt	0.0156–0.0313	9
Coarse Silt	0.0313–0.0625	2–6
Sand	>0.0625	<2

The Nolin River similarly transports significant amounts of clastic alluvial sediments though it might be expected that the sediments are on average coarser as the Nolin also drains areas of Pennsylvanian clastic rock in the Western Kentucky Coalfield to the north of MACA.

Herrera (2007) described the nature and distribution of alluvial deposits of the Upper Green River between the Green River Dam and MACA by analysis of flood plain and bank sediments at two representative field sites, at the confluence of the Green with Pitman Creek and at WKU's Upper Green River Biological Preserve. Methods included stratigraphic description of bank exposures, as well as radiocarbon and textural (sediment size distribution) analysis. He found that sediments were dominated by medium to coarse silt having been deposited by vertical aggradation, and are underlain in places by sands and gravels that resulted from lateral migration of channel deposits. Radiocarbon dating of organic carbon incorporated with sediments identified an increase in sediment deposition rates since European settlement, consistent with an increase sediment supply associated with land clearing activities. Overbank deposition rates of about 0.67 to 0.87 in/year from the most recent deposits are associated with modern agriculture since about 1770–1810. This is consistent with other observations in the Ohio and Mississippi River Basins (Alexander and Prior 1971, Knox 1987).

At the time of this writing there is a major, if temporary, rearrangement of sediment transport processes in the Green River in MACA downstream from the Mammoth Cave Ferry and in the lower several kilometers of the Nolin River following the 2016 breaching and subsequent removal of Green

River Lock and Dam #6 near Brownsville downstream from the park (see discussion in section 4.4.2. The river level dropped in the western end of the park by as much as three meters and so there is significant entrainment and transport of the sediment deposited during more than the 100 years of impoundment. As the water table has similarly dropped, this sediment scouring event is propagating through the cave system in the western part of the park. This can be seen, for example, at the karst window at Cedar Sink, where nearly a meter of alluvial sediment has been scoured out and the stream channel has been deepened considerably within the first year following the breach.

Reference Conditions/Values

Although there are no federal or state standards for sediment quality, Meiman (2006) conducted sediment analysis at various sites in MACA as well as adjacent karst drainage systems that flow to the Green River and the heavily impacted Lost River Basin near Bowling Green as points of reference.

Condition and Trend

Meiman (2006) concluded that overall, compared to other local karst drainage systems, similar in hydrogeology but largely unprotected, sediment quality in the park is good (Table 4.15) with a minor exception based on sampling in two of the park's major underground rivers, which are discussed in the section on cave sediments.

There is no evidence to suggest that either an upward or downward trend in sediment quality is underway. There are chronic sources of contamination upstream from MACA on the Green River, and to a lesser degree on the Nolin River, however in the absence either of significant land use change or a serious transportation accident, conditions should remain relatively static.

Level of Confidence and Data Gaps

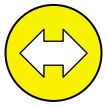
In general, although there is a lack of standard reference conditions, there is a medium level of confidence for the evaluations in the alluvial sediment section.

A particularly significant data gap was identified by Meiman (2006) who conducted the project "Chemical Analysis of Toxins in Stream Sediments" during FY01–02 during which he found four (of four) sediment samples upstream from MACA that were positive for congeners (different forms) of the highly toxic chemical dioxin. This has resulted from a train wreck in 1967 carrying barrels of concentrated Agent Orange (ELPO law 2017), a defoliant containing dioxin that was used extensively in the Vietnam War. Barrels of the chemical were dumped into a sinkhole near the town of Horse Cave which connects through the karst drainage system of the Gorin Mill Drainage Basin to Gorin Mill and Hicks Springs (Ray et al. 1998a, 1998b) on the Green River. Meiman found four positive detections of octachlorodibenzo-p-dioxin (OCDD) and one for 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin (HpCDD). These concentrations, all listed in parts per trillion (ppt) dry weight were 233 for Hidden River Cave, 470 at Gorin Mill Spring, 170 in the Green River below Gorin Mill Spring, and 700 at Hick's Spring. Although these springs are immediately upstream from park on the Green River and there is potential for bioaccumulation in fish and invertebrates, the potential risk to the park from the identified concentrations is uncertain, and these may be at typical background levels. A two-year follow up study was planned for more detailed sediment analysis as

well as analysis of mussel tissue in FY06–FY07 but was never carried out. We recommend this this analysis be completed.

Condition Summary

Table 4.15. Graphical summary of status and trends for alluvial sediment.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Alluvial sediments	Contamination by metals, organochlorines and organophosphates		There are no state or federal standards for sediment quality. Although Meiman (2006) concluded that in general MACA sediments were good compared to other regional drainage systems, there are sources of contaminated sediments upstream of MACA. There is uncertainty with regard to the potential threat posed by a known source of dioxin upstream from MACA on the Green River.

4.3.3. Cave Minerals

Although there is not a standard reference condition used to evaluate the condition of cave minerals, speleothems and other cave minerals are adequately protected at MACA. This indicator is judged as improving. Although in the past cave formations have been threatened both by commercial harvesting and vandalism, a multi-decade volunteer mineral restoration effort is underway in Floyd Collins Crystal Cave to repair severe vandalism that took place there in 1995–96.

Description

With the extensive nature and the range of the detailed geological conditions of the passages in Mammoth Cave and other caves at MACA, it is not surprising that a variety of cave minerals are present in the caves and these have been studied in some detail. Although in general the cave is in many places lacking in the traditional travertine speleothems that characterize many caves, minerals present can be listed in three different, though overlapping types: travertine speleothems, evaporate minerals that have grown as coatings of crystal clusters on cave walls, and minerals that have grown within the interstitial spaces of cave sediments.

The particular minerals present at any point in a cave depend on several factors that include presence of the source elements that make up the mineral's structure, the localized movement of water in the rock mass that deliver those elements to the location of deposition, and the detailed geochemistry of the fluid that results in conditions favorable to mineral formation (Hill et al. 1997; White 1988, 2017). In sedimentary rock settings, such as those found at MACA, precipitation of solid mineral phases from thermodynamically oversaturated solutions is the principal process by which this occurs.

The presence and movement of water that can potentially deposit minerals or dissolve the cave wall under chemically different conditions, is strongly influenced by the presence or absence of an overlying clastic "caprock" of the Big Clifty Sandstone (Figures 4.22, 4.23, and 4.24) The caprock

determines whether a waterproof cover above the cave can prevent the downward migration of mineral bearing waters (Figure 4.25).

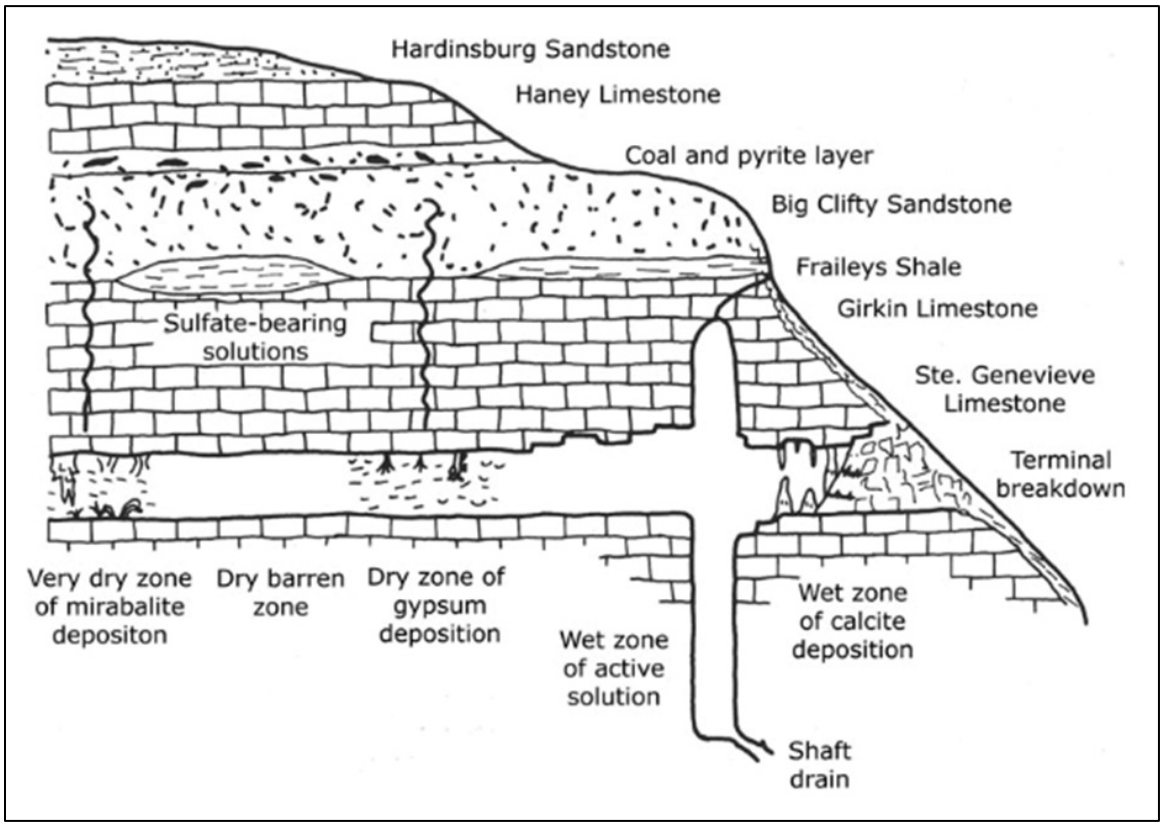


Figure 4.25. Diagrammatic representation of mineral deposition environments in the caves of MACA (White 2017). Much gypsum deposition is actually related to the immediate bedrock. Dolomite bedrock contains pyrite that weathers to gypsum (Metzger et al. 2015).

Speleothems (Moore 1952) are secondary mineral deposits, most commonly from a form of calcium carbonate—calcite—that can occur on cave ceilings, walls or floors as classic features such as stalactites, stalagmites, curtains are draperies (Figure 4.26). Although these are not present in many parts of Mammoth Cave because the impermeable, overlying rocks prevent the downward movement of mineral bearing waters, they are profuse in some areas where the caprock has been removed by erosion along the sides of ridges, such as the Frozen Niagara area, location of a popular tour at MACA (Figure 4.26).

In addition to calcite speleothems, there is a range of evaporate minerals, including very rare ones, that grow the cave walls from precipitation of oversaturated capillary fluids moving through the interstitial spaces that make up the primary porosity of the limestone cave walls (Table 4.16). Some minerals also grow within the sediments of Mammoth Cave, including gypsum and nitrocalcium, a mineral that was mined extensively during the late 18th and early 19th centuries and processed into saltpeter for gunpowder (Faust 1949, Olson and Krapak 1995) (See Appendix C).

Palmer and Palmer (1995) gave a very detailed description of five different zones in Mammoth Cave with regard to proximity to the edge of the sandstone cap rock and how the various hydrologic, chemical, and mineralogical conditions result in deposition of calcite or evaporate minerals, or the lack thereof (Figure 4.27).

Condition and Trend

In the past, some individuals have collected and sold cave formations such as speleothems and gypsum crystals as souvenirs although this is now illegal, with high penalties for doing so from a national park. Indeed, in a terrible incident in 1996 three men were arrested for breaking into Crystal Cave, an entrance to the Mammoth Cave System within the park, and removing hundreds of pounds of minerals to sell at local souvenir shops as are common around the periphery of national parks (Lexington Herald Leader 1996). The three were caught, found guilty and sentenced to prison sentences in federal court. Not long after, eight local souvenir shops were cited for selling speleothems after a raid by the Kentucky State Police. Many of the broken specimens were returned to the cave, and a painstaking process of restoration continues now 20 years later by volunteers who occasionally visit the park to continue the work (NPS 2010b; Figure 4.28). Many of the mineral pieces back in the cave are still marked with prices from the rock shops (Figure 4.29).

There are places where fragile minerals, particularly gypsum, occur along the accessible tour paths in the Mammoth Cave System and Great Onyx Cave. Although there is fencing in certain places, continued diligence is important to monitor cave visitors moving through these areas.

Although there is not a standard reference condition to evaluate the condition of cave minerals, speleothems and other cave minerals are adequately protected from vandalism at MACA (Table 4.17). All caves are closed to entry unless with a guide or by permit, and physical barriers exist at many caves. There is also a prohibition against selling cave formations through the Kentucky Cave Protection Act (KRS 433.871–431.885) (Kentucky Legislature 1988), which says, in part, that “It shall be unlawful for any person to sell or offer for sale any speleothems in this Commonwealth, export them for sale outside the Commonwealth, or import speleothems into the Commonwealth for sale.”

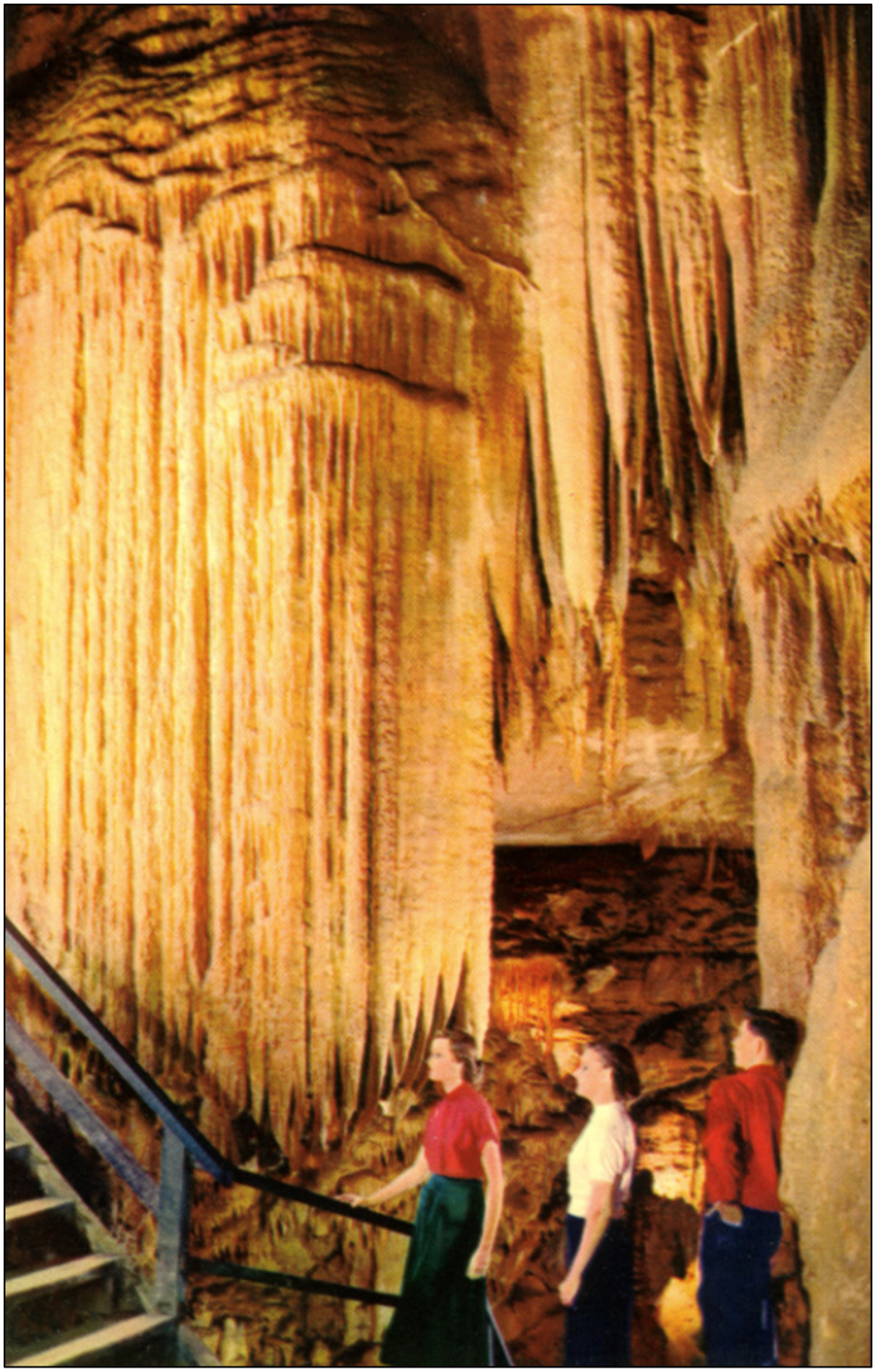


Figure 4.26. This old postcard shows draperies in the Frozen Niagara section of the Mammoth Cave System (used with permission of the Kentucky Digital Library at the University of Kentucky).

Table 4.16. Minerals of the Mammoth Cave System (White 2017).

Mineral name	Chemical Formula	Crystal symmetry
Aragonite	$CaCO_3$	Orthorhombic
Barite	$BaSO_4$	Orthorhombic
Birnessite	$Na0.3Ca0.1K0.1Mn^{4+}Mn^{3+}O_4 \cdot 1.5H2O$	Monoclinic
Blödite	$Na_2Mg(SO_4)_2 \cdot 4H_2O$	Monoclinic
Calcite	$CaCO_3$	Rhombohedral
Celestite	$SrSO_4$	Orthorhombic
Epsomite	$MgSO_4 \cdot 7H_2O$	Orthorhombic
Eugsterite	$2Na_2SO_4 \cdot CaSO_4 \cdot 2H_2O$	Monoclinic
Hexahydrite	$MgSO_4 \cdot 6H_2O$	Monoclinic
Hydromagnesite	$4Mg(CO_3) \cdot Mg(OH)_2 \cdot 4(H_2O)$	Monoclinic
Mirabolite	$Na_2SO_4 \cdot 10H_2O$	Monoclinic
Nitrocalcite	$Ca(NO_3)_2 \cdot 4H_2O$	Monoclinic
Todorokite	$(Na, Ca, K)_2(Mn^{4+}, Mn^{2+}, Mg^{3+})6\ O_{12} \cdot 3–4.5H_2O$	Monoclinic
Wattevilleite	$NaSO_4 \cdot CaSO_4 \cdot 4H_2O$	Orthorhombic

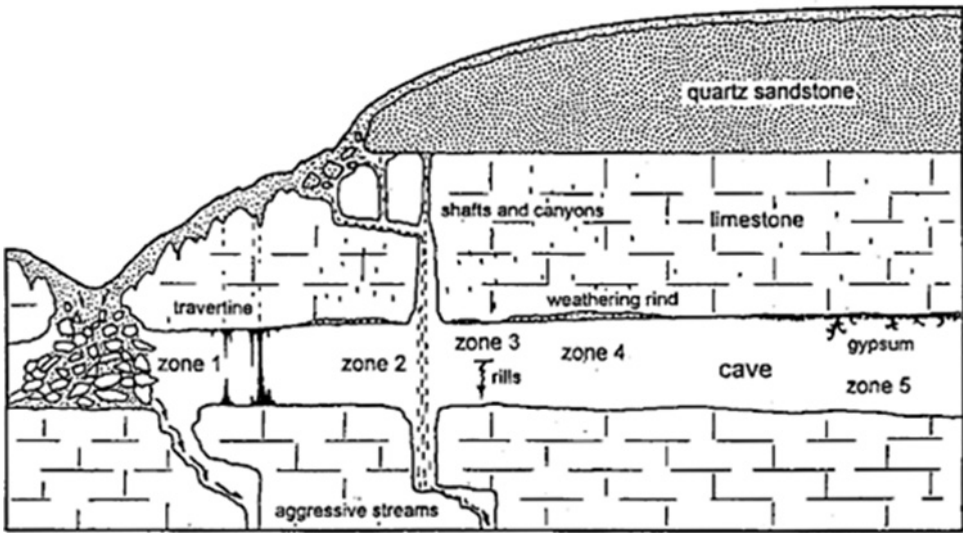


Figure 4.27. Generalized cave passage profile showing five zones with respect to geochemical interactions (Palmer and Palmer 1995).



Figure 4.28. Volunteer cave restoration expert Jim Werker has been working with his partner Val Hildreth-Werker for more than 20 years to return the stolen gypsum samples to their correct places within Floyd Collins Crystal Cave (NPS photo by Val Hildreth-Werker).



Figure 4.29. Broken stalactite that had been removed by vandals from Floyd Collins Crystal Cave in 1996 and was later returned. The number is the price tag from its time on sale at a local souvenir shop (photo by Chris Groves).

Level of Confidence and Data Gaps

There is a high level of confidence for the evaluations in the cave minerals section.

Condition Summary

Table 4.17. Graphical summary of status and trends for cave minerals.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Cave minerals	Threats from vandalism		Although there is not a standard reference condition to evaluate the condition of cave minerals, speleothems and other cave minerals are adequately protected from vandalism at MACA. A multi-decade volunteer mineral restoration effort is underway in Floyd Collins Crystal Cave to repair vandalism that took place in 1995–96.

4.3.4. Cave Sediments

Although Meiman (2006) concluded that in general MACA sediments were well protected compared to other regional drainage systems, low levels of metals likely from I65 and agricultural chemicals, in particular the herbicide atrazine, are accumulating in cave sediments within the active underground rivers of the Turnhole Basin.

Description

Although there have been several similar classifications of cave sediments (Bögli 1980, White 1988, Gillieson 1996, Ford and Williams 2007) there has been no standardized system. A classification system suggested by White (2007) attempted to compromise between these, and is shown in Table 4.18a and 4.18b, modified slightly to be appropriate to the conditions at MACA.

Sediments in the park caves can be divided between those that are part of the contemporary drainage system, either perennially or during flood conditions, and sediment that is currently abandoned above the level of even the highest floods. These abandoned sediments are important because they contain important minerals such as nitrocalcium historically used in saltpeter production, and species of fossil species such as bats. The sediments can be dated by several methods including paleomagnetism (Schmidt 1982) and by cosmogenic isotopes (Granger at al. 2001) to provide information on speleogenesis. Analysis of sediment characteristics has been widely utilized to provide information on paleoclimates (e.g., Harmon et al. 1975, White 2007).

Table 4.18a. Cave sediment classification modified from that of White (2007) for conditions at MACA: I. Clastic sediments. Several potential sources of sediment that he considered, such as phosphates, are not present in MACA caves in significant quantities.

Sediment Classification	Subclass	Type
A. Autochthonous sediments	1. Weathering detritus	–
	2. Breakdown	–
	3. Guano	–
B. Allochthonous sediments	1. Entrance talus	–
	2. Infiltrates	a. Soil washdown
	2. Infiltrates	b. Gravitational debris
	3. Stream transported sediments	a. Organic in-wash
	3. Stream transported sediments	b. Alluvial sediments
	4. Debris flows	–
	5. Aeolian deposits	–
A. Travertine	1. Flowstone	–
	2. Dripstone	–
B. Evaporites	1. Crusts	–
	2. Bulk deposits	–
C. Resistates	–	–
D. Ice	–	–

Table 4.18b. Cave sediment classification modified from that of White (2007) for conditions at MACA: II. Chemical Sediments. Several potential sources of sediment that he considered, such as phosphates, are not present in MACA caves in significant quantities.

Sediment Classification	Subclass	Type
A. Autochthonous sediments	1. Weathering detritus	–
	2. Breakdown	–
	3. Guano	–
B. Allocthonous sediments	1. Entrance talus	–
	2. Infiltrates	a. Soil washdown b. Gravitational debris
	3. Stream transported sediments	a. Organic in-wash b. Alluvial sediments
	4. Debris flows	–
	5. Aeolian deposits	–
A. Travertine	1. Flowstone	–
	2. Dripstone	–
B. Evaporites	1. Crusts	–
	2. Bulk deposits	–
C. Resistates	–	–
D. Ice	–	–

Reference Conditions

Although there are no federal or state standards for sediment quality, Meiman (2006) conducted sediment analysis at various sites in MACA as well as adjacent karst drainage systems that flow to the Green River and the heavily impacted Lost River Basin near Bowling Green as points of reference.

Condition and Trends

Based on an extensive sediment sampling and analysis program in the park and in other more heavily impacted karst drainage systems in the area, including the urban Lost River Basin in Bowling Green, Meiman (2006) concluded that overall, compared to the other drainage systems, sediment quality in the park, including cave sediment based on sampling locations (Owl Cave, River Styx, Logsdon River, Hawkins River and Golden Triangle within MACA), is good (Table 4.19). There is a minor exception of concern for low levels of lead and chromium in two of the park's major underground rivers, Hawkins River in Mammoth and Owl Caves and the Mill Hole River at Mill Hole. Mill Hole had about 45 mg/kg and Owl Cave about 10 mg/kg. Petroleum hydrocarbons were also found in MACA sediments, with about 10 mg/kg at Owl Cave, about 4 mg/kg in Hawkins River in Mammoth Cave, and about 2 mg/kg at Mill Hole. The Mill Hole River was sampled outside of the park, but from dye tracing (Ray et al. 1998a, 1998b) we know that this underground river flows into the park and discharges at Turnhole Spring on the Green River. The largest threat to cave sediment quality

comes from the possibility of accidental spills along I65 and the CSX railroad which could contaminate underground rivers within the Turnhole Groundwater Basin. There are also impacts to sediment quality from agriculture. Anderson (2002), for example, found atrazine moving through Hawins River in the park adsorbed onto fine sediments, that when desorbed had a concentration of 9 parts per billion, three time the legal drinking water standard. There is no evidence of a chronic trend indicating that cave sediment quality should get significantly better or worse.

Level of Confidence and Data Gaps

There is a high level of confidence for the evaluations in the cave sediments section, although additional sediment quality sampling within major underground rivers in the Turnhole Basin that drain areas outside of the MACA with agricultural and transportation land use would be beneficial.

Condition Summary

Table 4.19. Graphical summary of status and trends for cave sediments.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Cave sediments	Contamination by metals, organochlorines, and organophosphates		There are no state or federal standards for sediment quality. Although Meiman (2006) concluded that in general MACA sediments were good compared to other regional drainage systems, metals likely from I65 and agricultural chemicals, in particular the herbicide atrazine, are being transported by cave sediments.

4.3.5. Economic Mineral Resources

Although there is no threat *to* economic mineral resources in MACA, there is a potential for threats to park resources from exploitation of these resources near the park, especially the Arthur oil field just east of Brownsville.

Description

Several forms of economically important economic mineral resources are common in the Mississippian rocks in the vicinity of MACA including oil and gas as well as asphalt-impregnated "tar sands" (May 2013; Figure 4.30). Nearby Pennsylvanian rocks of the Western Kentucky Coal Field physiographic region, which covers the northern parts of MACA, contain important coal deposits.

Oil and gas production in southcentral Kentucky occur in relatively shallow, small volume wells that have been drilled in small waves of oil "booms" that have taken place since oil was accidentally discovered near Monticello in 1815 during drilling for salt brine (Jillson 1952). In the vicinity of MACA the most relevant production has been from the Arthur Oil Field where production of oil from Devonian dolomite near the base of Clear Creek Formation resulted in drilling of numerous wells just south of the park boundary just east of Brownsville (Figures 4.30 and 4.31). These wells are typically about 425 m deep, and while some wells have had initial production of over 1,000

barrels (a barrel being 160 liters) per day, it has been much more common for wells to produce less than five barrels per day (KGS 1998).

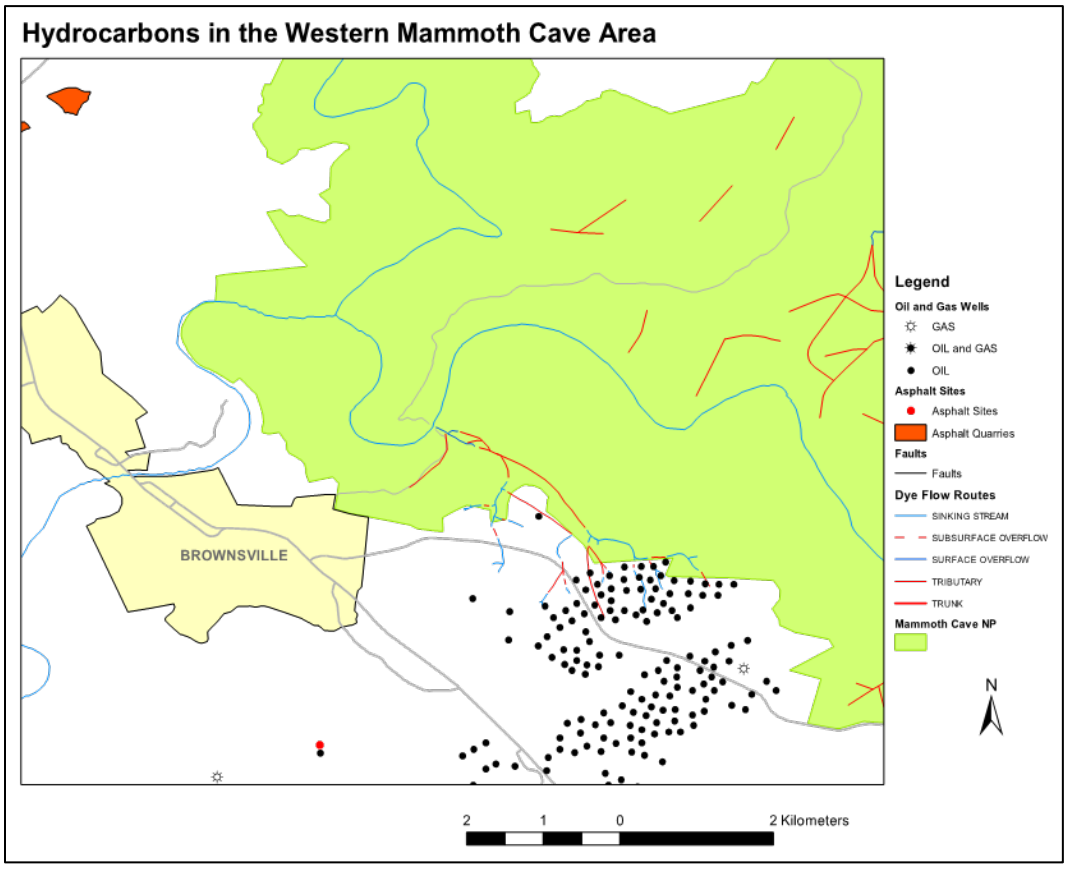


Figure 4.30. The southwestern part of MACA and the Arthur Oil Field. A 1997 spill flowed into the park (Ek et al. 2000). A series of dye traces delineated the relevant surface and underground pathways. Map by Rick Toomey.

In January 1997 a fitting on well adjacent to the park ruptured and about 2,000 liters of crude oil flowed across the surface into park (Ek et al. 2000). Only a quick effort prevented the oil from contaminating the primary karst aquifer. This spill highlighted the potential threat posed by these wells, and demonstrated the need for a better understanding of the karst hydrogeology of this region of the park. A series of dye traces were undertaken by scientists and students at Western Kentucky University along with S&RM scientists (Figure 4.31).

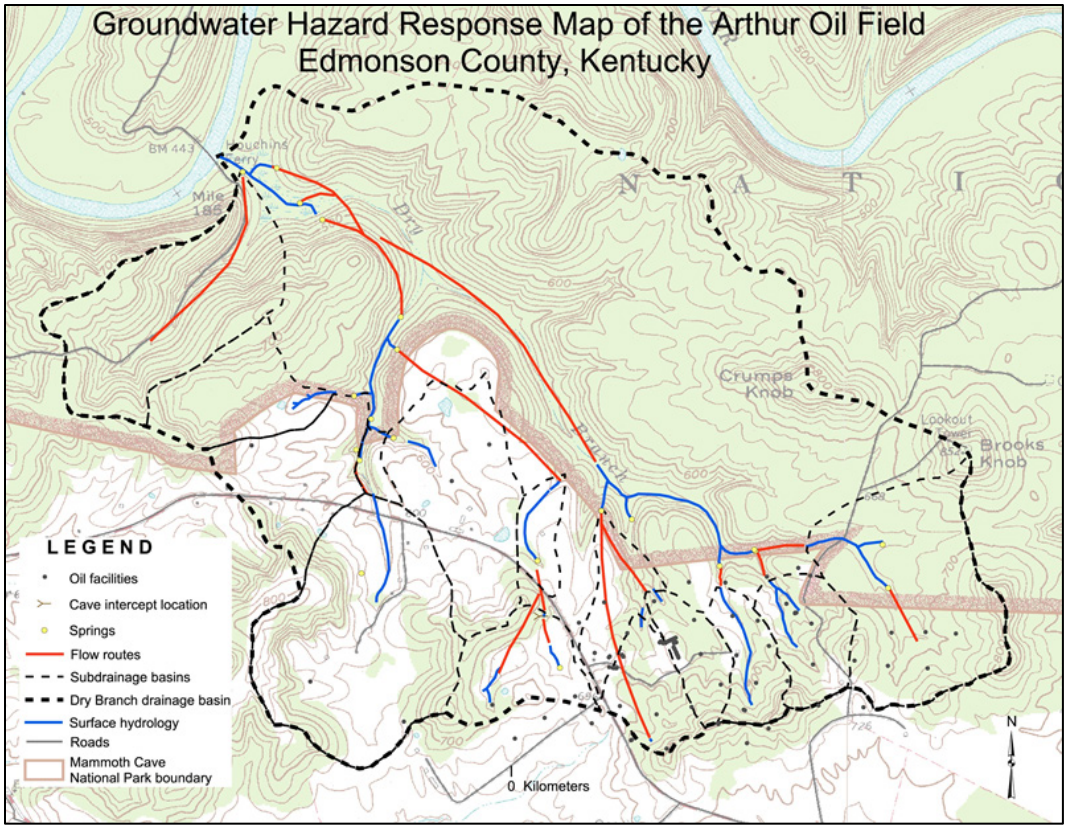


Figure 4.31. Hydrologic evaluation of surface and subsurface flow paths in the area of the Arthur Oilfield along the boundary of MACA just east of Brownsville Kentucky (Ek et al. 2000).

Asphalt ("unconventional high viscosity oil") deposits to the northwest of MACA occur within the upper Mississippian (Big Clifty) and lower Pennsylvanian sandstones (May 2013). These are chemically similar to petroleum resources found in other areas of North America, but cannot be recovered using conventional extraction methods because of their high viscosity. First discovered in 1856 near the Nolin River just upstream from MACA, there have been a variety of extraction efforts. Major production took place from 1917 through the 1950s by the Kentucky Rock Asphalt Company ("Kyrock") which sold the sands as paving materials to a far-reaching global market (May 2013). There is a potential for increased interest in future expanded exploitation of the asphalt sands, considering potential increases in product price as well as technological advances in proposed recovery methods.

An Abandoned Mineral Lands (AML) Inventory and Assessment project was conducted in December of 2011 (Burghardt et al. 2014). Nine abandoned oil/gas wells were evaluated within MACA (Figure 4.32), and of the nine locations evaluated, seven were located and two were not either because the casings had been removed or the locations were not correct. All that were located appear to be adequately plugged and currently present no hazards. No additional mitigation is planned for these features.

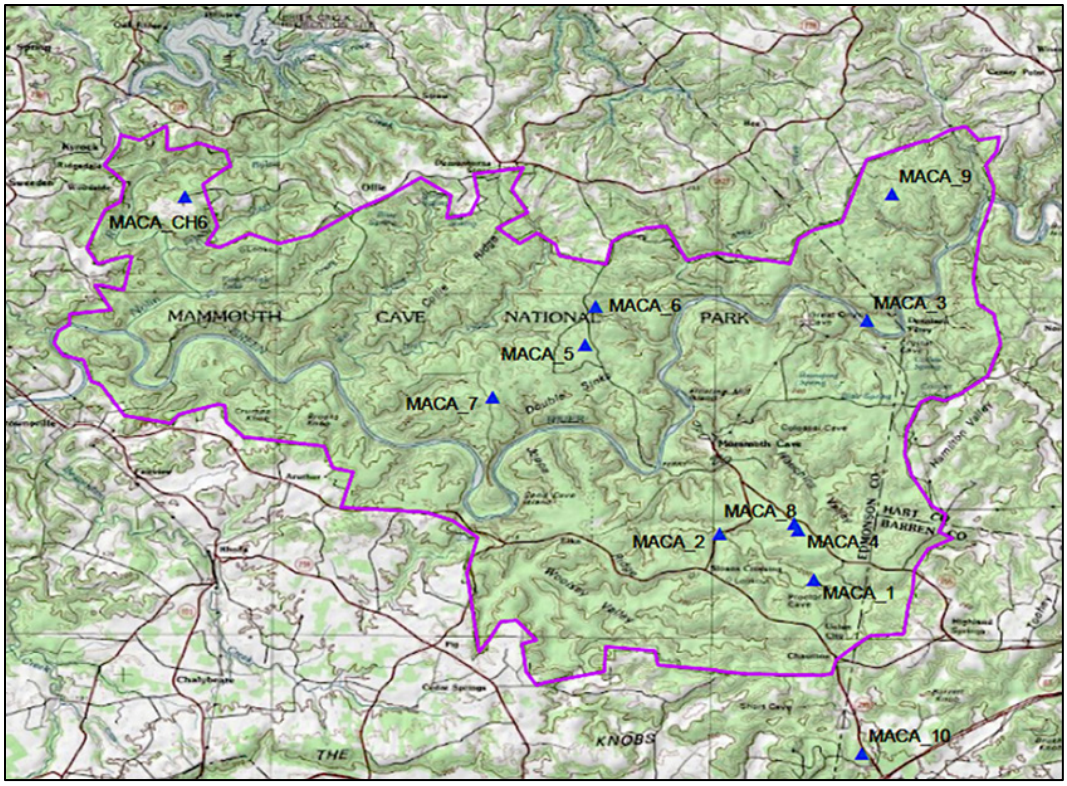


Figure 4.32. Abandoned oil and gas wells at MACA, shown in blue. These have been evaluated and pose no current threat. (CALIBRE Systems 2012).

Condition and Trends

The economic mineral resources of oil, gas, coal (one very small seam that may extend into the northwest corner of the park), and asphalt sands that may extend into the park are not threatened as land use management prohibits exploitation (Table 4.20). However, we note that there is a potential threat to water and ecological quality from accidents associated with exploitation near the park boundary. There may be continued mineral exploitation in the future in the vicinity of MACA and so this should be monitored carefully.

Level of Confidence and Data Gaps

There is a high level of confidence for the evaluations in the economic minerals section, although additional mineral exploitation near the park should be continually tracked and evaluated for new threats.

Condition Summary

Table 4.20. Graphical summary of status and trends for economic mineral resources.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Economic mineral resources	Impact to park resources from resource exploitation outside of MACA		There is no relevant standard reference condition. Although there is no threat *to* economic mineral resources in MACA, there is a potential for threats to park resources *from* exploitation of these resources near the park, especially the Arthur oil field just east of Brownsville.

4.3.6. Soils

Description

Fieldwork for a survey of soils in MACA was completed in 2009 as a joint effort of the US Department of Agriculture, the National Park Service, and state and local agencies (USDA NRCS 2010). Although the soil survey process involves a large number of direct observations of soil profiles, or the sequence of natural layers (horizons) of a soil, relationships among the characteristics of the profiles are organized through the development of models that relate these characteristics to landscape conditions that include the steepness, length and shapes of slopes, natural drainage patterns, native pants, and bedrock (USDA NRCS 2010). In this way, the resulting models can be used to make predictions about what soil types could be expected in a given setting.

Soils in the park have been subdivided into six General Soil Map Units that define broad areas with unique patterns of soil, relief, and drainage. For example, these relationships are diagrammatically shown in Figure 4.33 for the Wellston-Clarkrange general soil map units.

These units are further subdivided into Detailed Soils Map Units determine the suitability of the soil in a particular area for given uses. This detail is based on application of Soil Taxonomy, the systematic soil classification systems used in the United States (USDA NRCS 1999), which is based principally on the soil properties and arrangement of horizons within a given soil profile. However, the purpose of this survey is not as much to delineate pure taxonomic classes as it is to “separate the landscape into landforms or landform segments that have similar use and management requirements” (USDA NRCS 2010). Detailed descriptions and maps of these units are provided in the survey.

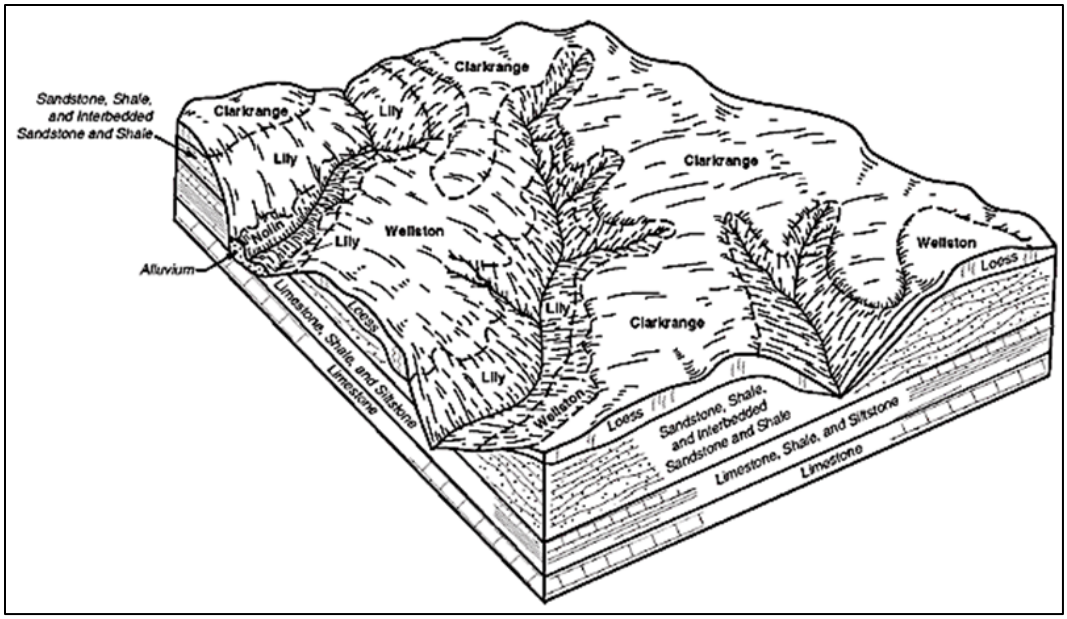


Figure 4.33. Block diagram representing a typical pattern of soils along with the underlying slopes and geologic materials for the Wellston-Clarkrange general soil map units (USDA NRCS 2010), shown as an example of such relations for soil mapping at this scale. There are six such units in MACA.

Data and Methods

Data used for this section came from the Soil Survey of Mammoth Cave National Park, Kentucky (USDA NRCS 2010). The Survey describes various "interpretive ratings" for soils to describe suitability for various types of land use, such as "capability classification" with respect to row crops. Land use at Mammoth Cave National Park is dominated by forest cover (Figure 4.34), so it seems the most relevant, quantitative soil indicator is the *potential productivity* of *common trees* on a soil, expressed as an average *site index* and as a *volume number* and these are tabulated for the soils of the park. The *site index* is the average height in feet that dominant and codominant trees of a given species attain in a specified number of years. The site index applies to fully stocked, even-aged, unmanaged stands. Site index was determined at age 50 years for most species (Schnur 1937, Coile and Schumacher 1953, Broadfoot and Krinard 1959, Broadfoot 1960, Nelson et al. 1961, Beck 1962 Broadfoot 1963, Broadfoot 1964). While the site index values for MACA range from 44 to 110 feet, and the volumes from 43 to 186 ft^3/acre (USDA NRCS 2010) there are no reference conditions identified, and through the literature and conferring with locally knowledgeable horticulture and soil scientists, we have been unable to identify such reference conditions otherwise. No concerns about threats to soil quality or suitability for the intended land use purposes was expressed in the survey, and considering the carefully protected land management within MACA, we judge that soil conditions are good and are not subject to any negative trends.

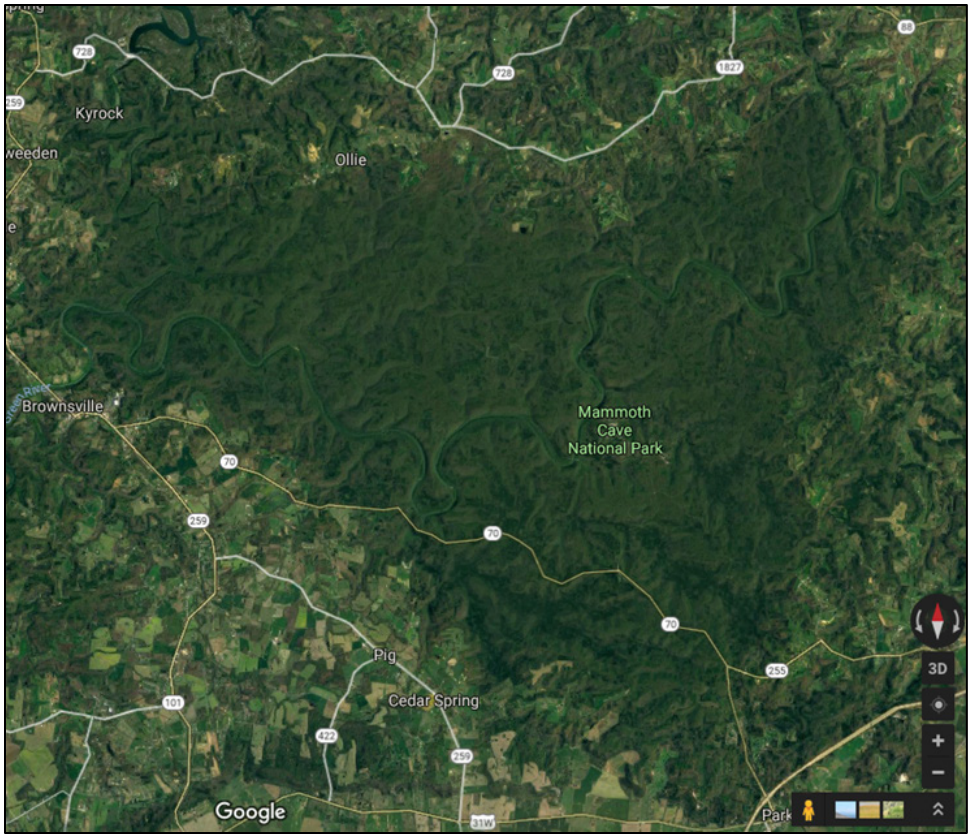


Figure 4.34. Aerial view of MACA illustrating dominance of forest cover (Google Earth photo).

Reference Conditions/Values

While there are quantitative indicators of soil conditions that determine suitability for different land use, including forest cover, there are not reference conditions with which these can be compared.

Condition and Trends

Although there is a lack of quantitative reference conditions for soils at MACA, we conclude that they are adequately protected by land management practices and there are no indications of negative trends that may impact their condition in the future.

Level of Confidence and Data Gaps

There is a high level of confidence that soils are adequately protected by land management in the park (Table 4.21), and these soils have been studied and analyzed in very good detail and so we have not identified any significant data gaps.

Condition Summary

Table 4.21. Graphical summary of status and trends for soils.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Soil	Threats from erosion or other conditions that would threaten soil quality		There is not a standard reference condition for the condition of soil. Soil is adequately protected by land management practices in the park.

4.4. Hydrology and Water Resources

Surely as much as in any U.S. national park, water is the thread that binds the physical and biological systems that make up the ecological framework of MACA. The globally significant cave systems and karst landforms that have been shaped by water in a complex interaction of geology, climate and biology, and the landscape here hosts a remarkable set of aquatic ecosystems.

The park is fortunate to have had a comprehensive evaluation of its water resources in 2005 (Meiman 2006) and this section draws significantly from that work. Additional water quality data have been also collected since that publication. The two considerations that one can make to evaluate water resources in any area, including MACA, include water quantity and water quality and there are sufficient data to draw conclusions about the current health of water resources of the park.

The discussion below is segregated into sections on surface water and groundwater, but it is important to understand that at MACA, as is many well-developed karst areas, the distinction between surface and groundwater can be blurred. Surface streams can flow along the surface for some distance and then sink underground into the cave system below, flowing as underground rivers until it reaches a spring and then reemerges as a surface stream again. This idea, critical to understand the nature of the park's landscapes, is illustrated by following the path of water flowing down valley wall slopes towards the Green River in the "Hilly Country" of the northern part of the park (Meiman and Ryan 1992, 1993; Meiman 2006; Figure 4.35). This flow starts off on the Mammoth Cave Plateau as "normal" surface streams flowing across the Caseyville Sandstone, and then sinks underground upon reaching the Glen Dean Limestone below. The water emerges at perched springs on top of the Hardinsburg Sandstone then after flowing on the surface for some distance sinks underground again, this time into the Haney Limestone where it eventually emerges perched atop the next layer below, the Big Clifty Sandstone. After some distance flowing on the surface again, the water sinks into the Girkin Limestone at the top of the principal karst aquifer. The water eventually emerges at one of the major regional springs at the level of the Green River, where it ultimately leaves the park. So, the distinction of what constitutes surface or groundwater in karst regions, and certainly within MACA, becomes blurred. With a well-developed karst landscape underlying a significant part of MACA and the surrounding area, underground rivers provide much of the flow to the park's main waterway, the Green River. Therefore, groundwater within the boundaries of MACA has outsized importance compared to most national parks. At the same time,

quantitatively, surface water resources of the park are dominated by drainage coming into the park within the Green and Nolin Rivers from an area of the landscape totaling 7,374 square kilometers—an area some 35 times larger than the park itself.

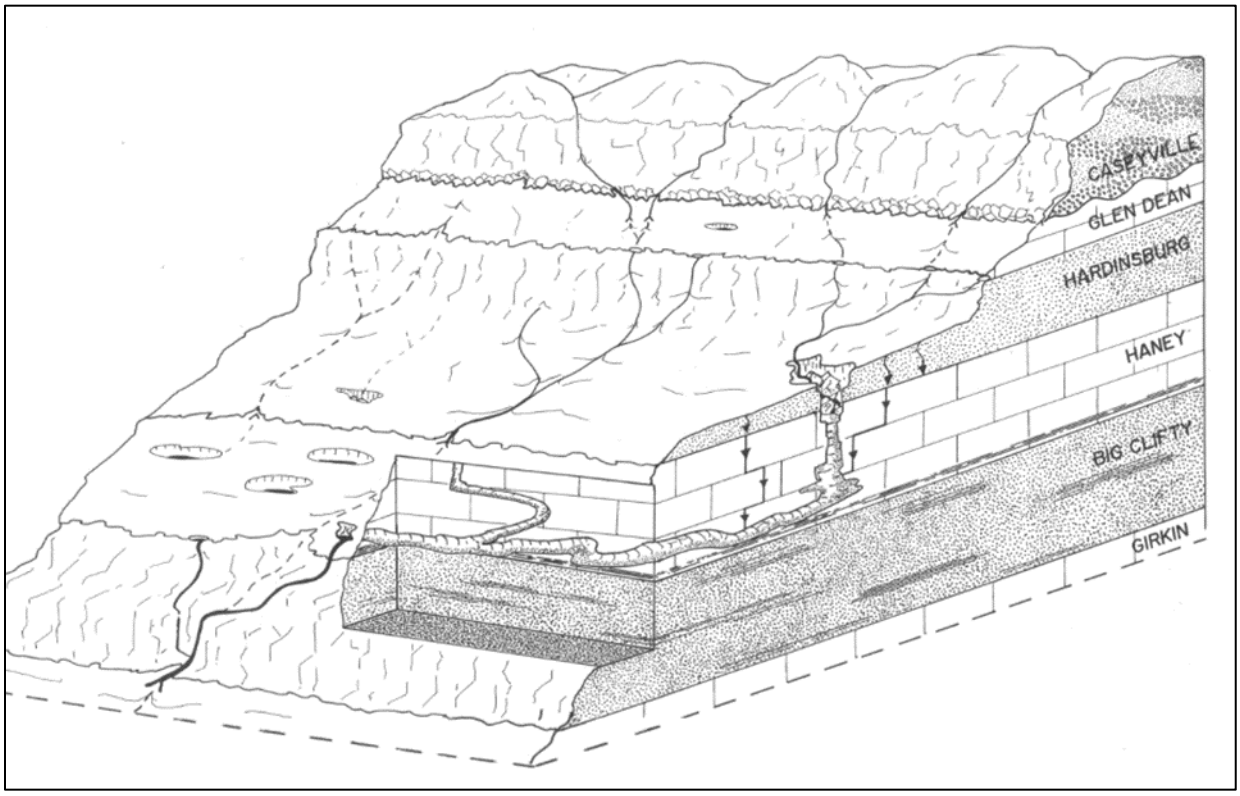


Figure 4.35. Hydrogeology of the Hilly Country north the Green River in MACA, illustrating the difficulty of discriminating between surface and groundwater in such karst landscapes. Water flows on the across the clastic Caseyville Formation at the top of the ridge, then alternately sinks into and emerges from the carbonate rocks of the Glen Dean, Haney, and Girkin Limestones on its way to the Green River. Illustration from Meiman (2006).

The water resources that are included in this analysis include:

- 4.4.1. Precipitation Water Quality
- 4.4.2. Surface Water Quality
- 4.4.3. Groundwater Quality

4.4.1 Precipitation Water Quality

Description

While precipitation amounts vary across the park and contributing drainage area, the landscape has relatively little relief and precipitation is correspondingly uniform. Rainfall at MACA is representative for this region with average annual rainfall of 1,341 mm per year (Kentucky Climate Center 2018). This is more or less evenly spread out through the year (Figure 4.36) though wetter in spring and dryer in fall. South central Kentucky has a humid-subtropical climate, with a mean-annual

temperature of 13ºC. Late summer and early fall are drier than other months. Hess (1974) estimated that mean-annual potential evaporation is about 80 cm, varying from near zero to over 10 cm per month. There is typically at least a small amount of snow accumulation each winter, though snow usually melts between winter storms so there is not a seasonal accumulation at MACA.

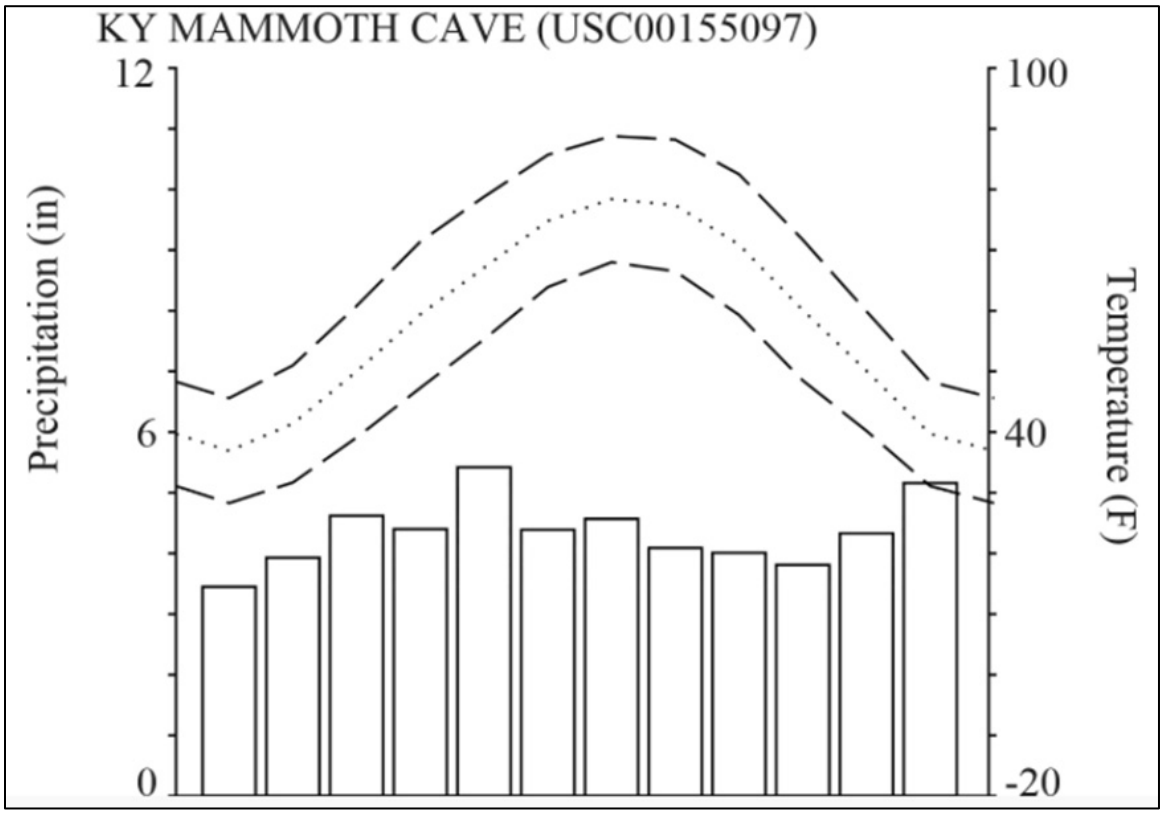


Figure 4.36. Climate summary for Mammoth Cave, Kentucky. The bars at the bottom shown monthly mean rainfall (Source: Kentucky Climate Center).

Data and Methods

The information collected in this section was based on review of internal NPS reports and external literature from scientific papers and conference presentations and Master's theses as cited above, as well as discussions with CUPN and MACA S&RM staff. Particularly useful in this section has been Meiman's (2006) Mammoth Cave National Park Kentucky Water Resources Management Plan. Data also came from the Kentucky Mesonet (Kentucky Mesonet 2018), and the National Atmospheric Data Program (NADP 2020).

In all cases the relevant available information on each resource was reviewed and the information synthesized to draw conclusions about the status and trends of the evaluated resources. Although in the section on surface water there are quantifiable indices of water quality to guide the determination of reference conditions. There are not such standards for precipitation, and evaluations in places relied on the experience and judgement of the authors in determining the nature of degradation that has occurred previously and whether there is a threat of new or continued degradation into the future.

Reference Conditions/Values

In general, there are not standard reference values for water quality of the precipitation considered in the section, but we can evaluate the conditions of these resources by considering their present status, whether some amount of degradation or improvement has occurred previously and whether there is a threat of new or continued degradation into the future. One case where there is a reference standard is for EPA and Kentucky State drinking water maximum contaminant level (MCL), although it would not be expected that these would be exceeded. Levels of the herbicide atrazine, however, have been found at low levels in park rainfall (Groves and Meiman 2004), and two samples has been measured nearby but outside of the park that exceeded the atrazine MCL of 3 μg/L (Kuykendal and Groves 2003).

Condition and Trend

Based on available water quality date for precipitation at MACA, we focus on the following water quality data: 1) acid rain (pH), 2) sulfate (SO4), 3) specific conductance (SpC). Because of the limited data, we note that while atrazine has been measured in park precipitation, we are not considering it as an indicator. However, we do suggest in the data gaps section below that measurements might be considered in future years to assess the nature of this contamination in more detail.

Acid Rain (pH)

Rainwater in southcentral Kentucky has a long history of contamination by sulfuric acid (H_2SO_4) produced from regional coal combustion for electricity generation. Acidity measures the concentration of hydrogen ions (H^+) and is generally measured by the pH scale, which is defined as the negative logarithm of the hydrogen ion activity (Stumm and Morgan 1981) where activities are closely related to concentrations. Two aspects of this technical definition are that 1) the scale is such that lower pH values represent more acidic solutions, and 2) as pH drops one value, say from 7 to 6, the acidity goes up by a factor of 10. A solution with pH=5 is ten times as acidic as one with pH=6, and in turn 100 times as acidic as one where pH=7. Solution with pH=7 are considered to neutral, while lower pH is associated with *acidic* solutions and higher pH associated with *basic* solutions.

Even without pollution being added, natural rainfall is not neutral because naturally present CO_2 the atmosphere creates mild carbonic acid, that in a typical, unpolluted atmosphere would have a pH of about 5.7 (e.g., Drever 1982). Note that as a solution with pH=6 would be ten times as acidic as neutral with pH=7, and this is even a bit lower than that, natural water is more than 10 times as acidic as pure water. Even so, this is not harmful at all on its own at these concentrations.

The trends of pH are a bright spot for resource management at MACA as the conditions, especially since the mid 2000s, have been improving (Figure 4.37). Pollution of rainfall by sulfuric acid has improved significantly with a triple combination of improvements related to regional coal combustion. These first include the use of cleaner coals with lower amounts of the sulfur bearing mineral pyrite which is the source of the sulfur after it burns and ends up in the atmosphere. Regional coals that had been used for many years, particularly from the western Kentucky Coalfield to the north of MACA, are often relatively high in pyrite. Following amendments to the federal Clean Air Act in 1990 (EPA 2017) power plants were required to lower sulfur air emissions and one way this

was done was by switching from western Kentucky coal to cleaner coal from Wyoming's Powder River Basin, even with the costs of shipping it by train that distance. Cleaner air emissions have also been realized by "scrubber" technology, technically called flue gas desulfurization (FGD), which removes sulfur from the gasses produced by the combustion before they are released to the environment. A third consideration is that recently increasing availability of relatively inexpensive natural gas that also produces lower emissions has encouraged its use in power generation, in some cases replacing coal units. Natural gas, for example, accounted for the 10% of power at the Tennessee Valley Authority's (TVA) 16 electricity generating facilities in 2007 and grew to 20% by 2017. By 2020 natural gas is expected to account for 23% of power. Coal, in contrast, should drop to only 22%, compared to 58% in 2007. The air quality at MACA and the surrounding areas reflects these trends (Figures 4.37 and 4.38).

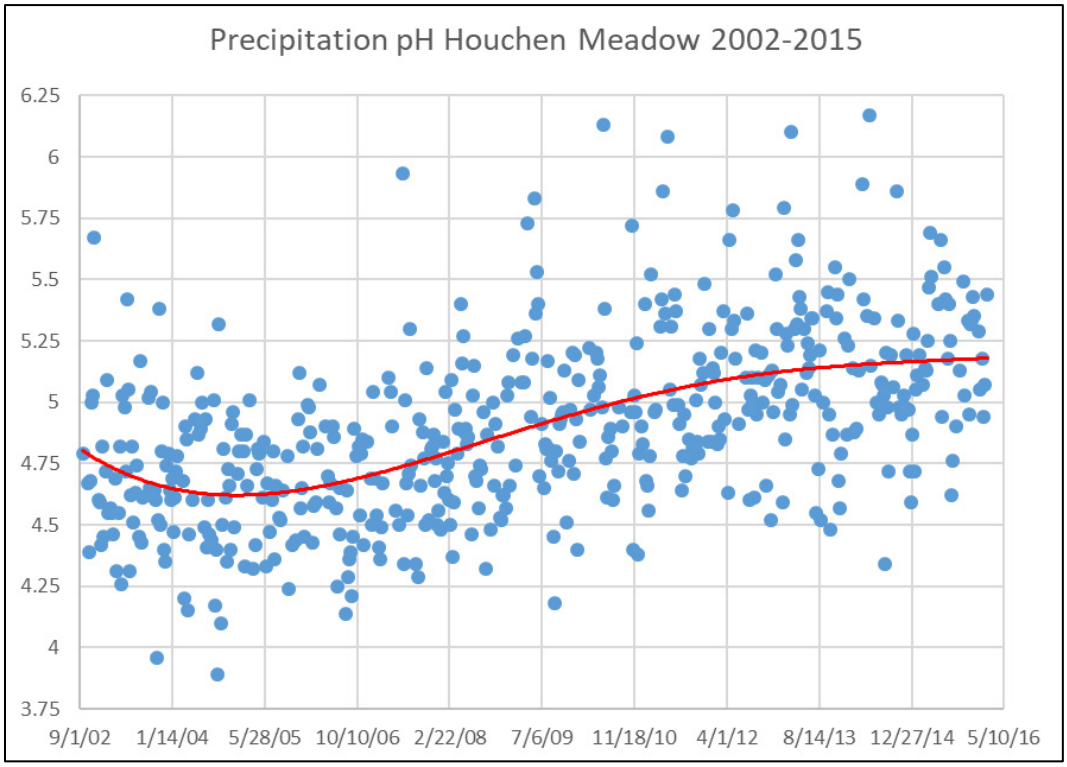


Figure 4.37. Weekly rainfall pH from the Houchen Meadow NADP site just south of MACA. Trend values shown in red range from about 4.6 to 5.2, a drop in acidity—when the log scale of pH is taken into account—of almost 75% (NADP 2020).

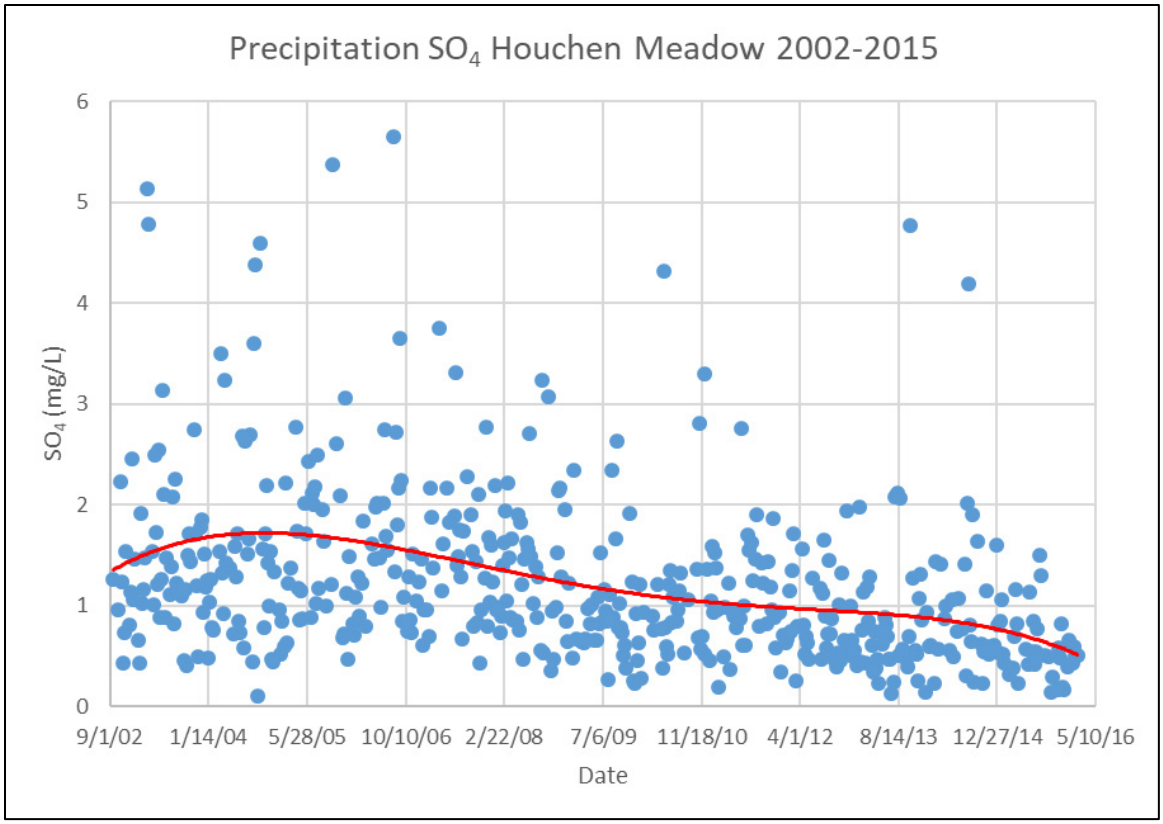


Figure 4.38. Weekly rainfall SO4 from the Houchen Meadow NADP site just south of MACA from 2002 to 2015. Trend values shown in red range from about 1.8 to 0.5 mg/L, a drop of almost 75%. This is consistent with drop in acidity as measured with the rise in pH over the same period (NADP 2020).

Sulfate

Sulfate (SO_4) also enters the atmosphere with the burning of high sulfur coals, in turn forming solutions of strong sulfuric acid rain (H_2SO_4). The rise in pH (Figure 4.37) has been accompanied by a concomitant decrease in SO_4 (Figure 4.38). The trend line shown in red in the figure indicates a drop of SO_4 of nearly 75%, which is close to the drop of acidity as measured by the rise in pH (Figure 4.37) over the same period.

Conductivity

An important characteristic of natural waters concerns the concentration of dissolved substances present, which in different settings can provide useful information on processes that influence the water's quality and more broadly its overall chemistry. Rainwater, for example, is typically very dilute. Water that has been in contact with soil or rocks, in contrast, generally is more concentrated as dissolved constituents are added by dissolution of those soil materials. Pollution can also be a source of dissolved components. Karst groundwater tends to be relatively high because the limestone bedrock is especially soluble in natural waters (Palmer 1991).

Fortunately, there is an easy and inexpensive way to measure this through determination of either of two closely related properties called conductivity and specific conductance (SpC) (Miller et al. 1988), both of which describe the ease with which a substance can transmit an electric current. While

there is some variation in the detailed usage of these terms in relevant literature, as we use the terms here conductivity measures this ability for any given sample, regardless of its size or geometry, so that for example a pure copper wire of a given diameter and length transmits electricity with less energy loss than one that is identical except for being twice as long, because in the longer one there is more wire that the current has to make its way through. When used to describe current flowing through wires and other electronic components, conductance is the inverse of the more commonly used term resistance.

For water samples, SpC is typically used instead. This is a normalized value for conductivity that describes this property over a standardized distance across the fluid (commonly one centimeter) and temperature (25ºC) with this normalization done easily and automatically using a conductivity meter. This instrument consists of two wires coming from the meter that terminate at a probe where the wires end at electrodes which are exposed. When a reading is taken, the meter sends a current through one of the wires, but as the electrodes are separated from one another, if there is air between them there is no connection and no current can flow back through the other wire towards the meter. If a connection was made somehow between the electrodes, however, a continuous loop would be made and the current would flow back to the meter, which would register the voltage and show a reading. The magnitude of the voltage is related to how easily the current flowed through the connection between the electrodes, which in turn depends on what is allowing the connection.

The SpC of rainfall has dropped over the past ten years at MACA (Figure 4.39) indicating that the water has a lower concentration of dissolved ions which indicates an overall lower impact of anthropogenic contamination. This reflects the improvement of air quality with the amelioration of coal combustion impacts, and is consistent with the drop in SO_4 shown in Figure 4.38.

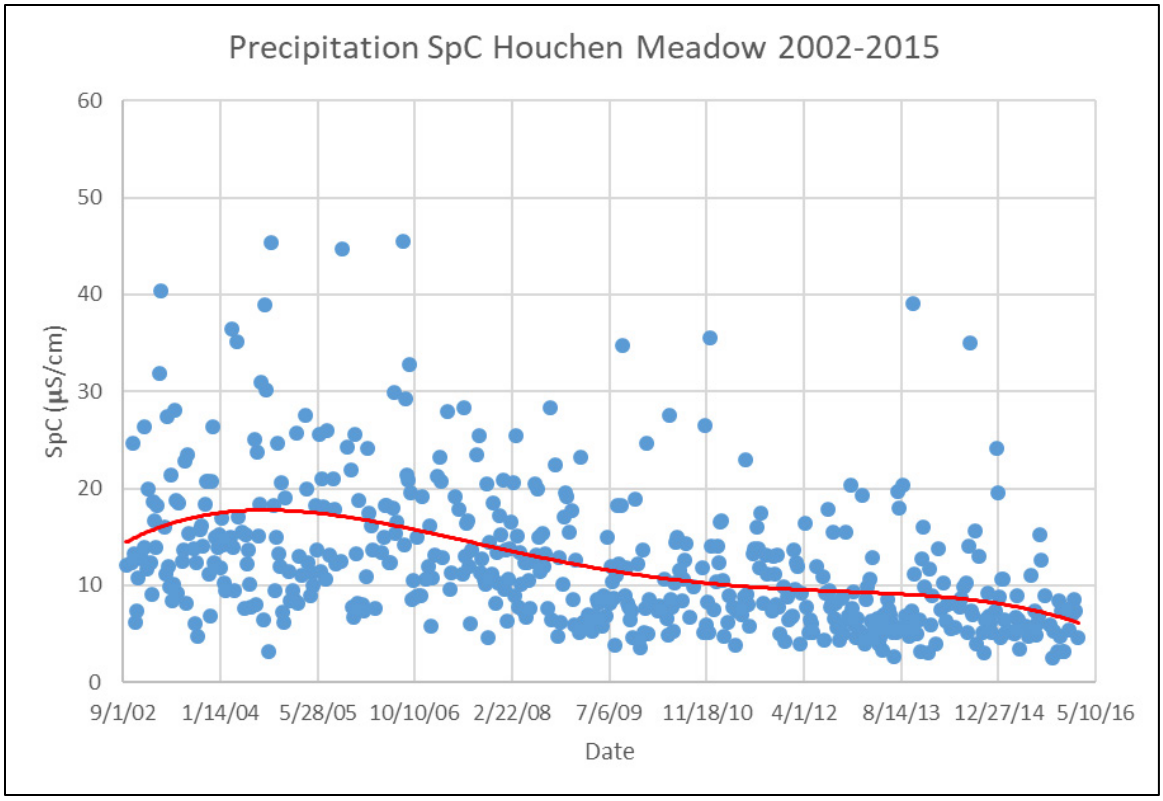


Figure 4.39. Weekly rainfall SpC from the Houchen Meadow NADP site just south of MACA from 2002 to 2015. Trend values shown in red range from about 18 to 7 µS/cm, a drop of more than 50%. This is consistent with drop in sulfate as measured over the same period (NADP 2020)

Mercury

Mercury is a widespread and potent environmental concern that can have significant adverse health effects on both people and wildlife. It is released into the environment through a variety of pathways, but most important for MACA is mercury put into the atmosphere through regional coal combustion. Elemental mercury participates in reactions that alter it to the highly toxic methyl mercury (CH_3Hg^+) which is dangerous both to human and ecological health. Mercury is very persistent in the environment and can bioaccumulate as it moves up the food chain, through for example water to insects to bats. Bat hair at MACA has been measured with mercury concentrations as high as 2 ppm (van der Heiden and Webb 2013). Methyl mercury is a neurotoxin that can easily enter and be distributed through the human or animal bodies. Low levels have been associated with learning disabilities in children and reproductive interference in animals, and it is a suspected human carcinogen.

Weekly mercury deposition is measured at Houchins Meadow under the auspices of the NADP MDN. Samples are collected according to modifications of the EPA Method 1669 and analyzed in the laboratory by oxidation, purge and trap, and Cold Vapor Atomic Fluorescence Spectrometry using EPA Method 1631. Data are expressed as concentrations in micrograms per liter (µg/l) which is equivalent to parts per billion (ppb) and also combined with rainfall data to develop a measured deposition rate in nanograms per square meter (ng/m^2).

The NPS and EPA have not published specific criteria to discriminate between levels of concern for atmospheric mercury deposition. Using professional judgement, we consider here a range of studies that show that mercury contamination is widespread at MACA, along with consideration of the element's environmental and human toxicity. In a three-year mean (2006–2008) of mercury deposition rates at 13 national parks across the country, MACA was fourth worst, with levels higher than the average of those parks, and there has not been a significant upward or downward trend since that study (NPS 2010a). Mercury deposition rates from Houchin Meadow from 2003–2016 are shown in Figure 4.40. Data that show that mercury contamination is widespread at MACA, having been detected in water, sediment, insects, fish, and bats. Measurements of mercury in prehistoric and recent bat guano deposits show significant increases following the industrial revolution (Hagan 2014). No discernable trend has been identified in the MDN data between 2003 and 2016.

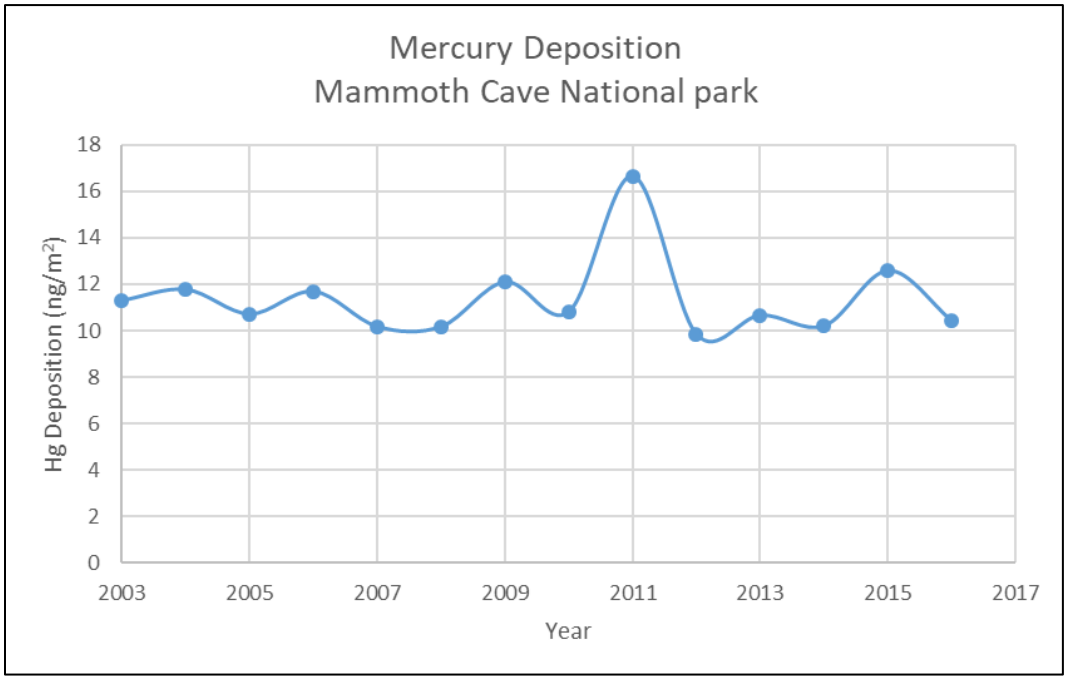


Figure 4.40. Mercury deposition rates at the Houchin Meadow Site near MACA from 2003 through 2016. Data from the NADP MDN (NADP 2020).

Level of Confidence and Data Gaps

These long-term, high-quality data come from the Houchin Meadow station adjacent to MACA (Figure 4.1) collected and analyzed with the protocols of the National Atmospheric Data Program NADP NDN, as well as additional data from a variety of specialized studies throughout the park, and therefore there is a high level of confidence (Table 4.22).

If resources permit in the future, MACA might also consider adding methylmercury analysis at Houchin Meadow through the NADP, and additional students to quantify bioaccumulation would be useful. The park also participated in the NADP mercury litter fall study for several years between 2007 and 2009 and we recommend that this program should be continued moving forward.

Although based on limited data, there is evidence that herbicides move through the park during the spring application seasons, including in rainfall (Kuykendal and Groves 2003, Groves and Meiman 2004). It might be prudent to add atrazine as an indicator to get a better understanding of the nature of the contamination in the park.

Condition Summary

Table 4.22. Graphical summary of status and trends for precipitation.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Precipitation	pH, SO4, SpC, mercury		There is not a standard reference condition for precipitation water quality. However, with changes in regional coal combustion technology and practices, rainfall chemistry has improved greatly over the past decade and this trend is likely to continue. We list moderate concern due to mercury.

Sources of Expertise

Information used in the water resources section comes primarily from staff of the MACA Division of Science and Resource Management and the Cumberland Piedmont Inventory and Monitoring Network, in particular Joe Meiman, Larry Johnson, Bobby Carson and Johnathan Jernigan.

4.4.2. Surface Water

Surface water resources of MACA are dominated by the Green River and its major tributary, the Nolin, which flows from the north to join the Green in the western part of the park. These rivers have significant tributaries flowing on clastic rocks to the north of the Green, including First, Second, and Bylew Creeks in the Nolin drainage and Buffalo and Ugly Creeks flowing to the Green. South of the Green flow within the park is generally underground within the limestones of the karst aquifer, although there are a few short sections of surface flow where cave streams emerge at springs to flow across the bottoms of karst depressions to sink again on the other side. These are called karst windows and a great example can be seen at Cedar Sink in the southwestern part of the park.

Description

The Green River (Figure 4.41) is a tributary of the Ohio, and historical flow data have been collected about 1.6 kilometers downstream from the park at a US Geological Survey gaging station (Station USGS 03311500) in Brownsville (USGS 2017). The mean discharge for the Green River at the gage is 123.7 m^3/s, which includes the flow of the Nolin River which flows into the Green from the north about 2.9 kilometers upstream from the station, and which has a mean discharge of 26.6 m^2/s (Meiman 2006). The Green River within the park flows from east to west for about 40 kilometers from about river mile 207.8 at the park's northeastern end downstream to river mile 182.7. These are river kilometers upstream from the Green's confluence with the Ohio, and so the park is roughly in the center of the overall Green River basin, which has a total length of about 614 kilometers.

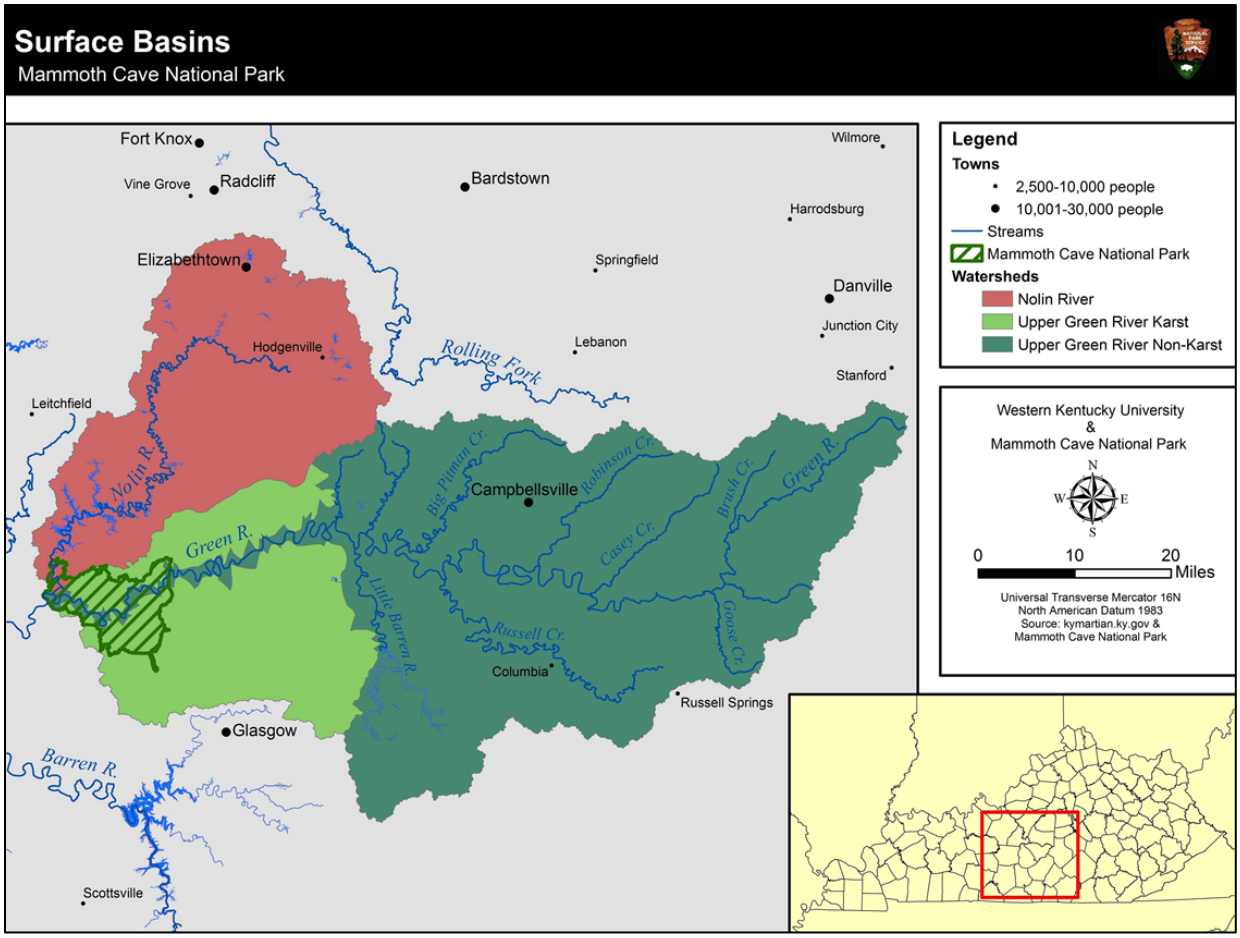


Figure 4.41. Drainage areas flowing into MACA (Groves et al. 2016).

The Green River has been significantly impacted by a collection of at least twelve dams that were constructed starting in 1836 (USACE 2004). Six of these, Green River Locks and Dams 1–6 were built for navigation. Green River Dam was built by the impoundment of Green River Lake at river mile 305.7 in 1969 for flood control and visitor recreation. Four of these dams have influenced conditions in the Green at MACA, including Green River Dam, Lock and Dam #5, Lock and Dam #6, and the Nolin River Dam (Figures 4.42–4.46). Green River Dam is 157.1 kilometers upstream from the park, and thus operation of the dam artificially controls flows coming downriver. Prior to 2002 the decisions about the dam operation and the resulting distribution of flows were made with respect to flood control, without ecological considerations. This had significant influence on both physical and biological conditions of the river basin.

In response to ecological challenges, in 2000 The Nature Conservancy (TNC) partnered with the US Army Corps of Engineers (USACE) through a Memorandum of Understanding between USACE and TNC to establish the Sustainable Rivers Project (SRP) (USACE/TNC 2011a, USACE/TNC 2011b). This national program, which includes the Green River Basin, develops protocols to modify dam operations to enhance ecological conditions downstream by establishing what have been termed *environmental flows*, which are river flow distributions that sustain environmental conditions. In the

Green River Lake Reoperation, for the first time USACE received approval to modify water releases from the dam to mimic more natural flow distributions to help restore the natural biodiversity of the river. A trial period ran from 2002–2005, after which numerous clear benefits had been observed and were expected, including within MACA. In 2006 Midkiff (2001) wrote that:

> Positive impacts to threatened or endangered species of mussels have been identified during the three-year experimental period. No adverse impacts have been observed. By restoring more natural hydrologic variability in flows and temperature downstream of the lake, ecosystem functions along with rare plants, animals, and communities that are indigenous to the area are experiencing some degree of recovery. Proof of such occurring is the identification of many species of juvenile mussels, 2 to 3 years old, including three endangered species, i.e., clubshell (*Pleurobema clava*), fanshell (*Cyprogenia stegaria*), and ring pink (*Obovaria retusa*) (Monte McGregor, KDFWR, Aquatic Ecologist, December 2015, personal communication). This is the only known reproducing population of the endangered ring pink anywhere. More common species, such as the rabbitsfoot (*Quadrula cylindrical*), are also demonstrating evidence of recent reproduction and recruitment.

In an overall summary of the operation, he concluded that:

> A more dependable source of water supply is created as the quantity available at winter pool is increased with the re-regulation. This increase along with changes in filling and release schedules associated with re-regulation has resulted in no adverse impact to wetlands in the project area or downstream of the lake. Air quality will improve as odors associated with hydrogen sulfide will continue to be reduced or eliminated at the tail water as fall drawdown releases will not occur until after destratification. The overall lack of adverse impacts with the proposed plan, as demonstrated during the three-year experimental period, has resulted in beneficial cumulative impact.

Based on these results, the modified operation became permanent. These flows focus on the seasonal timing of the usual fall drawdown (Mike Hensley, The Nature Conservancy, Green River Project Coordinator, August 2017, personal communication). Instead of releasing water from the lake at near the maximum discharge rate, flows are pulsed to mimic more natural rises and falls of the water level. This approach has been based on scientific data that showed that significant mussel and fish spawning activities was occurring during the fall and coinciding with the lake drawdown activities every year.

While such flows would not create a problem if occurring every once in a while, reproduction was clearly affected by the fact that this was happening year in and year out. The new drawdown operational procedure developed by USACE and TNC focused on two ideas: 1) waiting until fall turnover when cooling near-surface lake water sinks and 2) allowing the lake drawdown to be done

through more natural fluctuations rather than lowering the water level quickly in a more linear fashion. The operation was also modified through the use of multiple depth releases of water rather than a focus on using the main gate only, which had principally drawn cold water from the bottom of the lake (Meiman 2006).

Several other structures have impacted the river at the western end and just downstream from MACA and in the rivers. A series of structures have been constructed at the current location of Lock and Dam #5 (Figure 4.42) beginning with a navigation lock in 1900. This was replaced by a new lock and dam, just upstream from the original location, which was placed into service in 1934. This is located at river mile 168.1 and the pool extends upstream into the western end of MACA. Lock and Dam #6 was constructed in 1904 and for many years impounded the lower half of the park's section of the Green River (Figures 4.43–4.46), with significant hydrologic, water quality and ecological impacts to both surface water and karst groundwater (USACE 2004). Mike Hensley, The Nature Conservancy Green River Project Coordinator (pers. comm., June 2015) described the situation this way:

> Even though they no longer provide passage for commercial barge traffic, the lock and dam systems located along the Green and Barren rivers continue to have an impact on people and wildlife located in their drainage. For example, some municipalities have situated water intake structures in pools created by the dams. If dams are removed, these structures may need to be redesigned.
>
> From a different perspective, the locks and dams present a barrier to recreational use of the river and present a serious safety hazard to boaters.
>
> The dams also disrupt the natural flow patterns of both rivers, resulting in negative impacts to fish, mussels and other river species and on the cave systems within MACA. In fact, the National Park Service has stated that the continuing presence of Green River Lock and Dam #6, out of operation since 1951, poses "the single greatest unresolved ecosystem management issue at Mammoth Cave National Park."

After many years of scientific and political discussions about removing the dam, and considerable local controversy, in December, 2016 the US Congress passed the Water Infrastructure Improvements for the Nation Act, which included language authorizing the disposition of Lock and Dam #6 including transfer of the adjacent land on the north side of the Green River to the State of Kentucky and on the south side of the river to MACA, and "removing Lock and Dam #6 from the river at the earliest feasible time." The dam breached on its own accord on November 25, 2016 and the water level dropped over two meters behind the dam, which was subsequently removed in early 2017 (Figures 4.45 and 4.46). The Green and Nolin Rivers are free flowing now through much of the park, except for the western end where impoundment from Lock and Dam #5 impounds the lower ends of both rivers. Impacts of the associated lowering of the water table are also being realized throughout the underground river systems of the western portions of the Mammoth Cave System and other caves. One place that this can be easily seen at the surface is at Cedar Sink, where the underground Hawkins River emerges for a short distance at a karst window at the low point of this

large sinkhole between Mammoth Cave and Owl Cave. The water table has dropped about a meter here, and a small "canyon" can be seen actively forming in the streambed as the sediment is washed out in an adjustment to the new hydrologic conditions, even though the Green River is over a kilometer away.

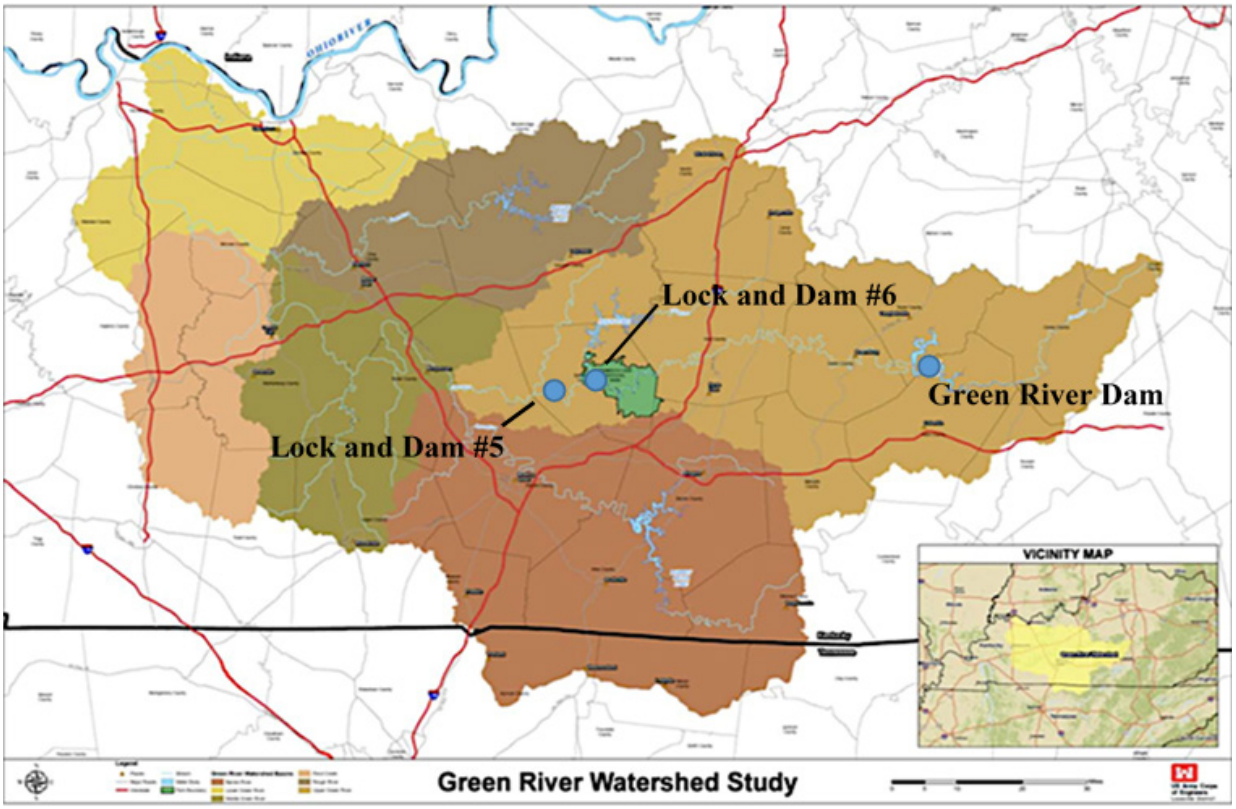


Figure 4.42. Location of Green River Dam and Lock and Dam #5, and former location of Lock and Dam #6. MACA is shown in green near the center of the basin. Source: USACE/TNC 2011a.



Figure 4.43. Green River Lock and Dam #6 near Brownsville, Kentucky. This picture shows the dam in April 2015, intact before the November 2016 breach. Photo by Mike Hensley.

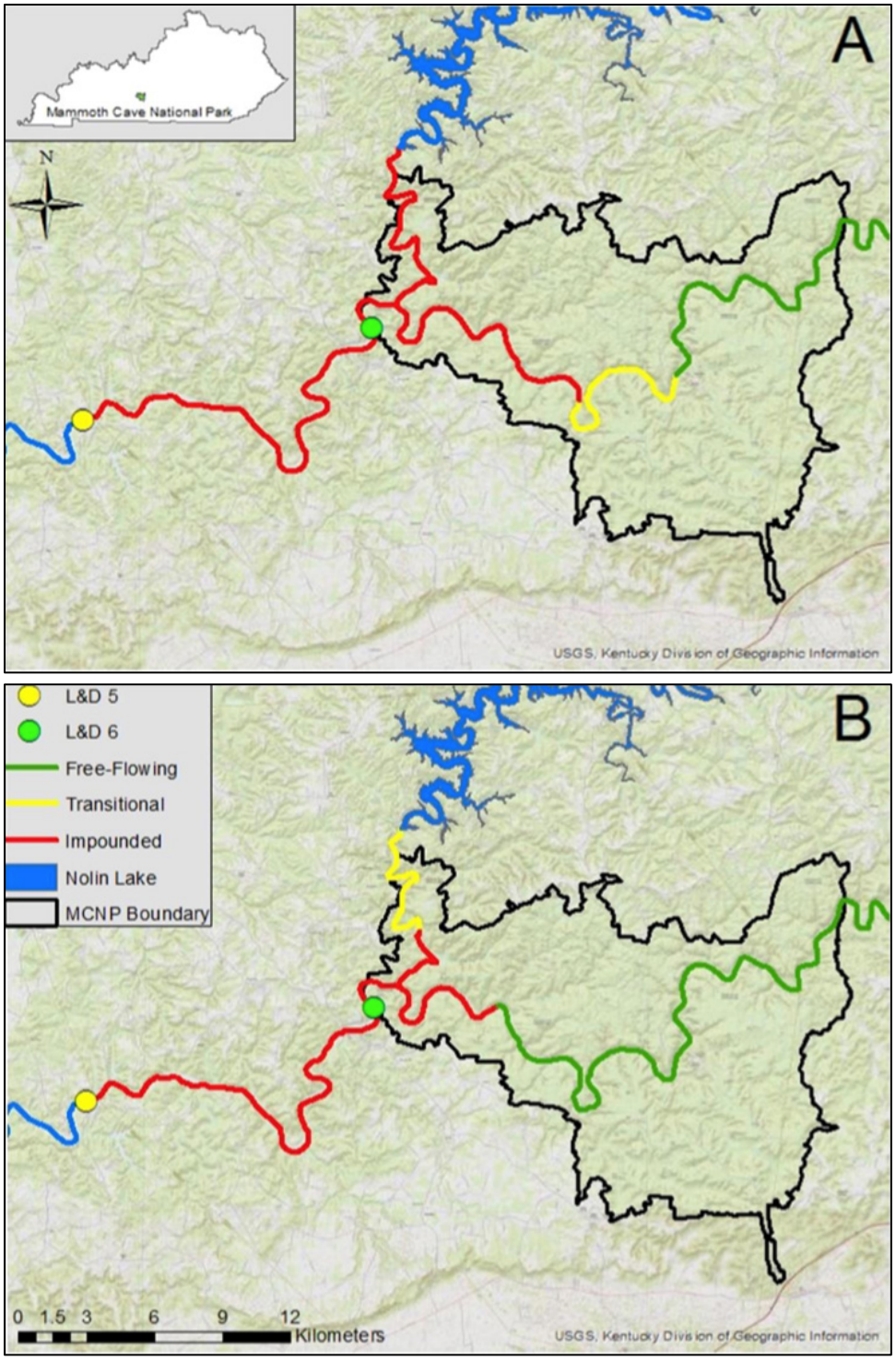


Figure 4.44. Historical (A) and Current (B) hydrology of the Green and Nolin Rivers near Mammoth Cave National Park (Compton et al. 2017).



Figure 4.45. Houchen's Ferry on the reach of the Green River formerly impounded by Lock and Dam #6 before the dam breached. Photo courtesy of Kentucky Department of Fish and Wildlife Resources (https://fw.ky.gov/Fish/Pages/Houchins-Ferry-(Mammoth-Cave-National-park).aspx)



Figure 4.46. Houchens Ferry after the removal of Lock and Dam #6. The white line shows the approximate level of low water in the impounded area for the dam was breached and removed. The section of the river is still in the currently impounded section behind Lock and Dam #5 (see location indicated on Figure 4.44) Photo by Chris Groves.

The Nolin River flows from the north joining the Green River a short distance upstream from MACA's western boundary (Figure 4.41). It drains an area of 1787 km^2, dominated by surface drainage. Seven miles upstream from the river's confluence with the Green and just over a kilometer

upstream from the park's northern boundary, the Nolin River Dam lies in a relatively deep and narrow gorge where the river has begun cutting down through the resistant, Pennsylvanian sandstones of the Western Kentucky Coalfield. It was authorized by the 1938 Comprehensive Flood Control Plan for the Ohio and Mississippi Rivers (USACE 2017) that followed the catastrophic Ohio River flood of 1937 (Casto 2009). Construction of the dam, which impounds a lake of about 9 mi^2, began in 1959 and took four years. The dam's principal purpose is for flood control and so the river's discharge downstream into the park is artificially influenced by its operation. The lake also provides benefits as a source of drinking water, ecological habitats and recreation. Until November of 2016 most of the Nolin River in the park was impounded Lock and Dam #6. This impoundment was also drained when the dam breached and as of this writing, although the river was unpassable by boat and canoe for several months because of trees that have toppled into the river as the sediment of the river banks has slumped in response to the lowering of the water table, the river has now been cleared and is passable by canoe.

There are other, comparatively minor surface waters at MACA, mostly where water is perched on the nearly horizontal sandstones of the prominent ridges of the dissected Mammoth Cave Plateau south of the Green River, and thicker clastic rocks that thicken northward. In the south, these are generally small ponds on the ridgetops along with relatively small streams that sink underground into the cave system upon reaching the Girkin limestones on the sides of the ridges where the sandstone has been removed by erosion. The two largest ponds are First Creek Lake on the park's north side and Sloan's Crossing Pond about a kilometer southeast of the Visitor Center. First Creek Lake is a 2.8 ha pond along the creek that has been enlarged by beaver activity.

Data and Methods

Our ability of evaluate water quality of MACA is based on a number of sampling programs that have been undertaken through the years, and data from 1990 through 2017 are included in this analysis. There are in general three types of data collection included in these assessments, which include 1) the Mammoth Cave Water Quality Monitoring Program WQMP, 2) storm pulse monitoring, and 3) various other "snapshot" programs that have focused on evaluation of a particular setting or topic of interest.

The most important of these programs has been the WQMP that was established in 1990 (Meiman 2006). The structure of this program is based on the US Geological Survey (USGS) National Water Quality Assessment (NAWQA) (USGS 2020). The WQMP is a synoptic, non-conditional program. It is synoptic in the sense of providing a general summary or synopsis of the conditions at the selected sites, and non-conditional in that the samples have been collected on pre-selected days. In this case the during the 1990–2002 sampling campaign, for example, Meiman and his crews collected samples from each of the locations on the tenth of each month, every time, regardless of the conditions on that day. This made a long day each time: of the twelve sites nine were sampled by boat along a 64 km roundtrip and three were sampled by land, two from wells. Although choosing the sampling days in advance in a rigid framework do not initially sound very random, it actually is because this means that the conditions on a particular sampling day might be wet or dry, cold or hot Cave National Park (Compton et al. 2017).

So, a non-biased range of conditions ends up being sampled. If in contrast, on the designated sampling day the team decides not to go because it is too rainy or cold or for any other reason inconvenient, then a conditional bias is introduced to the data. The locations chosen for the monitoring were considered to serve as "integrator" sites located at the downstream ends of their respective surface or subsurface drainage basins and thus have water quality signatures that reflects the integrated impact of land use within the area draining to the site. For this assessment, the Green River and Nolin River data characterize the major surface water bodies, and groundwater is assessed through consideration of springs that flow into the Green River on its south side (Turnhole Spring and Echo River Spring) and more remote north side (Big Spring). While the surface basins such as that for the Green and Nolin Rivers can for the most part be determined by examination of topographic maps, groundwater basins draining to the spring and well sites have been determined through extensive dye-tracing work (Anderson 1925; Brown 1966; Quinlan and Ray 1981, 1989; Ryan 1992; Murphy 1992; Meiman and Ryan 1992, 1993; Ryan and Meiman 1996; Hall 1996; Ray et al. 1998a, 1998b; Meiman et al. 2001).

Meiman (2006) described the field and laboratory procedures for the collection of, and interpreted results from 56 samples taken during the 1990–92 and 1997–99 sampling campaigns. Additional samples under the auspices of the WQMP were taken from 2002–2005 and 2010–2012. For this assessment, we have selected nitrate (NO_3^-), specific conductance (SpC), pH, and dissolved oxygen (DO) through that entire period as well as *Escherichia coli* (*E. coli*) data from 2005, and then split out each year from 2010–2012.

Reference Conditions/Values

Reference conditions for a particular body of surface water depend on its designated use, in Kentucky according to state law through 401 KAR 10:031, Section 3–8 or 401 KAR 10:026, Section 5. These are listed as:

1. Warm water aquatic habitat
2. Cold water aquatic habitat
3. Primary contact recreation
4. Secondary contact recreation
5. Domestic water supply
6. Outstanding state resource water

Meiman (2006) listed the various designated uses for waters of MACA in descending order of quality:

Outstanding Resource Waters: All underground rivers in MACA as well as the main stem of the Green River in the park are designated as Outstanding Resource Waters. This is an automatic designation if a water body contains endangered species, and examples in the Green (Cicerello and Hannan 1990, Meiman 2006) include the fanshell mussel, the northern riffleshell (*Epioblasma rangiana*), the ring Pink, the clubshell, the pyramid pigtoe (*Pleurobema pyramidatum*). There are additional details on these mussel distributions in 4.12.2. There are also other endangered mussel

species that have early reports but have not been collected in several decades, as well as others that are in the Green but not reported in the park. The park's underground streams are also home to the endangered Kentucky cave shrimp (*Palaemonias ganteri*; Holsinger and Leitheuser 1982a, 1982b; Holsinger et al. 1986). The Green River in the park is also designated and as Kentucky Wild River.

Cold Water Aquatic Habitat: Waters and associated substrate that will support indigenous cold water aquatic life or self-sustaining trout populations on a year-round basis. All cave streams within the park meet the Cold Water Aquatic Habitat criteria. Although the state stocks rainbow trout (Onchorhynchis mykiss) in the tailwaters of the Nolin dam just upstream of the park's boundary, which is listed as cold water habitat, the population is not self-sustaining.

Warm Water Aquatic Habitat: Waters and associated substrate that will support indigenous warm water aquatic life. The Green and Nolin Rivers can be considered under this category, although the Outstanding Resource Waters designation of the Green supersedes this category.

Primary Contact Recreation: Those waters suitable for full body contact recreation during the recreation season of May 1 through October 31. Both the Green and Nolin fall under this category.

Secondary Contact Recreation: Those waters that are suitable for partial body contact with minimal threat to public health to water quality. All park waters would fall into this minimum category.

Condition and Trends

The following data show the trends of water quality for the chosen parameters of *E. coli*, nitrate, dissolved oxygen (DO), Specific Conductance (SpC), and pH using WQMP data to characterize conditions for the Green River, the Nolin River. Results of an analysis of the impacts of trail crossings on small streams north of the Green River are also included.

Green River

Figure 4.47 shows the trends of *E. coli* for the years 2005 and then split out yearly for 2010 through 2012. Bacteria samples were collected in the earlier sampling period but were quantified as fecal coliform which are not as specific an indicator of fecal contamination as there are other bacteria including *Klebsiella pneumoniae* and *Klebsiella oxytoca* that can create a positive fecal coliform result even when no fecal material is present (IDEXX 2017). *E. coli* is a more specific indicator of fecal bacteria. The two tests are comparable when the task is to identify the Presence/Absence of the bacteria rather than a quantitative enumeration. The Colilert System has become available as a simple and cost-effective method for total coliforms and *E. coli*, which is a more reliable indicator of the presence of fecal contamination. As the numbers are not directly comparable, the bacteria data from the WQMP considered in this assessment are the *E. coli* data beginning in 2005 and showing each of the three years 2010–2012. Contamination of MACA surface waters by fecal bacteria is the most widespread and ubiquitous water quality problem. The levels are highly variable, with relatively low levels during low flow conditions. During storms, when agricultural lands are flushed by water which drains into the Green, *E. coli* levels can exceed 1,000 colonies per 100 ml.

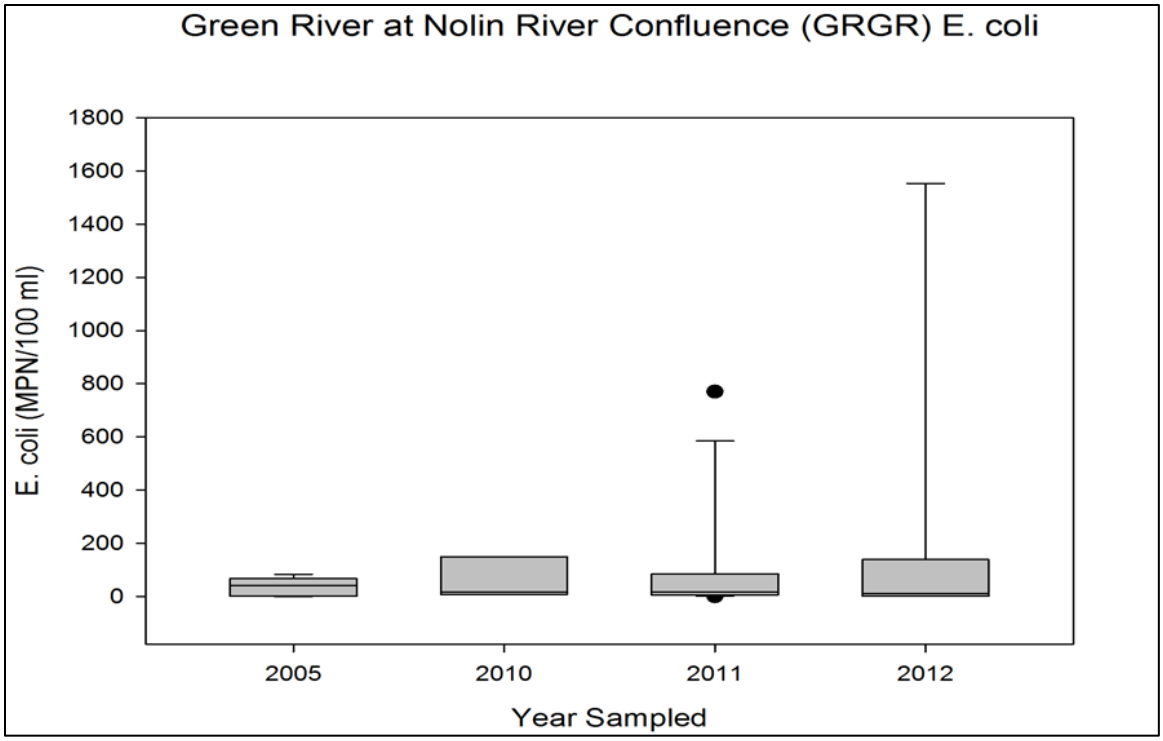


Figure 4.47. *E. coli* levels for the Green River from 2005 and 2010–2012 WQMP data. 2005 data are characterized by fecal coliform concentrations and so are not directly comparable (Meiman 2006).

Figure 4.48 shows nitrate in the Green River at its confluence with the Nolin through four two-year sampling campaigns between 1990 and 2012. Nitrate levels are all acceptable with regard to the designated use, though some sample exceed the drinking water standard (Maximum Contaminant Level, or MCL) of 10 mgl/L. There appears to an increasing trend in nitrate between 1996 and 2012, although the levels are not creating water quality problems for MACA with regard to either human health or ecological concerns.

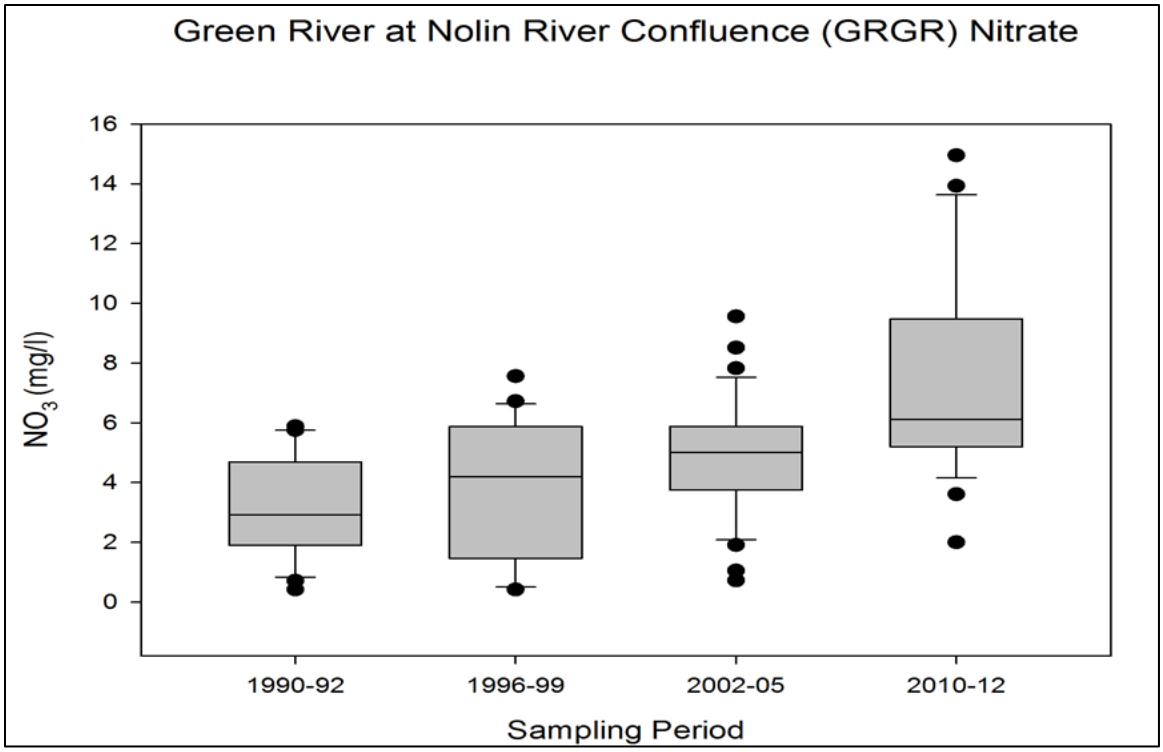


Figure 4.48. Dissolved nitrate concentrations for the Green River from the 1990–2012 WQMP (Meiman 2006).

Dissolved oxygen (DO) levels for the Green River from 1990 through 2012 are shown in Figure 4.49. These waters are all sufficiently oxygenated and appropriate for the designated uses. Green River pH levels are shown in Figure 4.50. As would be expected for an area with extensive limestone bedrock, the highly buffered waters are well within the state standards range of pH 6–9. No particular upward or downward trends are evident.

Specific conductance levels are relatively high compared to that of many natural waters (Figure 4.51), which is to be expected given then the extensive exposures of soluble carbonate rock limestone. Waters of MACA tend to be high in calcium and bicarbonate from dissolution of this rock. Stream waters in several parks in igneous and metamorphic rocks in the NPS National Capital Region, for example, including Cacoctin Mountain Park and Prince William Forest Park, have SpC values all below 170 µS/cm (Weaver and Northrup 2016). There are no legal standards for SpC.

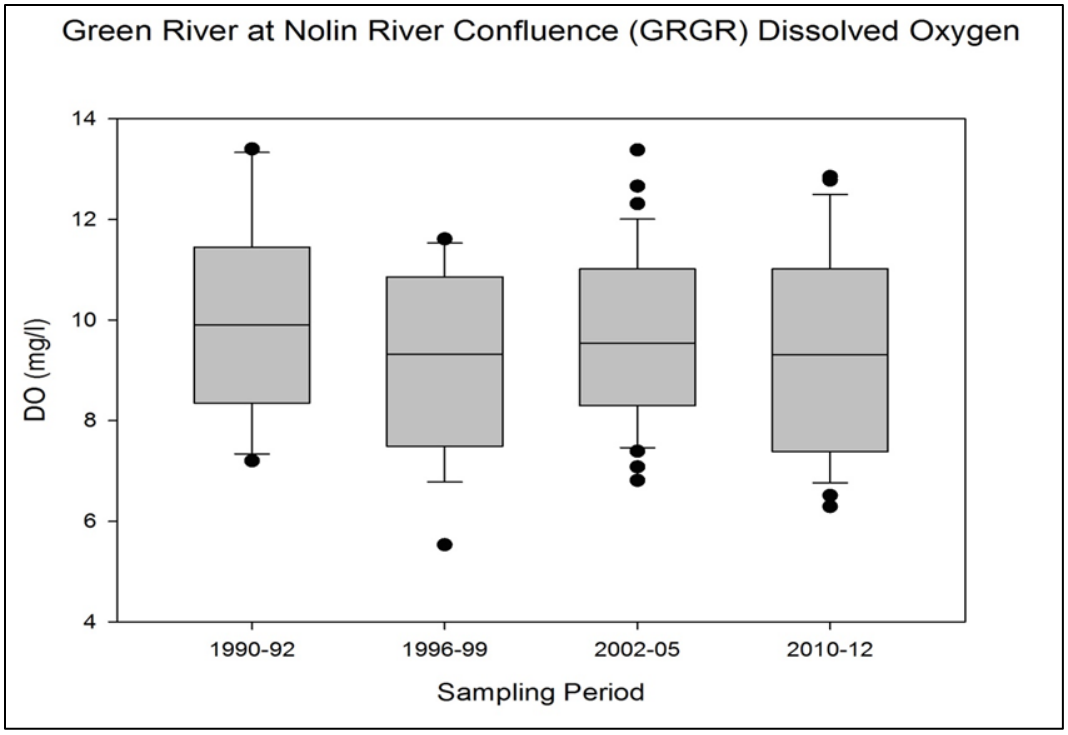


Figure 4.49. Dissolved oxygen concentrations for the Green River from the 1990–2012 WQMP (Meiman 2006).

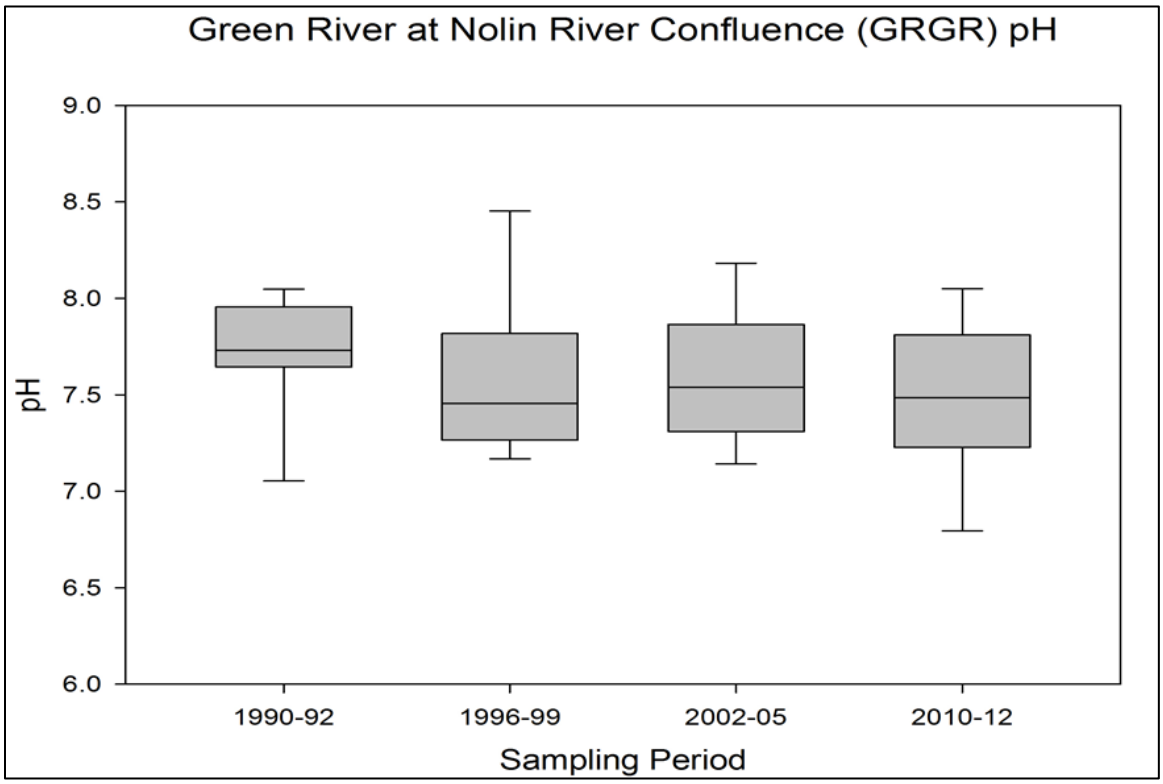


Figure 4.50. pH data for the Green River from the 1990–2012 WQMP (Meiman 2006).

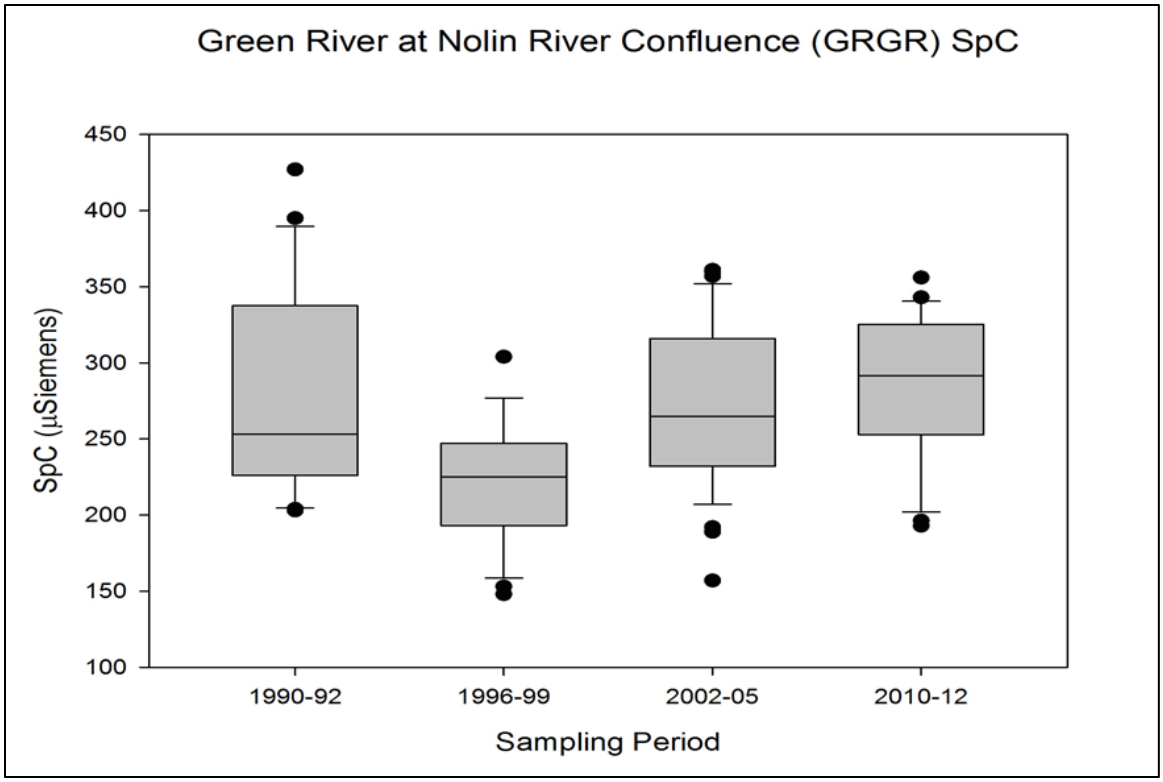


Figure 4.51. Specific conductance data for the Green River from the 1990–2012 WQMP (Meiman 2006).

Nolin River

Conditions in the Nolin based on the same sampling campaigns (Meiman 2006) a broadly similar to the Green and for the most part the same conclusions may be reached (Figures 4.52–4.56). Fecal bacteria levels stay more consistently low in the Nolin and lack some of the large spikes shown in Figure 4.48 for the Green River, which may reflect the larger influence of karst groundwater inputs through large springs on the south side of Green that are highly vulnerable to agricultural contamination. The data also suggest an increasing trend in NO_3 (Figure 4.53) over the last three sampling campaigns, which would seem to be related to the significant amounts of agricultural land use in both river basins that can contribute nitrate to surface and groundwater. An interesting common feature between the Green and Nolin River data sets is that SpC is lower in both rivers during the 1996–99 sampling periods than before and since. The fact that this is true in both basins suggests a regional cause, perhaps just a wetter period for which flows are higher and thus somewhat ore dilute. This is just a curiosity and not really related to water quality impairment, and so this was not investigated further.

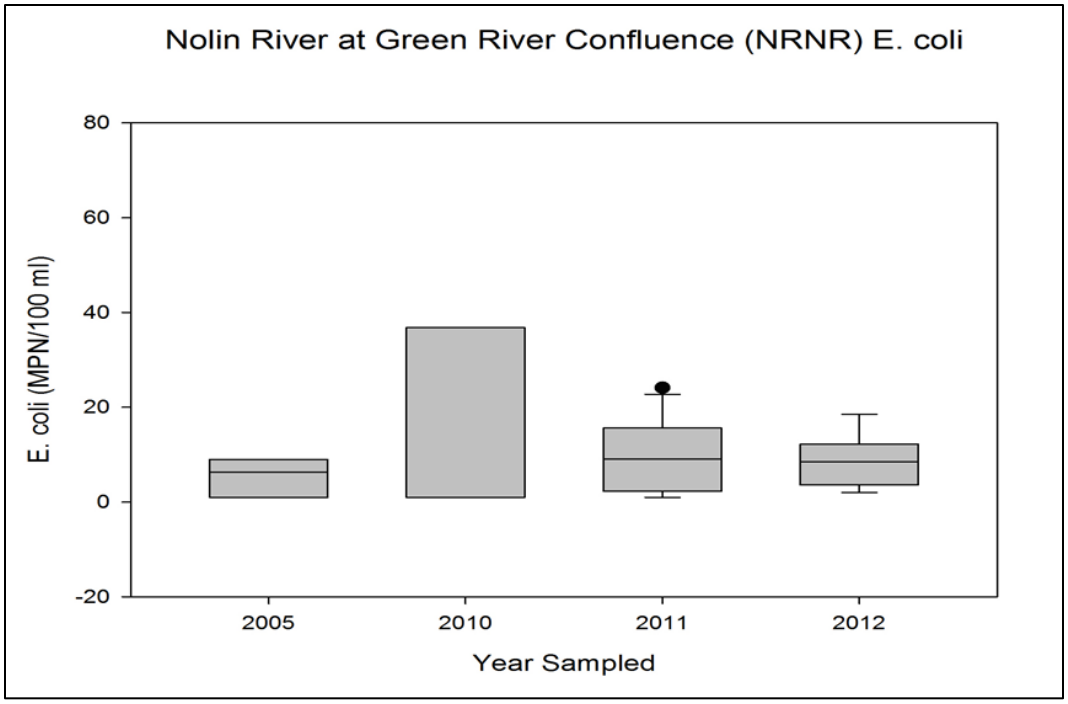


Figure 4.52. *E. coli* data for the Nolin River from the WQMP, 2005–2012 (Meiman 2006).

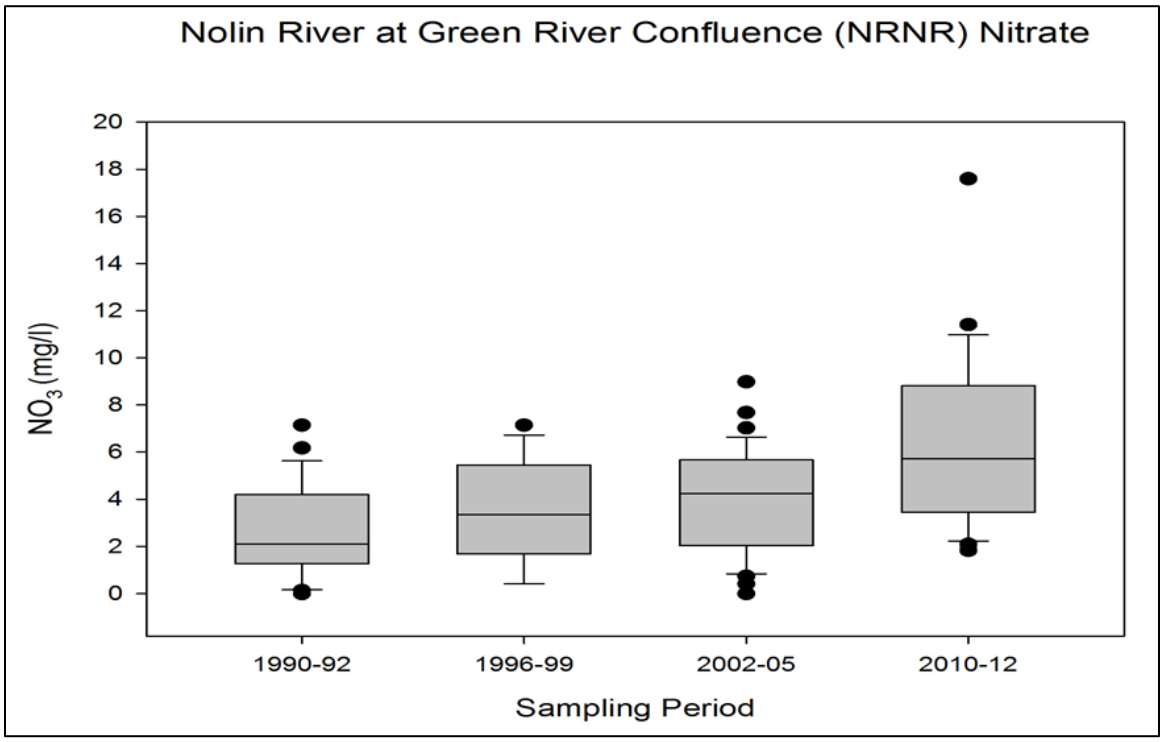


Figure 4.53. Dissolved nitrate concentrations for the Nolin River from the 1990–2012 WQMP (Meiman 2006).

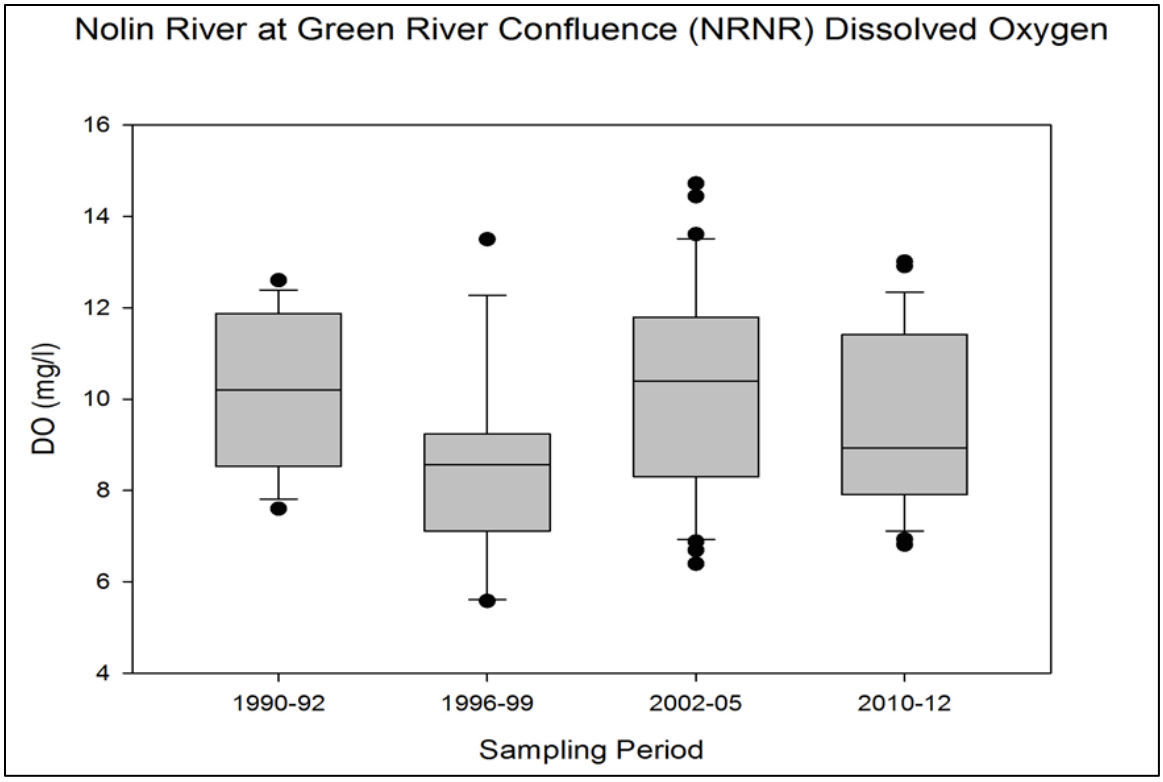


Figure 4.54. Dissolved O2 concentrations for the Nolin River from the 1990–2012 WQMP (Meiman 2006).

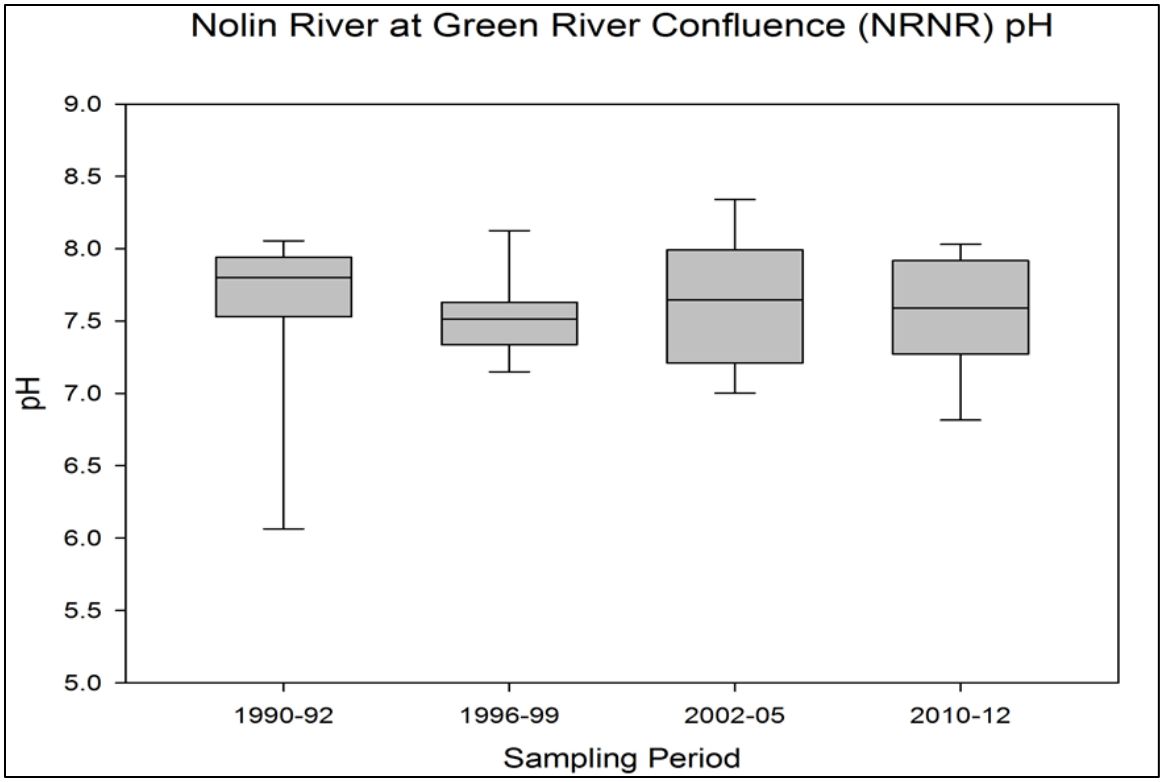


Figure 4.55. pH data for the Nolin River from the 1990–2012 WQMP (Meiman 2006).

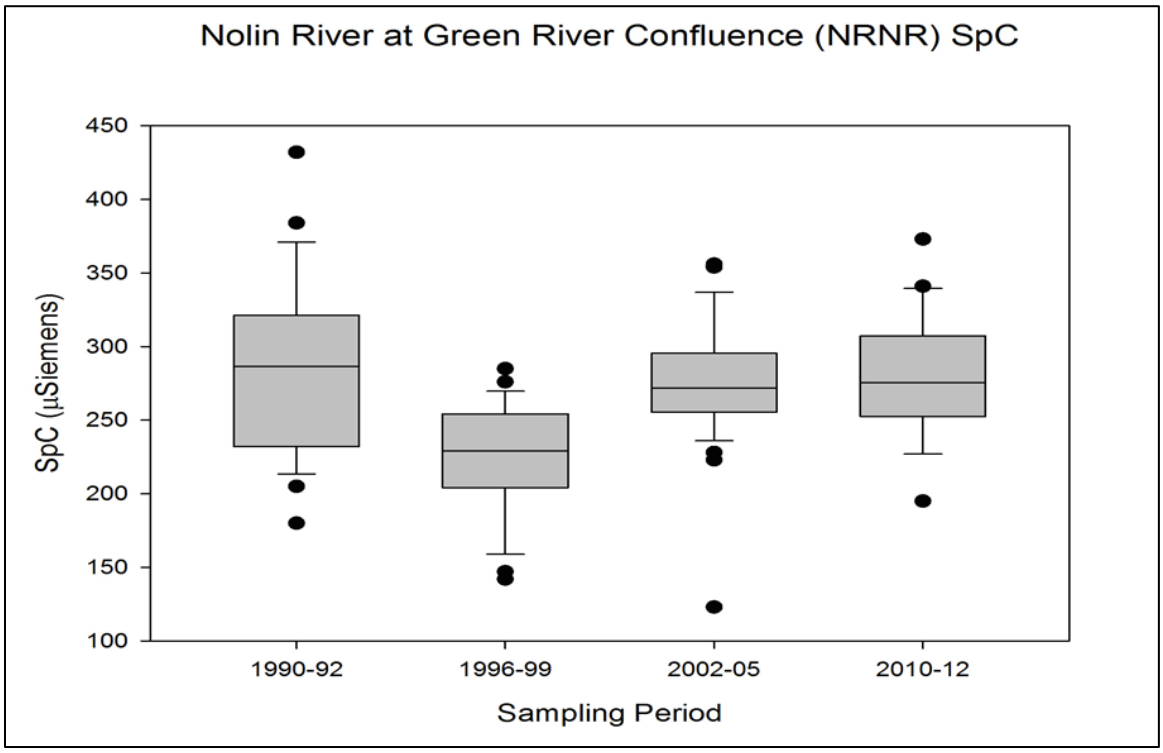


Figure 4.56. Specific Conductivity data for the Nolin River from the 1990–2012 WQMP (Meiman 2006).

North Side Backcountry Streams

There are a number of smaller stream basins that are tributaries to the Green and Nolin that flow across the Pennsylvanian and Mississippian clastic rocks to the north of the Green in the park. Motivated by concern of impacts of human and horse trail use on the water quality and biological integrity on these streams, Johnson (2014) conducted assessments of about 62 kilometers of hiking and horse trails and the resulting impacts on water quality and biota. Johnson monitored temperature, specific conductance, pH, dissolved oxygen, and stream flow at three north side streams including Raymer Hollow, the Upper Wet Prong of Buffalo Creek, and the Lower Wet Prong of Buffalo Creek. Two sites were selected for each stream, one each within 9 m upstream and downstream, respectively from trail crossings, as well three unimpacted control stream sites not in proximity to a trail. In addition to the water quality parameters, the sampling assessed general biological integrity with surveys of benthic macroinvertebrates (BMI) whose population structures can provide insight into stream health. Johnson (2017a) described this process:

BMI were identified to a broad taxonomic level (stonefly, mayfly, caddisfly, etc.) and sorted into three weighted groups or categories 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. A water quality score was calculated for each sample site based on the abundance of individual organisms from the respective Groups. Water quality ratings under this system are then assigned as either "Good," "Fair," or "Poor" based on the water quality score; the higher the score, the higher the water quality.

Results showed that in general all sites sampled, even below trail crossings, scored in the "Good" category (Figure 4.57). However, impacts of the trails were noted both from visual evidence of sedimentation as well as changes in species composition. Mill Creek, for example (Figure 4.58), has had visible sedimentation for at least 30 m downstream from the stream crossing with the Good Springs Trail. The BMI was also negatively affected. With this in mind, MACA has been implementing trail improvements such as gravel and trail hardening, and the section of the Good Springs Trail that had led to the sedimentation shown in Figure 4.58 was closed in 2013. There are plans to revisit that site in the summer of 2018 to evaluate what recovery, if any, there has been since the trail closure (Larry Johnson, MACA Division of S&RM, Resource Management Specialist, June 2018, personal communication).

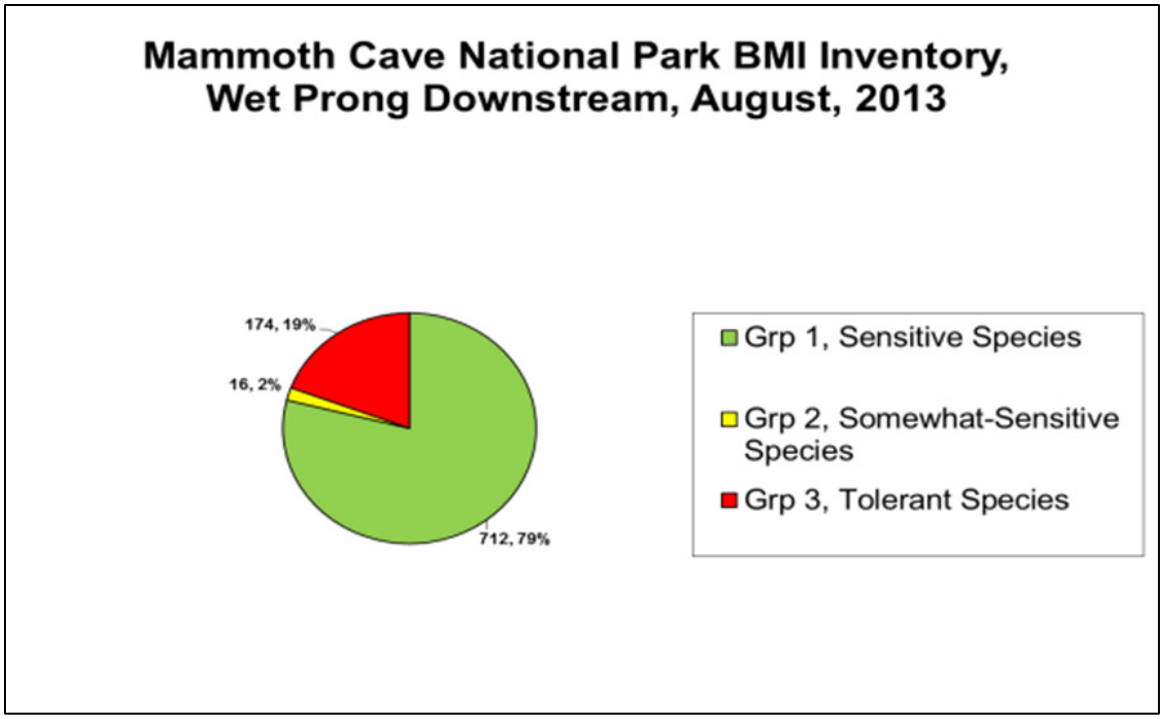


Figure 4.57. Impacts of trail erosion and sedimentation from the trail crossing along Mill Branch. Upstream is shown to the left, and the muddy downstream reach to the right. (Johnson 2014).



Figure 4.58. Impacts of trail erosion and sedimentation from the trail crossing along Mill Branch. Upstream is shown to the left, and the muddy downstream reach to the right. (Johnson 2014).

Level of Confidence and Data Gaps

There is an extensive data set of representative surface and groundwater sites at MACA over many years through the WQMP (Meiman 2006) and so these waters are well characterized (Table 4.23). Confidence in the conclusions is therefore high. It is important for MACA to continue to provide ongoing support for this monitoring program going forward.

Condition Summary

Table 4.23. Graphical summary of status and trends for surface water.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Surface Water	*E. coli,* SO_4, dissolved oxygen, pH and SpC		In general, waters of the park meet their designated uses. While there are continuing stressors to the waters of the park based on agricultural, urban and transportation land use outside of the park. These are in general therefore outside of MACA's ability to influence. The largest single negative impact to the water resources and aquatic ecology of the park, the impoundment from Lock and Dam #6, has been removed and conditions are improving.

Sources of Expertise

Expert information from this section came from scientists with the MACA Division of S&RM and the Cumberland Piedmont I&M network, primarily Joe Meiman, Brice Leech, Rick Toomey and Larry Johnson, along with Mike Hensley of The Nature Conservancy and Mike Turner of the US Army Corps of Engineers.

4.4.3. Groundwater

Groundwater resources at MACA are extensive and important because of the spectacularly developed karst landscape/aquifer system.

Description

The gently dipping limestones of the St. Louis, Ste. Genevieve and Girkin Limestones contain one of the world's great karst aquifer and this dominates the groundwater condition of MACA, especially to the south of the Green River. The cave systems contain large underground rivers that flow for many kilometers, and exploration since MACA was established have shown that the cave, and the contemporary drainage systems, extend far beyond the park boundaries (Figure 4.59). The continuing exploration and survey of the caves system is described below in Appendix C.

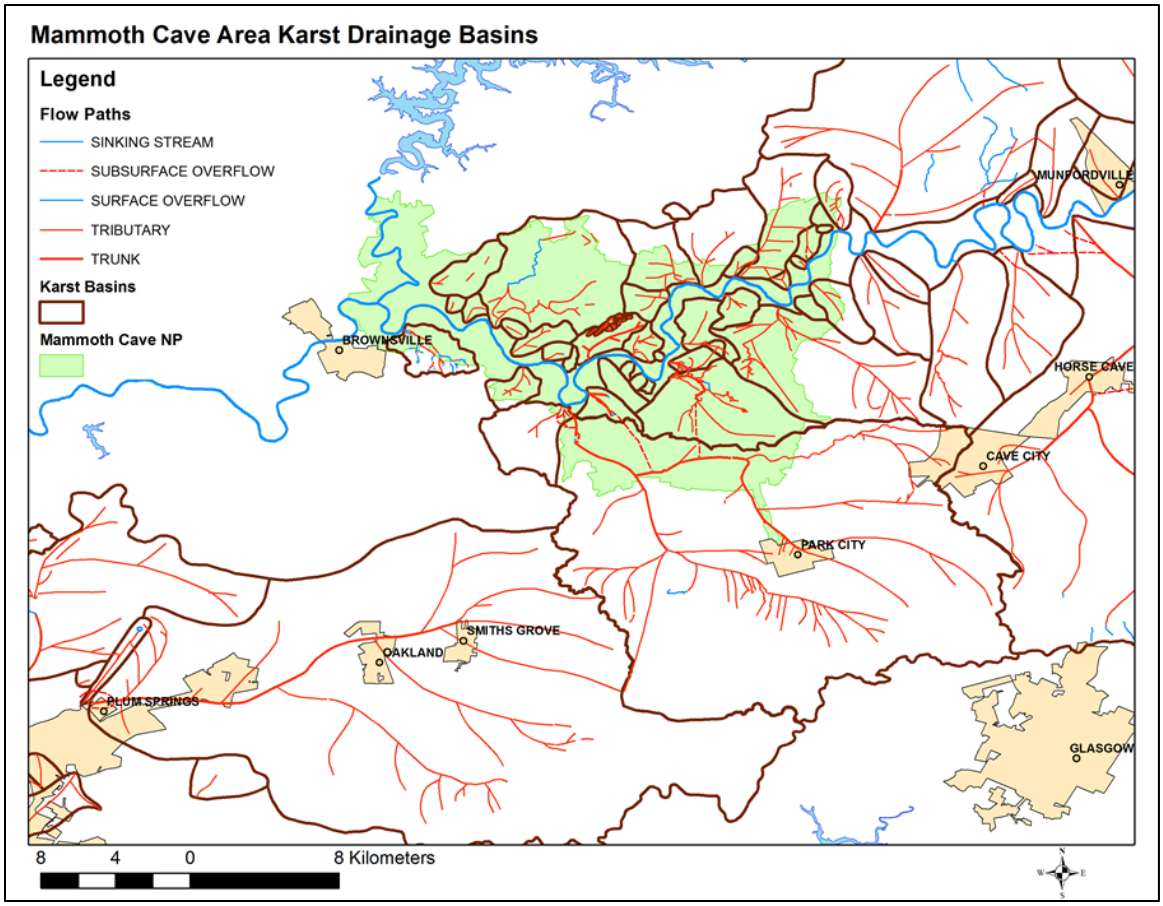


Figure 4.59. Subsurface drainage of the Mammoth Cave region, based on groundwater dye tracing and direct exploration and survey of underground rivers (Ray et al. 1998a, 1998b) and subsequent, unpublished dye tracing complied by Rick Toomey, MACA Division of S&RM.

Data and Methods

Data used in assessing groundwater quality at MACA has come from the park's WQMP established in 1990 (Meiman 2006). Details of the program and the data were described in the section on surface water above.

While the surface basins such as that for the Green and Nolin Rivers can for the most part be determined by examination of topographic maps, groundwater basins draining to the spring and well sites have been determined through extensive dye-tracing work (Quinlan and Ray 1981, 1989; Ryan 1992; Murphy 1992; Meiman and Ryan 1992, 1993; Ryan and Meiman 1996; Hall 1996; Ray et al. 1998a, 1998b; Meiman et al. 2001).

There are two ways that groundwater is sampled within the context of the MACA WQMP, including through directly through wells and at springs where the groundwater emerges back to the surface. Three groundwater basins that are representative of different land use conditions are discussed below, including Turnhole Spring, Echo River Spring, and Big Spring (Figure 4.60).

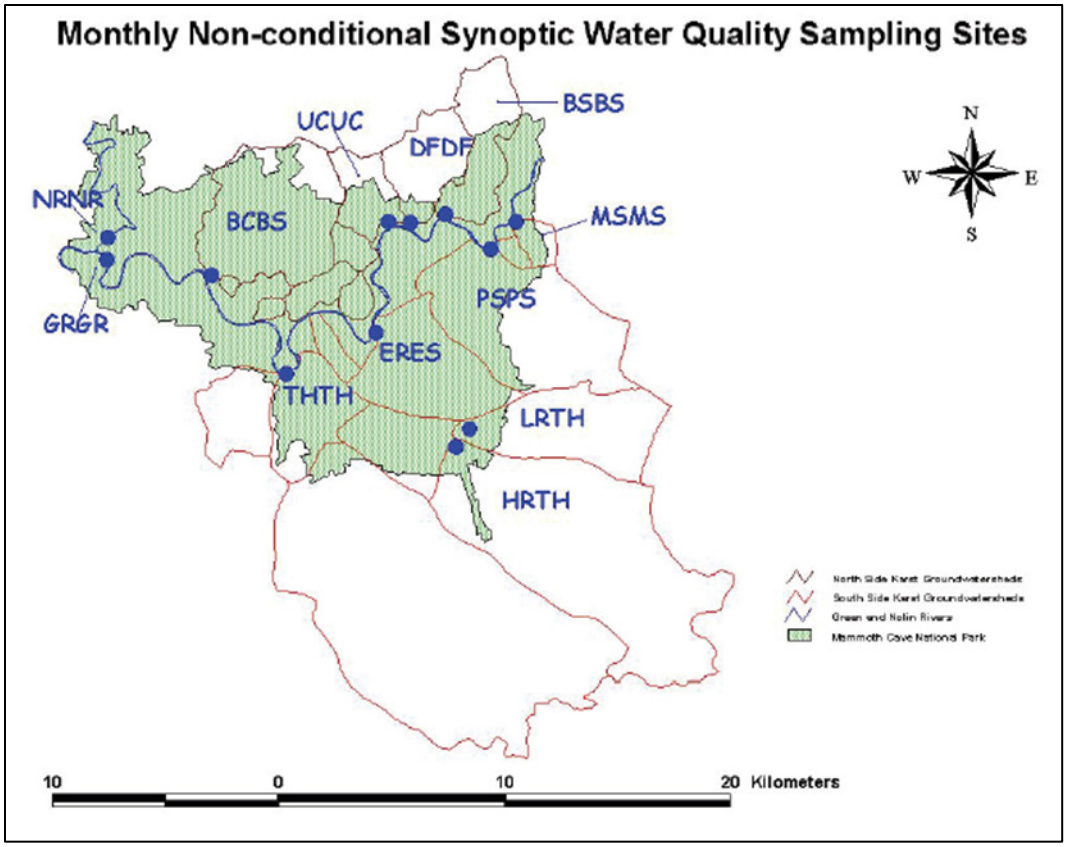


Figure 4.60. Surface and subsurface drainage basins from the Water Quality Monitoring Program (WQMP) (Meiman 2006). Groundwater data from two groundwater basins on the south side or the river, including Turnhole Spring (THTH) and Echo River Spring (ERES), along with Big Spring (BSBS) the north side, are discussed in this assessment.

Reference Conditions/Values

There is an unusual regulatory situation regarding groundwater of MACA. Although the various legally designated uses for water that determine water quality standards have been established for *surface* water, the underground rivers of the park are designated in ways analogous to surface water, indeed under the state's surface water regulations (Kentucky code 401 KAR 10:026. Designation of Surface Waters). MACA's underground rivers are designated by this law as Cold Water Aquatic Habitat, Primary Contact Recreation, Secondary Contact Recreation, and Outstanding State Resource Waters, and can therefore be evaluated with respect to the water quality criteria described by Meiman (2006).

Condition and Trend

The following data show the trends of water quality for the chosen parameters of E. coli, nitrate, dissolved oxygen (DO), Specific Conductance (SpC), and pH using WQMP data to characterize conditions for groundwater data including Echo River Spring, Turnhole Spring, and Big Spring.

Turnhole Spring

With a drainage area of 259 km^2, Turnhole Spring is the state's third largest spring. Much of this area is (223 km^2) outside of the park. Meiman (2006) described detailed land use for seven sub-regions of the Turnhole Spring Basin, with inputs from agricultural, forest, transportation, urban, and park lands, as well as some oil and gas production.

Water quality results from Turnhole Spring are shown in Figures 4.61–4.65 In general the quality signature resembles the surface water of the Green more than might be expected for groundwater if it was not considered that karst groundwater is very highly vulnerable to contamination from land use. Fecal bacteria are the most pervasive contaminant. The higher concentrations of *E. coli* (Figure 4.61, data shown only since 2005 after *E. coli* was measured rather than fecal coliform) through time do not necessarily represent a worsening trend through time, because these concentrations are highly flow dependent. Bacteria from human and animal waste is flushed through during storms, and so the data can be skewed from one or a few storm pulses that coincide with a sampling event. In contrast to the other constituents, fecal bacteria *concentrations* can increase by more than 100 times (Meiman 2006). When this is combined with the increased discharge to determine the *loading* (the total quantity of a contaminant leaving the basin per unit of time as the product of concentration times the discharge), the increase can be astronomical. Hall (1995) for example found within the Cave City subbasin of the Turnhole Spring basin that a storm pulse caused the bacteria loading in to rise from near zero to about 200,000,000 bacteria colonies per second.

Nitrate, also from agriculture, is a problem as well with a number of samples exceeding the water standard for both Cold and Warm Aquatic Habitats of 10 mg/L (Figure 4.62). As in both the Green River and Nolin Rivers, there is a similar disturbing trend of increasing nitrate concentrations between the 1996–99 and 2010–12 sampling campaigns. With a few exceptions, the waters are well oxygenated (Figure 4.63) and both pH (Figure 4.64) and SpC (Figure 4.65) are well within the range that should be expected for waters within a well-developed carbonate rock aquifer.

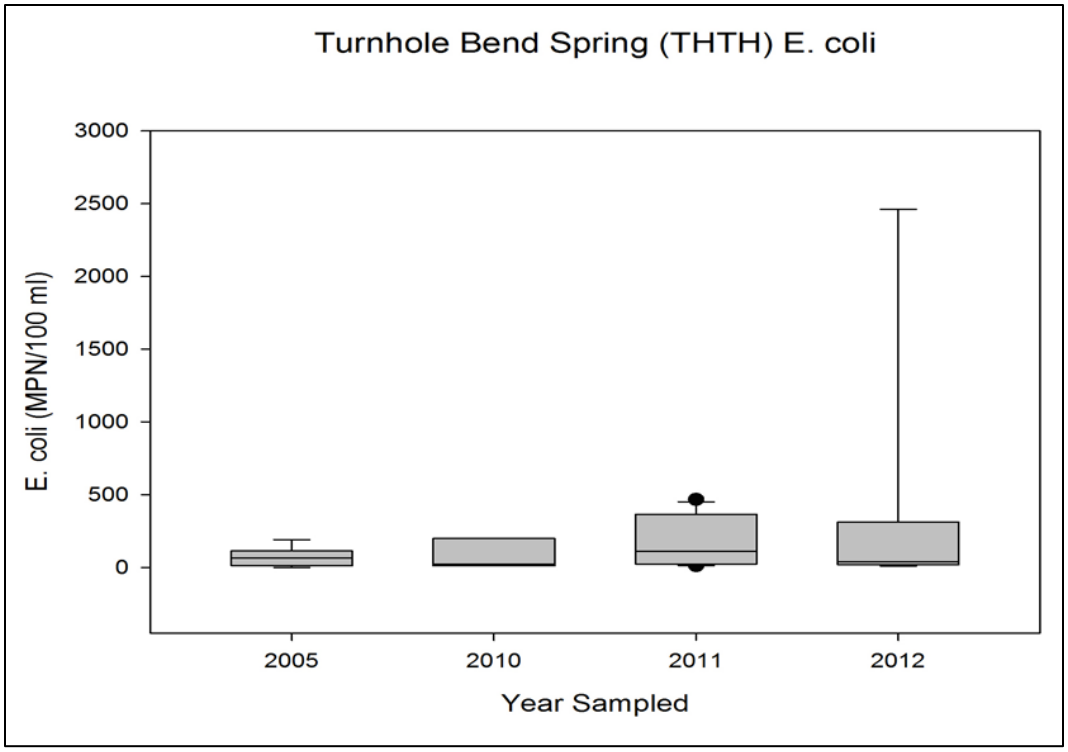


Figure 4.61. *E. coli* data for Turnhole Spring from the WQMP, 2005–2012 (Meiman 2006).

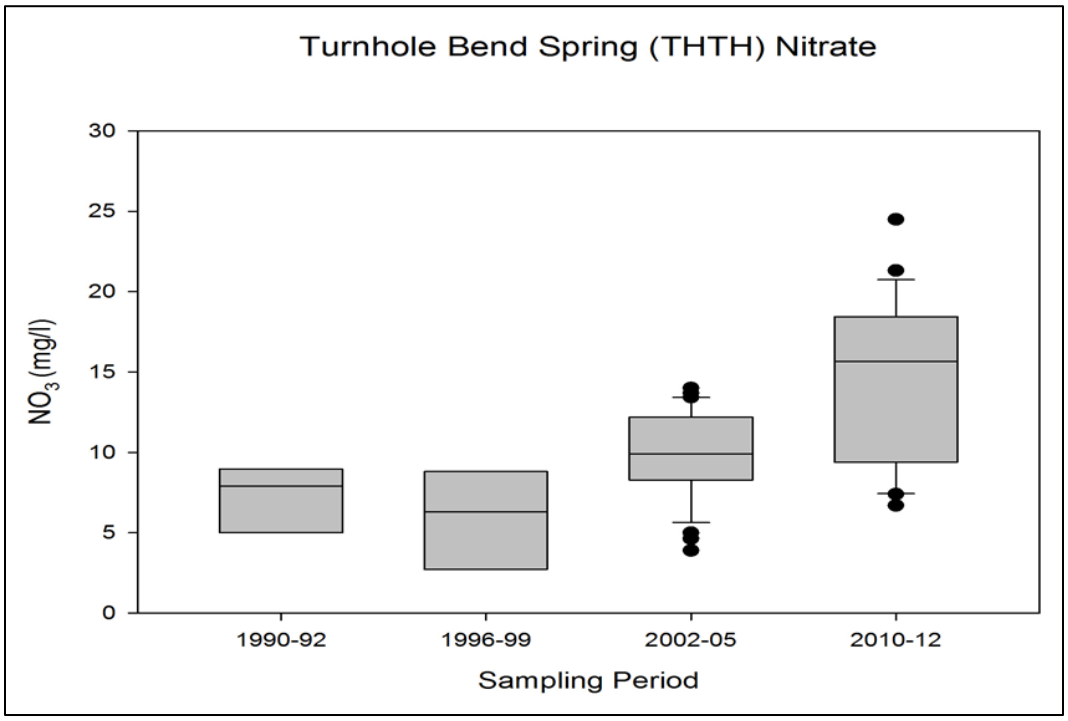


Figure 4.62. Dissolved nitrate concentrations for Turnhole Spring from the 1990–2012 WQMP (Meiman 2006).

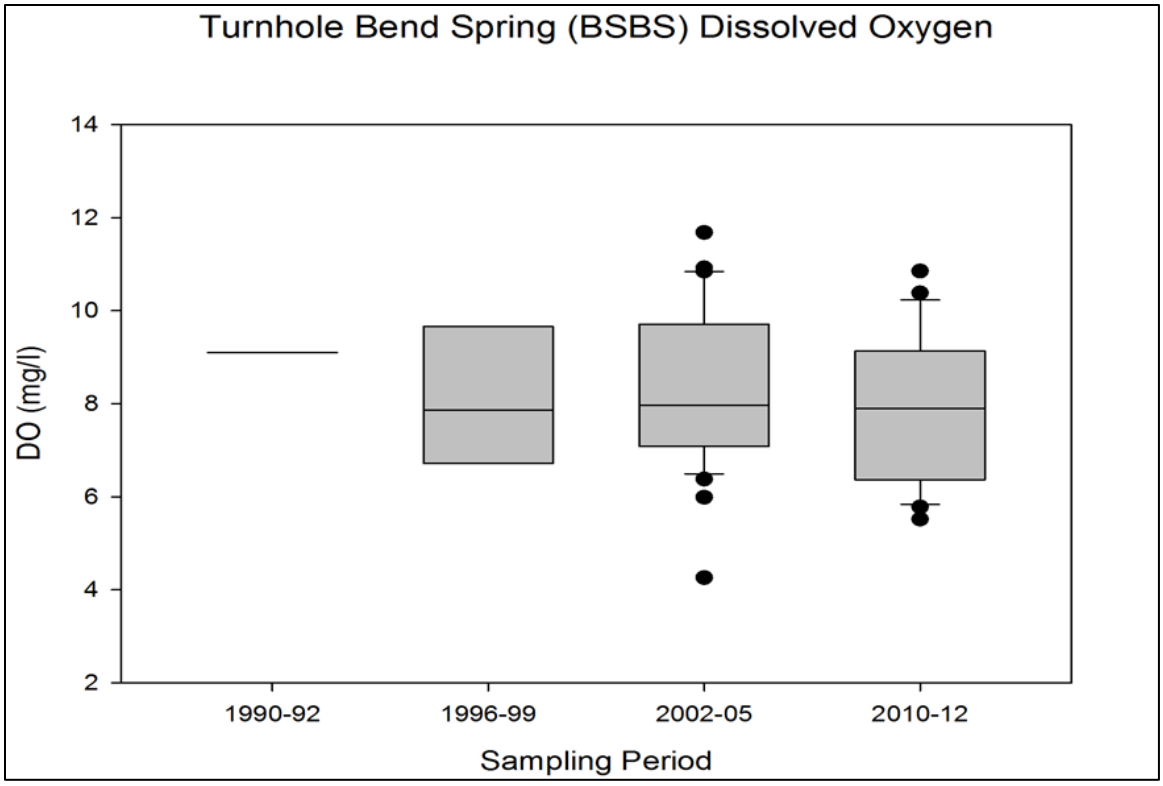


Figure 4.63. Dissolved O2 concentrations for Turnhole Spring from the 1990–2012 WQMP (Meiman 2006).

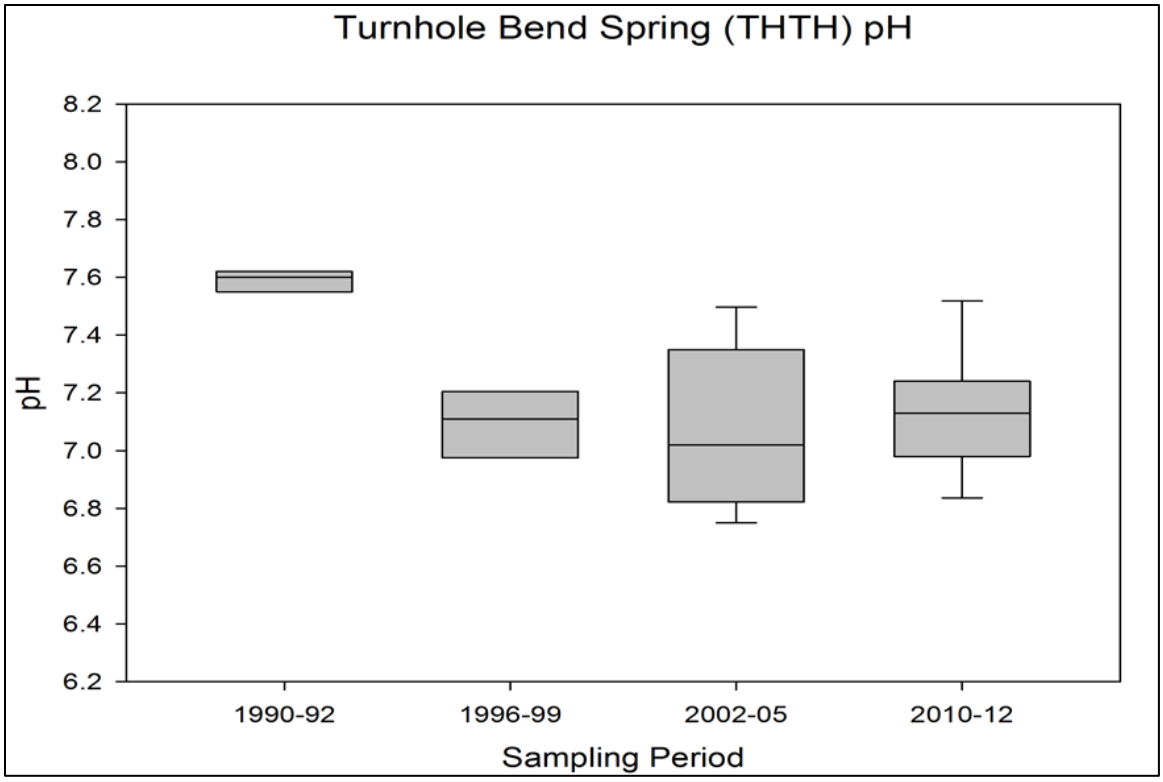


Figure 4.64. pH data for Turnhole Spring from the 1990–2012 WQMP (Meiman 2006).

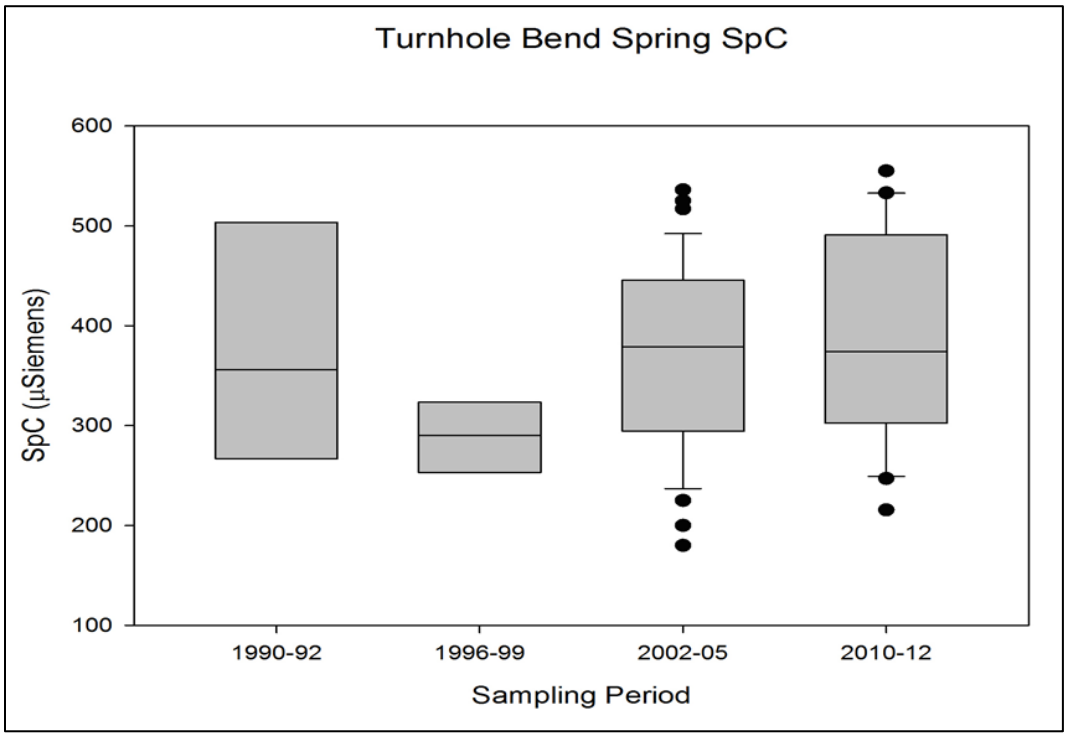


Figure 4.65. Specific Conductivity data for Turnhole Spring from the 1990–2012 WQMP (Meiman 2006).

Echo River Spring

Under most conditions Echo River Spring drains an area of 9 mi^2 (Meiman 2006; Ray et al. 1998a), which is wholly contained with forested land of the park. Except a very small area of pasture in the upstream end of the basin, the park administrative infrastructure, including the MACA Visitor Center, is the only developed area within the basin, covering less than 1% of its area. Water quality would be expected under these conditions to be relatively good (Figures 4.66–4.70). During higher flows, however, contaminated water spills through one or more normally dry conduits from the much larger Turnhole Basin into the Echo River Basin with a concomitant decrease in water quality as impacted by agricultural land use outside of the park as described above. With respect to the agricultural inputs of *E. coli* (Figure 4.66) and nitrate (Figure 4.67) are both better than Turnhole, reflecting the fact that the occasional but high-impact inputs from the Turnhole Spring Basin skew the data upward. Note the difference in y-axis scaling between the Turnhole (Figure 4.61) and Echo River Spring (Figure 4.66) *E. coli* graphs.

Dissolved oxygen (Figure 4.68), pH (Figure 4.69) and SpC (Figure 4.70) are all within the ranges of appropriate water quality standards.

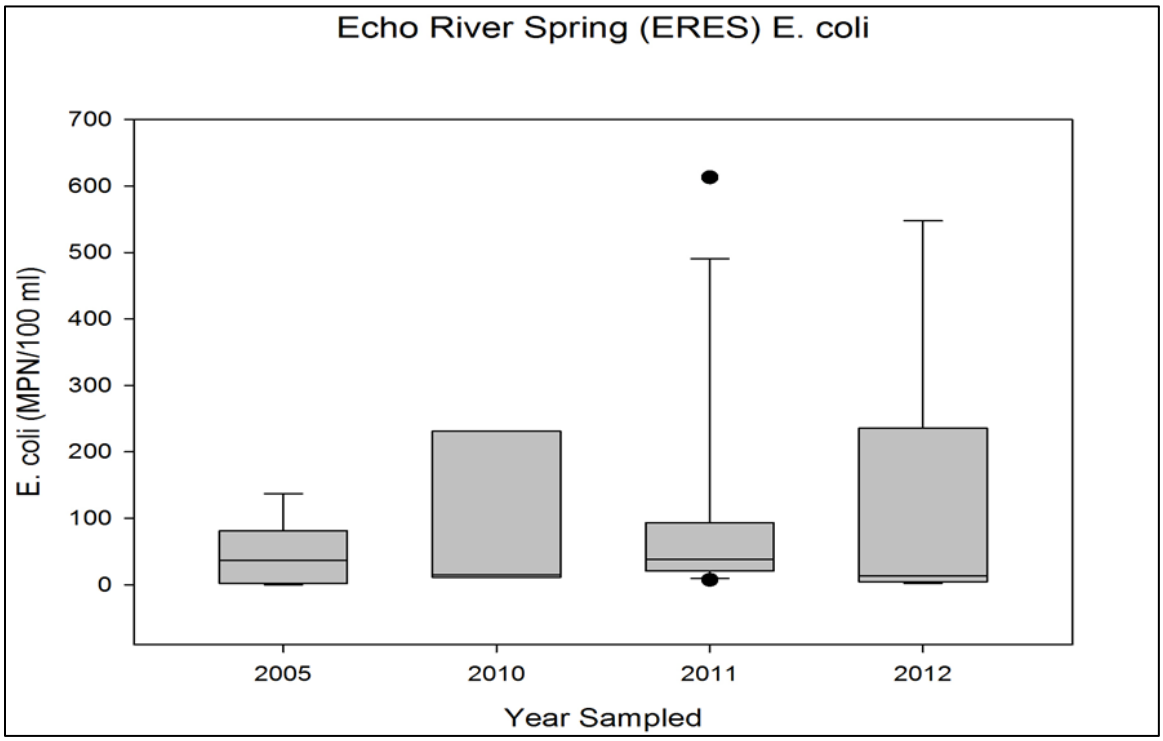


Figure 4.66. *E. coli* data for Echo River Spring from the WQMP, 2005–2012 (Meiman 2006).

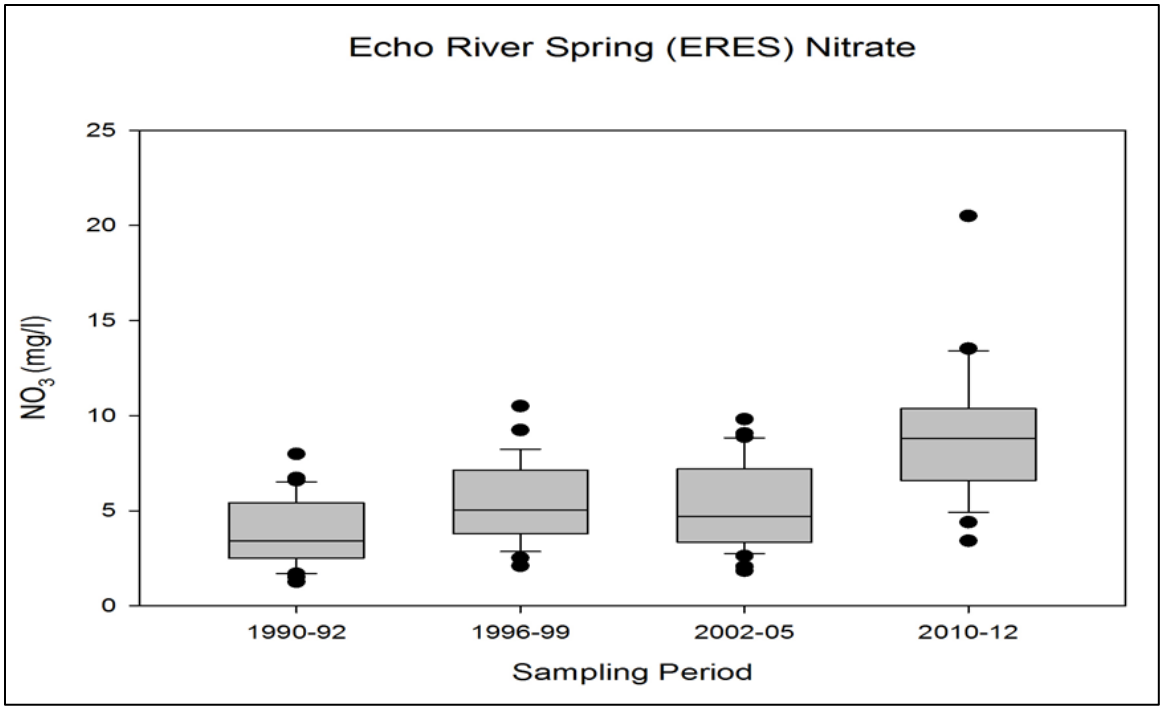


Figure 4.67. Dissolved NO3 concentrations for Echo River Spring from the 1990–2012 WQMP (Meiman 2006).

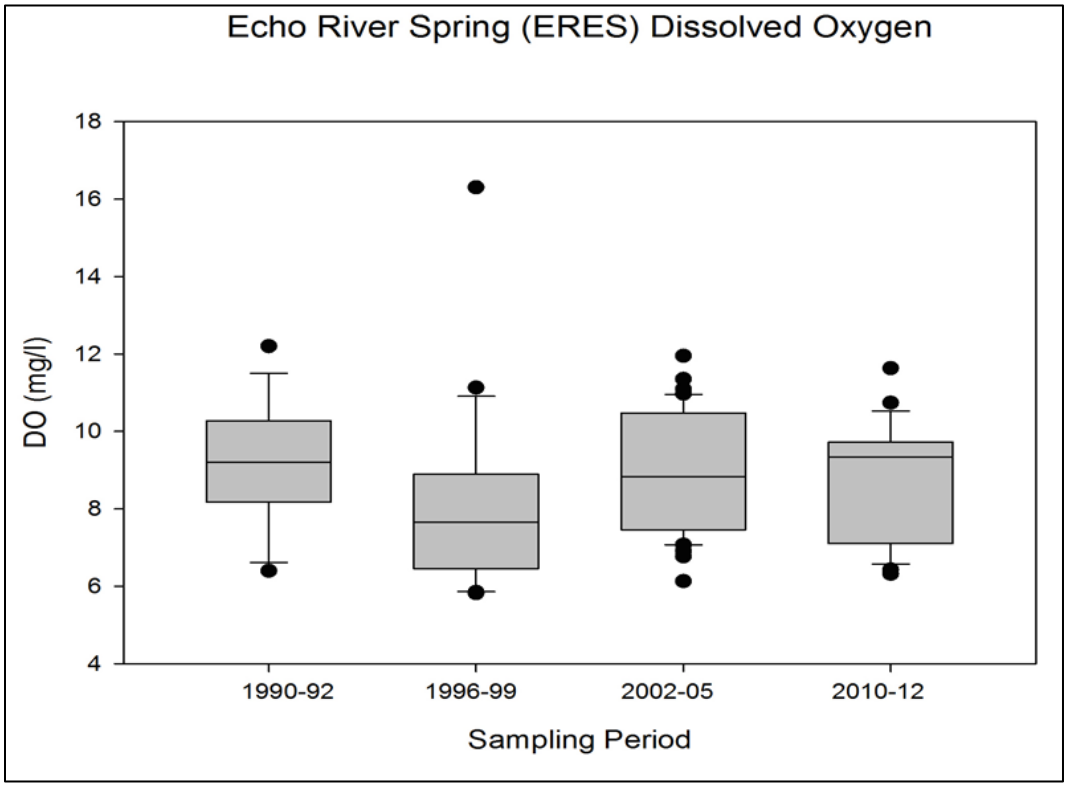


Figure 4.68. Dissolved O2 concentrations for Echo River Spring from the 1990–2012 WQMP (Meiman 2006).

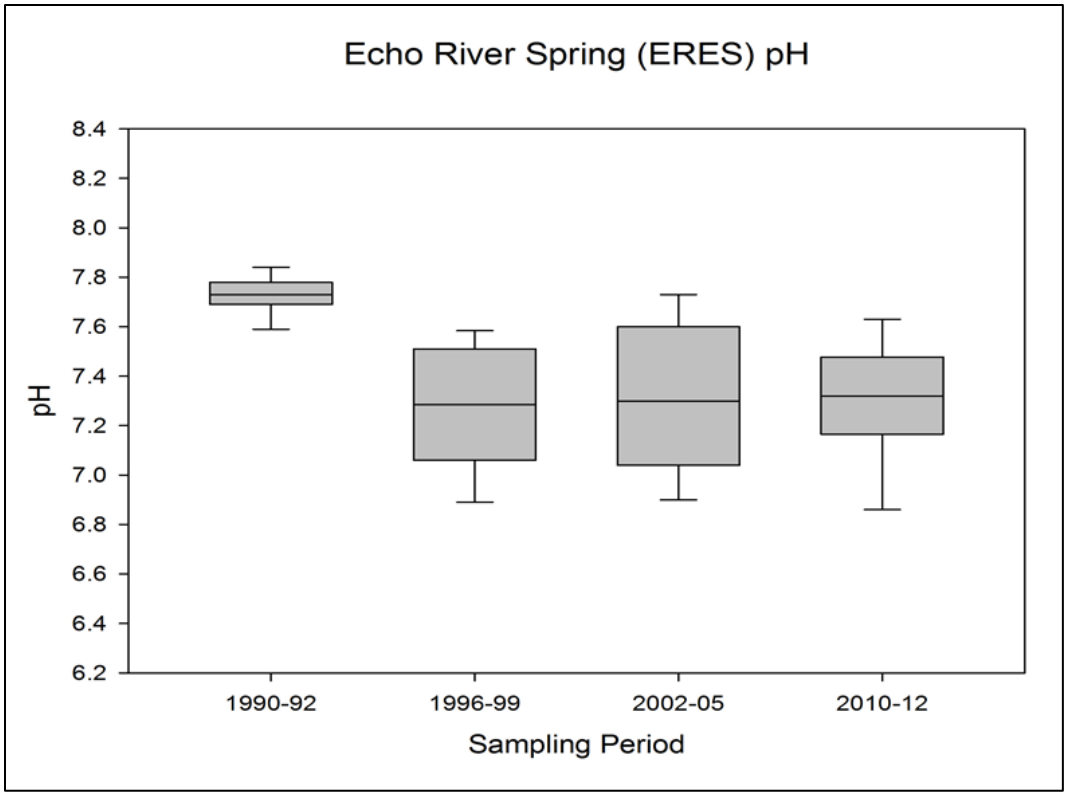


Figure 4.69. pH data for Echo River Spring from the 1990–2012 WQMP (Meiman 2006).

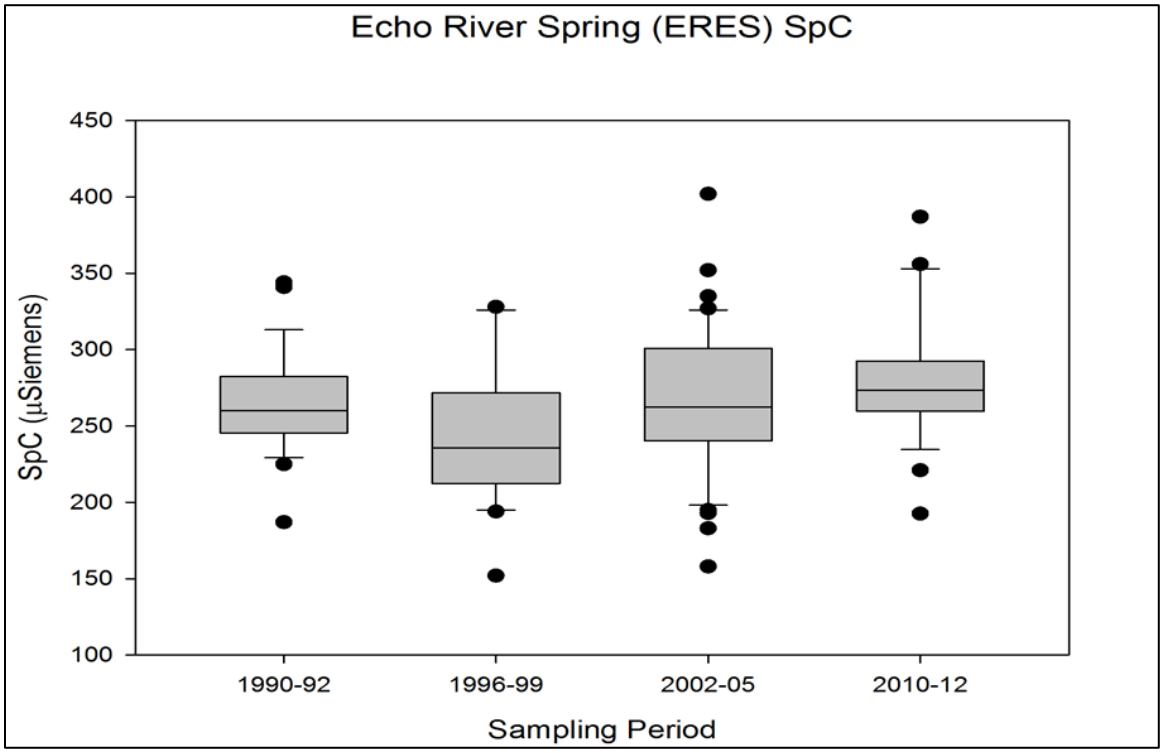


Figure 4.70. Specific conductivity data for Echo River Spring from the 1990–2012 WQMP (Meiman 2006).

Big Spring

Big Spring flows into the Green River from its north side and represents land use typical of the northern, more remote part of the park. About half of the 6 km^2 basin lies within the protected, forested area of the park, and that outside of the park is also mostly forested, with only about 240 hectares of light residential (Meiman 2006). The Big Spring drainage includes the Big Woods, a 100 hectare tract of old growth forest.

Ryan and Meiman (1996) undertook what was at the time a pioneering study at Big Spring in the use of electronic data logging to quantify storm-based changes in flow and water quality. They showed that concentrations of two nonpoint source pollutants, fecal coliform bacteria and suspended sediment, greatly exceeded prerunoff event values for very short periods of time. A phreatic conduit segment, calculated at 17 million liters in volume, instantaneously propagated head changes, caused by direct runoff entering the aquifer, from the ground-water inputs to Big Spring. A significant delay between the initial increases in discharge and the arrival of direct runoff, as indicated by a steady decrease in specific conductance, represented the time required to displace this volume of phreatic water. The delay showed that sampling a karst spring only during peak discharge would be an unreliable sampling method.

Runoff from two different subcatchments was tagged with tracer dye and the timing of the passage of the resultant dye clouds through Big Spring were compared to water quality variations.

Data from Big Spring (Figures 4.71–4.75) show that the water quality reflects the lower impact of human land use and closer represent background water quality that would be expected within more remote parts of MACA. Except for elevated *E. coli* (Figure 4.71) all parameters, including nitrate (Figure 4.72) are within the established criteria for both Warm and Cold Water Habitat.

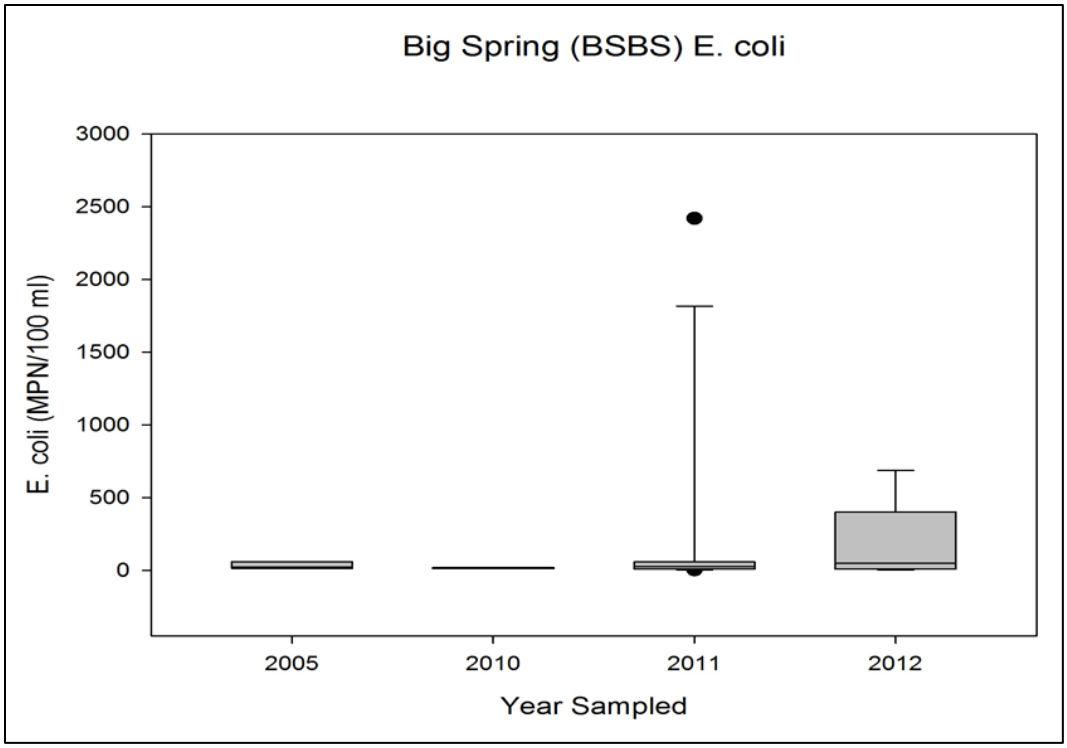


Figure 4.71 ***E. coli*** data for Big Spring from the WQMP, 2005–2012 (Meiman 2006).

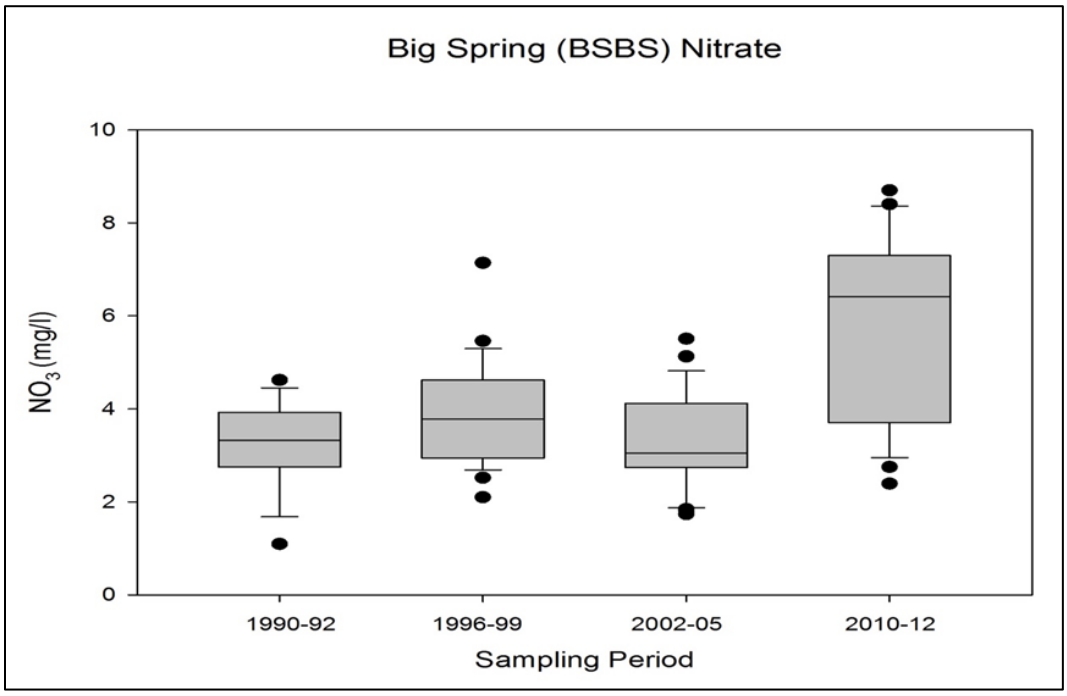


Figure 4.72. Dissolved nitrate concentrations for Big Spring from the 2002–2012 WQMP (Meiman 2006).

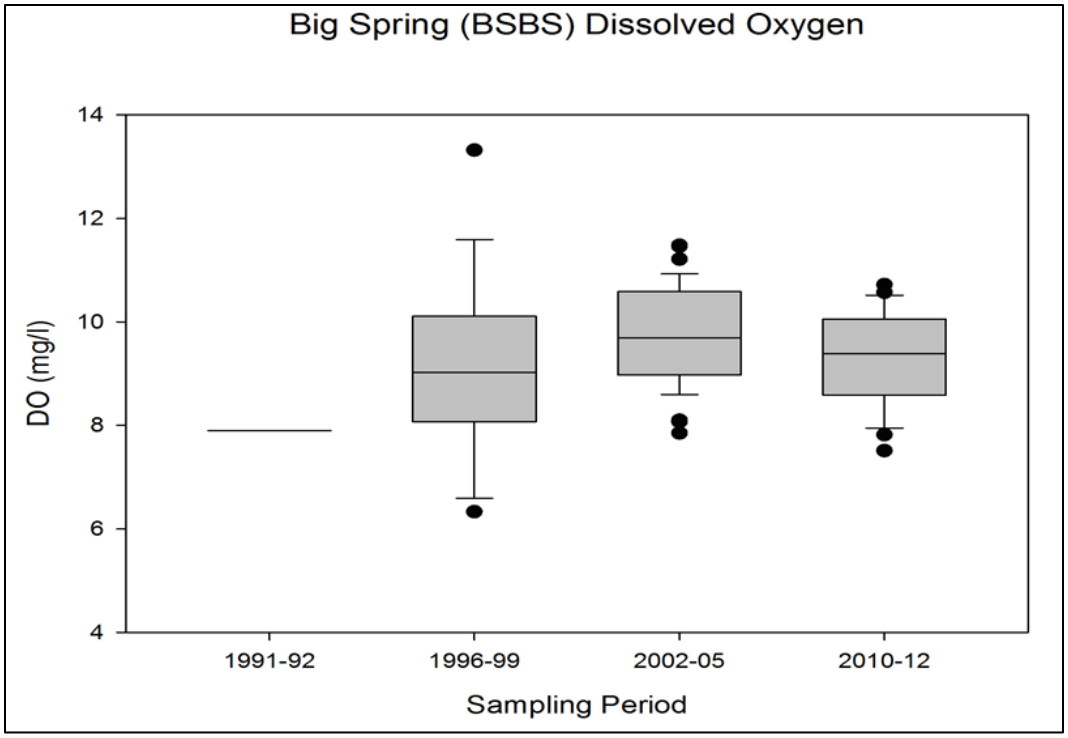


Figure 4.73. Dissolved O2 concentrations for Big Spring from the 1990–2012 WQMP (Meiman 2006).

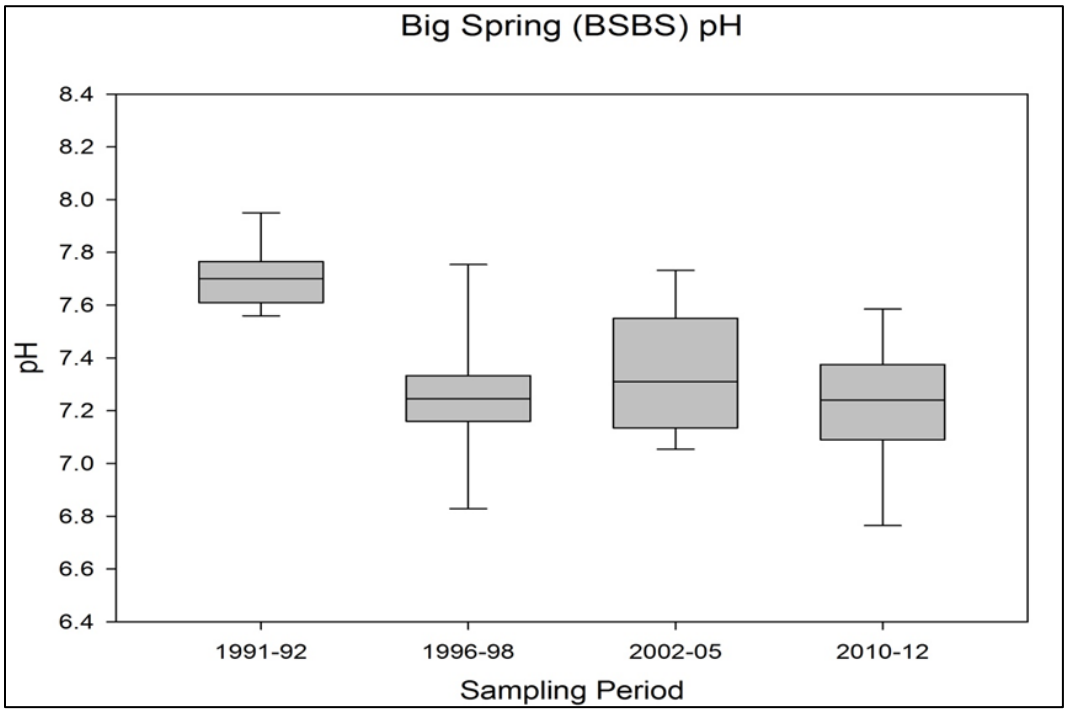


Figure 4.74. pH data for Big Spring from the 1990–2012 WQMP (Meiman 2006).

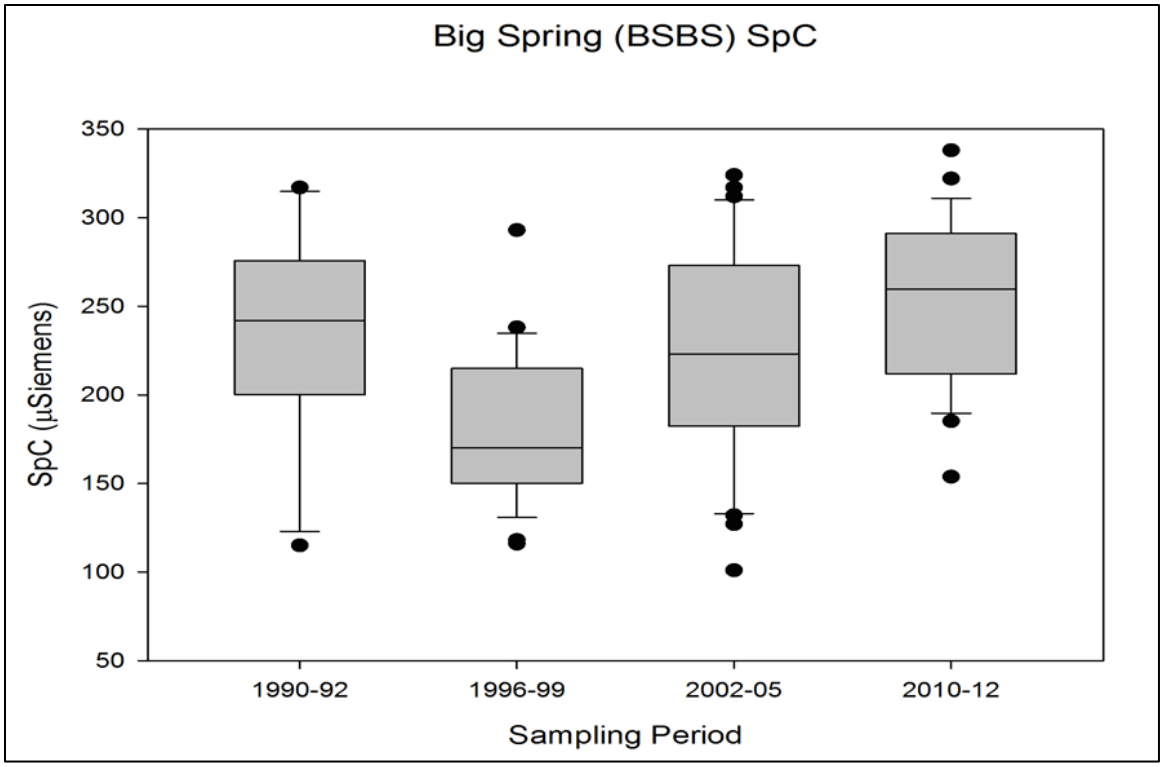


Figure 4.75. Specific Conductance data for Big Spring from the 1990–2012 WQMP (Meiman 2006).

Level of Confidence and Data Gaps

There is an extensive data set of representative surface and groundwater sites at MACA over many years through the WQMP (Meiman 2006) and so these waters are well characterized (Table 4.24). Confidence in the conclusions is therefore high. It is important for MACA to continue to provide ongoing support for this monitoring program going forward.

Condition Summary

Table 4.24. Graphical summary of status and trends for precipitation.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Groundwater	*E. coli,* pH, SO_4, and SpC		The underground river system with and around MACA has been designated according to surface water criteria, as Warm and Cold Water Habitat as well as State Outstanding Resource Waters. There is some chronic impact from agriculture and other land use. Acute problems have occurred with accident on I65 and the CSX railroad.

Sources of Expertise

Joe Meiman (CUPN hydrologist) provided expertise for this section.

4.5. Human Use

Humans have been attracted to the caves and other features of MACA for at least 11,000 years and have visited the deep cave environment for at least 4,500 years. Each year some 500,000 continue to visit the park. Like in any national park, in spite of the fact that extraordinary caution is taken to protect the resources that attract these visitors, there is some impact. Toomey (2009) noted that "Direct impacts of cavers and tourists are the most important manageable source of loss and damage of cave resources." There are, in general, four classes of people that interact with the resources of the park, particularly caves: 1) tourists, 2) scientists, 3) cave explorers, and 4) park staff and contractors. Activities of the last three groups are not considered here to be a threat to park resources, as in general these are trained and conscientious individuals working with close coordination with the park. However, even these groups cause some impact. There is, in contrast, a wide range of park visitors for tourism who may have more or less respect and appreciation for the need to preserve and protect sensitive resources, and for this reason it is necessary to control access and monitor the activities of this group.

This chapter analyses a set of human impacts on the park's resources, through evaluation to the following indicators:

- 4.5.1 Graffiti,
- 4.5.2 Entrance modifications,
- 4.5.3 Passage modifications,
- 4.5.4 Roadwork,
- 4.5.5 Tourism development
- 4.5.6 Surface Trail Conditions

4.5.1. Graffiti

Even with the protection of gates and closely monitored tour groups, vandalism through writing of graffiti on cave walls takes place on occasion. This can be a potentially serious threat as there are in places historically or archeologically significant areas on the walls of the active tour paths than can be irreparably damaged.

Description

The scratching of names, messages, or art on walls or other public spaces known as graffiti (in the plural with a single mark being a graffito), appears to stem from some deep urge of human nature to be remembered. In 78 B.C. a message translated as "Gaius Pumidiuos Diphilus was here" was scribbled on a wall in ancient Pompeii (Lafrance 2016). While it is not clear whether any of the ancient native American drawings on the walls of MACA and other area caves were made for the same motivation as a record for posterity, European names and dates started appearing on the walls of Mammoth Cave at least as far back as 1804 (Dr. Stan Sides, Cave Research Foundation, Past President, July 2008, personal communication). For many years, it was a common practice for cave guides to write the names of cave visitors on the walls and ceilings of Mammoth Cave (Figure 4.76), although these days guides at MACA sometimes remind tourists who see such adornments that

names on the walls made before the park was established in 1941 are called “historical signatures,” while that which is more recent is called a “federal offense.”

There has been considerable interest in studying the signatures on the walls of Mammoth Cave as a record of history of the cave. Names of the explorers who were the first to discover passages document the evolution of the known cave (Figure 4.77). One of those was Max Kaemper, a German engineer who with his guide Ed Bishop (see Chapter 2) made a great map of the cave in 1908 and then left the area. Although this was the most complete and important map of the cave for many years, Kaemper remained a mystery for many years until research into many place names on his map were matched to signatures in the cave of his and his companions (Decroix and Olson 2008, Decroix 2008). This provided a number of clues that through a long search on two continents led to Kaemper’s family and a detailed picture of his life including his time at the cave (Kliebhan and Thomas 2008).

The practice became illegal in 1941, and the most relevant issue for this analysis is whether ongoing visitor vandalism, particularly the writing of graffiti, is a significant threat to resources at MACA.



Figure 4.76. Hundreds of signatures, from the 1800s, cover the ceiling of Gothic Avenue in the Historic section of Mammoth Cave. The practice is now illegal (photo by Chris Groves).

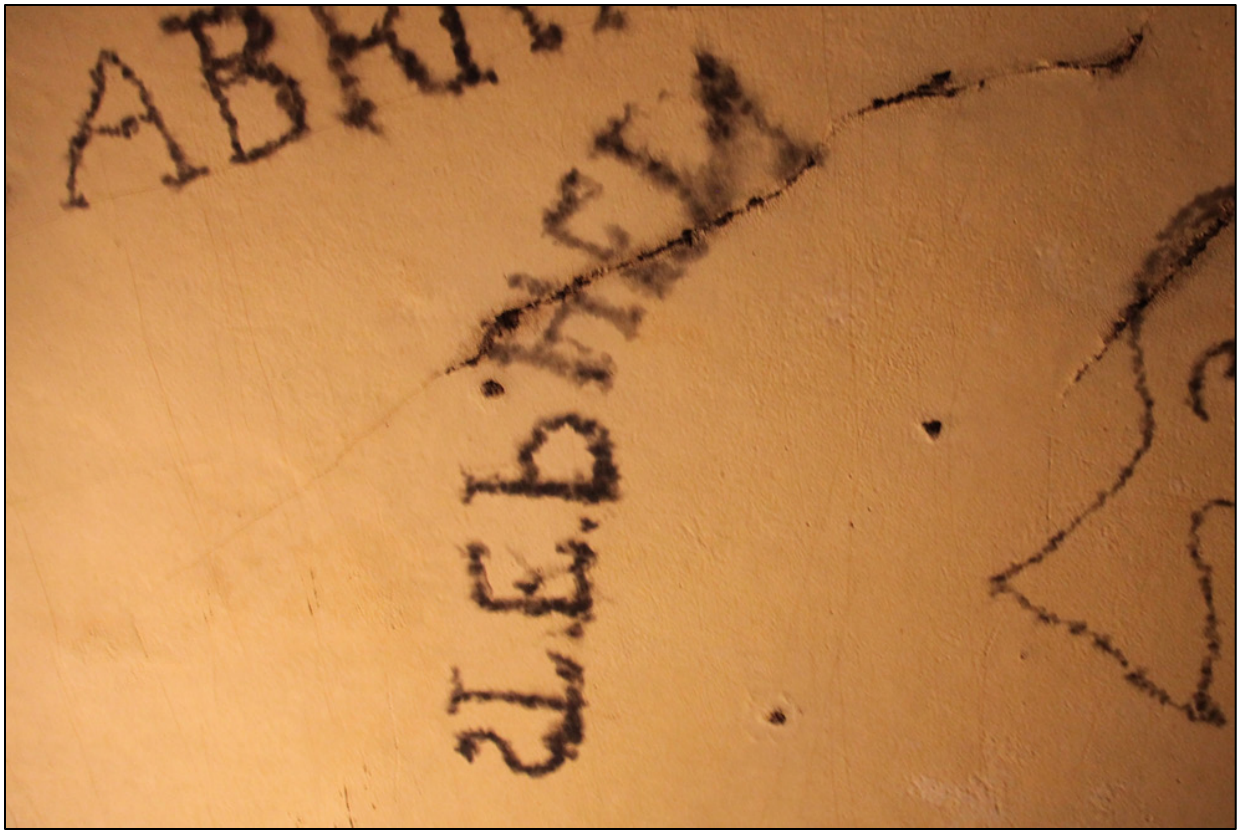


Figure 4.77. The exploration of Mammoth Cave is documented by the signatures of its early explorers, in this case Stephen Bishop's signature (see Chapter 2) on the ceiling of Gothic Avenue in Mammoth Cave, perhaps made in the 1830s. The letters (actually written backwards) are about 20 cm high (photo by Chris Groves).

Data and Methods

While there have been inventories and study of historic graffiti in the caves of MACA, we are not aware of any database of more recent graffiti that would qualify as vandalism. We have interviewed MACA staff from the S&RM, Interpretive and Law Enforcement Divisions about experiences with graffiti and the outlook of this as an ongoing resource threat.

Reference Conditions/Values

There are not standardized reference conditions for graffiti. In evaluating and appropriate level of concern we use professional judgement based on discussions with park staff. One complexity that becomes apparent in the early drafts of the Cave Management Plan currently under development at MACA is that that there are a variety of definitions in the various statutes that require careful interpretation of how existing graffiti is treated. Depending on age and context, existing graffiti can be of historical or archeological interest and/or significance and so decisions on how treating (removing or not, for example) can be complex.

Condition and Trend

Park staff report that graffiti is placed on tour cave walls (Figure 4.78), and occasionally the perpetrators are caught and cited (Larry Johnson, MACA Division of S&RM). MACA Chief Ranger Lora Peppers indicated that typically about two people are cited in a year, although some may be reported to S&RM rather than to Law Enforcement. There is not an increasing or decreasing trend (Table 4.25). While toured caves of the park are well protected by visitor management this is considered a resource threat not just because of the aesthetics of the cave walls, but that existing images or writing that could be of historic or archeological significance could be damaged. Management of graffiti is being addressed in MACA's draft Cave Management Plan.



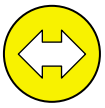
Figure 4.78. Recent graffiti is reported by cave guides typically several times per year. Scientists from MACA's S&RM Division are developing restoration procedures (photo by Chris Groves).

Level of Confidence and Data Gaps

These conclusions are based on discussions with MACA staff from several division based on their direct experience. However, the park has no systematic incident recording policy or database to track graffiti, and so there is only moderate confidence.

Condition Summary

Table 4.25. Graphical summary of status and trends for resource impacts from graffiti.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Graffiti	Presence and new occurrences		New graffiti is occasionally made on the walls of MACA's caves and visitors are sometimes cited and fined. It is not frequent, but damage to historic or archeological resources could be significant.

Sources of Expertise

Larry Johnson of MACA's S&RM Division, Charlie Henion of the Division of Interpretation and Visitor Services, and Lora Peppers from the Law Enforcement Division provide information for this section.

4.5.2. Entrance Modifications

Description

Although a program to place airlocks on the artificial entrances of MACA entrances to Mammoth Cave was completed in the 1990s which has ameliorated non-natural airflow and other impacts from past entrance modifications, there are still several artificial openings to the cave on which there are no airlocks. Other artificial entrances to the Mammoth Cave System include the Colossal Cave and Donkey Cave. The Visitor Center ventilation shaft (see section 4.1) that enters the cave on the north side of Houchen's Narrows near the Historic Entrance has modified water input into that portion of the cave and occasionally changes airflow during its use. There are also a number of small diameter, open boreholes that have been drilled into the cave for various purposes including for water pipes or electric cables. Each of these artificial entrances influences the flow of air, and in some cases water, into the cave. Echo River spring, a flooded cave entrance passage on Mammoth Cave Ridge, has been altered by gravel that has washed in from and old road, and work is underway to clean his out. There are indeed concerns regarding these modifications in some parts of the cave, discussed in the Condition and Trend section below. While these do in places impact the resource, the effects are relatively localized where they occur.

Data and Methods

This is based on discussions with MACA staff from the S&RM, Interpretation and Visitor Services, and Maintenance Divisions.

Reference Conditions/Values

There are no established reference conditions for this indicator so we gage concern on the probability of the potential of negative impacts to resources from ongoing or future entrance modification.

Condition and Trend

A significant entrance that is currently experiencing modifications is the ventilation shaft that enters the cave on the north side of Houchen's Narrows. This artificial passage has been opened at various

times in recent years to facilitate the lowering of equipment and supplies during cave trail renovations. When open, this allows the movement of both air (from the surface) and water (from a higher passage or bedding plane down the level of Houchens Narrows) into the cave and presumably impacts the dynamics of airflow from the Historic Entrance. There is a concrete slab that covers the entrance when not in use. During use the slab is removed during the day and placed back over at night, and between projects it is covered with about two meters of dirt. Is serves as an effective airlock when covered, and as it is open relatively infrequently, overall impact from airflow is low (Table 4.26). Water flow that occurs as a result of shaft construction has caused saturation of soils around buried saltpeter pipes in Houchen's Narrows with increased deterioration of those pipes.

Other impacted areas include Cleaveland Avenue there is an old electrical drop boring that is allowing water in that is leading to dissolution of gypsum locally, and there is some leaking at the Mt McKinley utility drop that is putting water into the cave in an area where it is not naturally found. The same can be said of the Grand Central Station utility drop.

Level of Confidence and Data Gaps

This information comes from direct experience of MACA staff and we have high confidence.

Condition Summary

Table 4.26. Graphical summary of status and trends for impacts from entrance modifications.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Entrance Modifications	Ongoing impacts		There is moderate concern about impacts to both cultural and biological resources in the vicinity of the Historic Entrance, which has been modified from its original configuration, as well as water flow from the ventilation shaft. There is also concern about localized impacts from several holes in several areas of the cave, though no new holes are planned and no existing holes are being enlarged, so the situation is stable.

Sources of Expertise

Chuck Decroix of the MACA Interpretive Division, Rick Toomey of the Division of S&RM, and Steve Kovar of the Maintenance Division provided information for this section.

4.5.3. Passage Modifications

There either plans or discussion about trail modifications or upgrades in several areas of Mammoth and other park caves. MACA staff and its contractors have extensive experience in recent years in such work, however contractors have been responsible for cave damage, and so their work should be carefully monitored.

Description

There have been many passage modifications within the Mammoth Cave System, including early

saltpeter mining operations and development of electrically lit pathways for tourists. Toomey (2009) presented a comprehensive analysis of monitoring methods for evaluating cave and karst resources to support planning and protection, and noted that visitor impacts to cave passages can come from development and expansion of cave tour paths, breakage of cave formations (discussed in Section 4.1.3), wear from traffic, and graffiti (Section 4.5.1). A major refurbishment of the Historic Tour was implemented over several years and completed in 2016.

Data and Methods

These conclusions are based on discussions with MACA staff from the S&RM and Maintenance Divisions, as well as documentation concerning the planned trail restoration between Grand Central Station and the Snowball Room.

Reference Conditions/Values

There are no established reference conditions for this indicator so we gage concern on the probability of the potential for negative impacts to resources from ongoing or future passage modification.

Condition and Trend

There either plans or discussion about trail modifications or upgrades in several areas of Mammoth and other MACA caves (Table 4.27). This includes passage modifications in a trail refurbishment project that will run from Grand Central Station to the Snowball Room, as well as other parts of the toured area of the Mammoth Cave. There is also active discussion about trail upgrades in Wondering Woods Cave, Crystal Cave, and possibly Colossal Cave. MACA and its contractors have extensive experience in recent years in such work, however contractors have been responsible for cave damage, and so their work should be carefully monitored.

Level of Confidence and Data Gaps

This is a simple section and we have high confidence in this interpretation.

Condition Summary

Table 4.27. Graphical summary of status and trends for impacts from passage modifications.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Passage Modifications	Ongoing impacts		MACA and contractors have resources and experience to make the planned passage modifications in a way that should not threaten cave resources.

Sources of Expertise

Rick Toomey of the Division of S&RM and Steve Kovar of the Maintenance Division provided information for this section.

4.5.4. Roadwork

There are several potential resource threats created by the necessary infrastructure of the park's road network including 1) runoff from the Visitor Center parking lot, 2) impacts of road salting to help melt snow and ice, and 3) siltation from occasional construction projects. The park has used a proactive, science-based approach to ameliorate these and they are not considered to pose a significant threat to park resources.

Description

Roads and parking areas are a necessary infrastructure to allow park users to move around within and access features of the park. This traffic creates the potential for surface and groundwater contamination, as well potential impacts to biological resources, and in particular threatened or endangered species. These include silt from occasional construction projects, high specific conductance (SpC) from road salt application after winter storms, and runoff contaminated by automobile fluids. For the third, while it is not practical to protect against the expected small releases of these fluids along the kilometers of the park's roads, the parking lots at the Visitor Center area are a potentially significant source for this contamination and park scientists and partners have made a significant effort to ameliorate this threat and monitor the impacts of these interventions (West et al. 2010; McMillan et al. 2013) A careful study to quantify the potential impacts of road salt water contamination and on endangered species has also been completed in coordination with the US Fish and Wildlife Service (NPS 2012a, Johnson 2016). Occasional road projects within the park follow established protocols with respect to protection against accidental chemical spills and sedimentation.

Data and Methods

Information from this section was obtained from discussions with MACA staff and from published and unpublished reports. Analysis of road salt impacts measured SpC (also called electrical conductivity, as in Johnson (2016)) using a Solinst Levelogger Model 3001 conductivity sonde with 15 minute resolution for four months in the winter of 2015–16 at a roadside stream along the Cave City Road and another installed in Running Branch immediately below the roadway on North Green River Ferry Road. Additionally, following applications of salt-brine and/or the rock-salt/sand mixture, MAC S&RM staff also measured SpC at six pre-established roadside locations of first receiving waters at random times within one-day and four-day periods following salt applications during that winter using a calibrated Oakton pH/CON 300 Series Conductivity Meter or an Extech Exstik II Conductivity meter.

Filters have been installed to catch parking lot runoff from the Visitor Center area before it sinks into the karst aquifer near the Historic Entrance, motivated by the measurement of potentially toxic metals in cave recharge waters that were influenced by surface sources (Barr 1976) and dye tracing that showed that parking lot runoff was flowing into the cave (Meiman et al. 2001). In one study (McMillan et al. 2013) for example, waters were sampled and analyzed before and after passing through two-year old zeolite-perlite-granulated activated carbon filters, which were very effective at removing diesel range aromatic compounds from fuel. They were less effective at removing copper and zinc. Earlier tests on eight year filters (West et al. 2010) showed the necessity for regular maintenance.

Reference Conditions/Values

There are no standard reference conditions for impacts from road work. We rely on professional judgement based on analysis of published and unpublished data and conversation with MACA staff.

Condition and Trend

Potential impacts to park resources from road use are being adequately addressed by science-based evaluation of these threats (Table 4.28) and in the case of the parking lost filters, proactive resource protection. In the case of construction, standard protocols are used to control impacts of accidental spills and sedimentation.

Level of Confidence and Data Gaps

Based on the combination of data and direct experience of MACA staff with whom we have consulted, we have high confidence in the conclusions of this section.

Condition Summary

Table 4.28. Graphical summary of status and trends for impacts from roadwork.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Roadwork	Ongoing impacts		Potential threats have been adequately studied and where necessary, ameliorated.

Sources of Expertise

Rick Toomey and Larry Johnson from MACA's S&RM Division and Steve Kovar from MACA's Maintenance Division provide information for this report.

4.5.5. Development of Tourism

Beyond the existing tourist infrastructure at MACA the only new initiatives under discussion are the reestablishment of earlier but not currently shown tours in Colossal Cave, Crystal Cave, and Wandering Woods Cave. These would use lanterns rather than wiring of electrical systems and could be set up and implemented with little to no negative resource impacts.

Description

With a mandate to manage natural areas "for the use and enjoyment of the American people," the NPS provides access into the parks through roads and trails, and provides necessary infrastructure for the safety and comfort of park visitors. At cave parks, such as MACA, there is of course an additional challenge of providing access to the underground parts of the park in a way that adequately protects both resources as well and the safety and comfort of park visitors and staff. We define potential resource threats in this section to be those that would be made possible by new tourist infrastructure beyond what currently exists.

Data and Methods

These conclusions are based on discussions with MACA staff from the S&RM and Maintenance Divisions.

Reference Conditions/Values

There are no standard reference conditions for impacts from tourism development. We rely on professional judgement based on conversation with MACA staff.

Condition and Trend

The only new tourism infrastructure under discussion would be up to three tours, on existing but currently unused tourist trails, that would help to make up for lost visitor capacity during the period when parts of the Grand Avenue tour will be unavailable due to trail renovation. These tours would be into two different entrances to Mammoth Cave (Crystal Cave and Colossal Cave) as well as into Wandering Woods Cave. These tours would require no entrance or passage modifications, and would be run using portable lanterns using similar protocols to that currently used in Great Onyx Cave, which is not wired for electric lights. Under these conditions, and with the existing experience of MACA staff in visitor management, there would be little to no additional resource impact from these activities (Table 4.29).

Level of Confidence and Data Gaps

Based on the combination of data and direct experience of MACA staff with whom we have consulted, we have high confidence in the conclusions of this section.

Condition Summary

Table 4.29. Graphical summary of status and trends for resource impacts from tourism development.

Indicator	IMeasure	Condition Status/ Trend	Rationale and Reference Conditions
Development of Tourism	Ongoing Impacts		Based on current plans for the development of three tours on exiting but currently unused cave tour paths, little or no new resource impact is anticipated.

Sources of Expertise

Larry Johnson from MACA's S&RM Division, Steve Kovar from MACA's Maintenance Division provided expertise for this section.

4.5.6. Surface Trail Conditions

A 2009–2014 survey of MACA trails on the north side of the Green River (Johnson 2014) showed significant soil loss, with a total over that trail length of 3,358 cubic meters, or an average of 0.52 cubic meters of soil loss per linear meter of trail, primarily related to horse traffic. By 2014 human activity resulted in secondary, illegal trails called treads, such as shortcuts or side trails around mud holes, at 1,017 locations, a doubling since 2009. Trails improve where maintained and deteriorate

where they are not, and the park made progress on several trail restoration projects during the study period.

Description

More than 128 kilometers of trail for both human visitor and horse traffic wind through the park leading to various karst features such as Cedar Sink and Echo River Spring, overlooks such the one above Turnhole Bend, and backcountry campsites.

11.5 km of trails wind through the area near the Visitor Center (NPS 2018e) leading to important cultural features, ridgetop sinkholes, and clifftop views of the Green River. There are 17.3 km of accessible front country trails, and 105.2 km of backcountry trails. Of these, horse and pedestrian access is permitted on most, while mountain bikes and hikers are permitted on the Big Hollow Trail. Horses, pedestrians, and bikes are all permitted on the Maple Springs and White Oak Trail. Surfaces and maintenance vary, with most trails on dirt and some hardened by gravel and boardwalks.

Data and Methods

These conclusions are based on discussions with MACA staff from the S&RM Division and results from a six-year trail study by Johnson (2014).

Reference Conditions/Values

There are no standard reference conditions surface trail condition, although we can observe trends where trails are either improving through rehabilitation projects, maintain their condition, or deteriorate from use that exceeds amelioration by maintenance. We rely on professional judgement based on conversation with MACA staff.

Condition and Trend

Johnson (2014) completed a six-year survey of 63.1 km of trails on the north side of the Green River in the park that showed serious trail deterioration, principally from use by horses (Table 4.30). This resulted in significant soil loss, with a total over that trail length of 3,358 cubic meters, or an average of 0.52 cubic meter of soil loss per linear meter of trail. By 2014 human activity resulted in secondary, illegal trails called treads, such as shortcuts or side trails around mud holes, at 1,017 locations, a doubling since 2009. Trails improve where maintained and deteriorate where they are not, and the park made progress on several trail restoration projects during the study period. Rest areas along horse trails were the most heavily impacted, with disturbed, trampled ground, near total denudation of vegetation, and damage to numerous trees by chewing to get to the tender “inner bark” (the xylem and phloem) when tied to trees, which is illegal. In one example the impacted area at Wildcat Hollow grew from approximately 308 square meters in 2010 to 1,124 square meters in 2014, an increase of 363%. Trails on the south side of the river are not exposed to horse traffic and are this probably in better condition overall.

Level of Confidence and Data Gaps

Based on the combination of data and direct experience of MACA staff with whom we have consulted, we have high confidence in the conclusions of this section, although the last data analyzed

was on 2001. We suggest that trail monitoring and maintenance should be a significant priority moving forward.

Condition Summary

Table 4.30. Graphical summary of status and trends for surface trail conditions.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Surface trail conditions	Condition and ongoing impacts		A 2009–2014 survey of 63.1 km of trails on the north side of the Green River in the park showed serious trail deterioration, principally from use by horses. This resulted in significant soil loss and muddiness. By 2014 human activity resulted in Illegal treads 1,017 locations, a doubling since 2009. Trails improve where maintained and deteriorate where are not, and the park made progress on several trail restoration projects during the study period. Trails of the south side of the river are not exposed to horse traffic and are thus probably in better condition overall.

Sources of Expertise

Larry Johnson and Rick Toomey from MACA's S&RM Division provided expertise for this section.

4.6. Night Skies

One of the functions of national parks is to protect night skies (Figure 4.79) and minimize contamination by light pollution. This not only impacts the wilderness condition as conceived in the Wilderness Act of 1964 (Congress 1964, Landres et al. 2015, NPS 2016c) through preservation of "Solitude or a primitive and unconfined type of recreation: the opportunity for humans to experience these values, unaffected by signs of modern civilization, encounters with others, or reminders that a developed society exists," but has a critical role in ecosystem function. This section describes the extent to which MACA is impacted by light pollution. The one indicator in this section is "sky quality".

4.6.1. Sky Quality

Night sky quality remains good at MACA, esecially considering its location in the heavily light polluted eastern United States, as indicated through two independent measurements collected in 2008 and 2018. The ability of visitors to observe the night sky is expected to improve through ongoing implentation of an Outdoor Lighting and Lightscape Management Plan, which includes modification of lights and fixtures, public education and cooperative efforts with local communities outside of the park. Simultaneously, while the air quality has been one of the most heavily impacted resources at MACA with direct major pollution sources including operation of coal-fired power plants, industrial and mobile emissions as well as secondary sources that can form through chemical reactions in the atmosphere, visibility has shown continued improvement over the last decade and this trendis expected to continue (See this document section 4.1.1 for discussion).



Figure 4.79. Night sky above MACA during the January 18, 2018 dark sky survey (NPS 2018c). Several deep sky objects are marked as a way to gauge the limiting magnitude of the sky conditions (Photo by Theo Wellington).

Description

Light pollution from urban and other outdoor lighting creates a form of environmental decgradation that reduces the number and magnitude of stars and other astronomical phenomena that can be seen in the night sky. Among the other natural featues that national parks are created to protect, they offer a space from the encroachment of light sources and an opportunity to more closely experience the natural night sky. Recognizing this in an age where such pristine nighttime viewsheds are becoming increasingly endangered, the National park Service as a whole, and individual parks, are adapting

management considerations with regard to the protection of dark skies. The 2006 NPS Management Policies (NPS 2006a) codify that:

> The Service will preserve, to the greatest extent possible, the natural lightscapes of parks, which are natural resources and values that exist in the absence of human-caused light. The absence of light in areas such as caves and at the bottom of deep bodies of water influences biological processes and the evolution of species, such as the blind cave fish. The phosphorescence of waves on dark nights helps hatchling sea turtles orient to the ocean. The stars, planets, and earth's moon that are visible during clear nights influence humans and many other species of animals, such as birds that navigate by the stars or prey animals that reduce their activities during moonlit nights.
>
> Improper outdoor lighting can impede the view and visitor enjoyment of a natural dark night sky. Recognizing the roles that light and dark periods and darkness play in natural resource processes and the evolution of species, the Service will protect natural darkness and other components of the natural lightscape in parks. To prevent the loss of dark conditions and of natural night skies, the Service will minimize light that emanates from park facilities, and also seek the cooperation of park visitors, neighbors, and local government agencies to prevent or minimize the intrusion of artificial light into the night scene of the ecosystems of parks. The Service will not use artificial lighting in areas such as sea turtle nesting locations where the presence of the artificial lighting will disrupt a park's dark-dependent natural resource components.
>
> The Service will:
>
> - restrict the use of artificial lighting in parks to those areas where security, basic human safety, and specific cultural resource requirements must be met;
> - use minimal-impact lighting techniques;
> - shield the use of artificial lighting where necessary to prevent the disruption of the night sky, natural cave processes, physiological processes of living organisms, and similar natural processes.

MACA has been proactively working to protect this resource. With about 95% of the park undeveloped, it is a naturally dark area (NPS 2018c; Figure 4.80) . The park has applied for the International Dark Sky park Designation under the auspices of the International Dark Sky Association (IDA) (IDA 2016), and has worked collaboratively with local campgrounds and the nearby town of Park City just south of MACA, which is preparing a similar application to become a Dark Sky City.

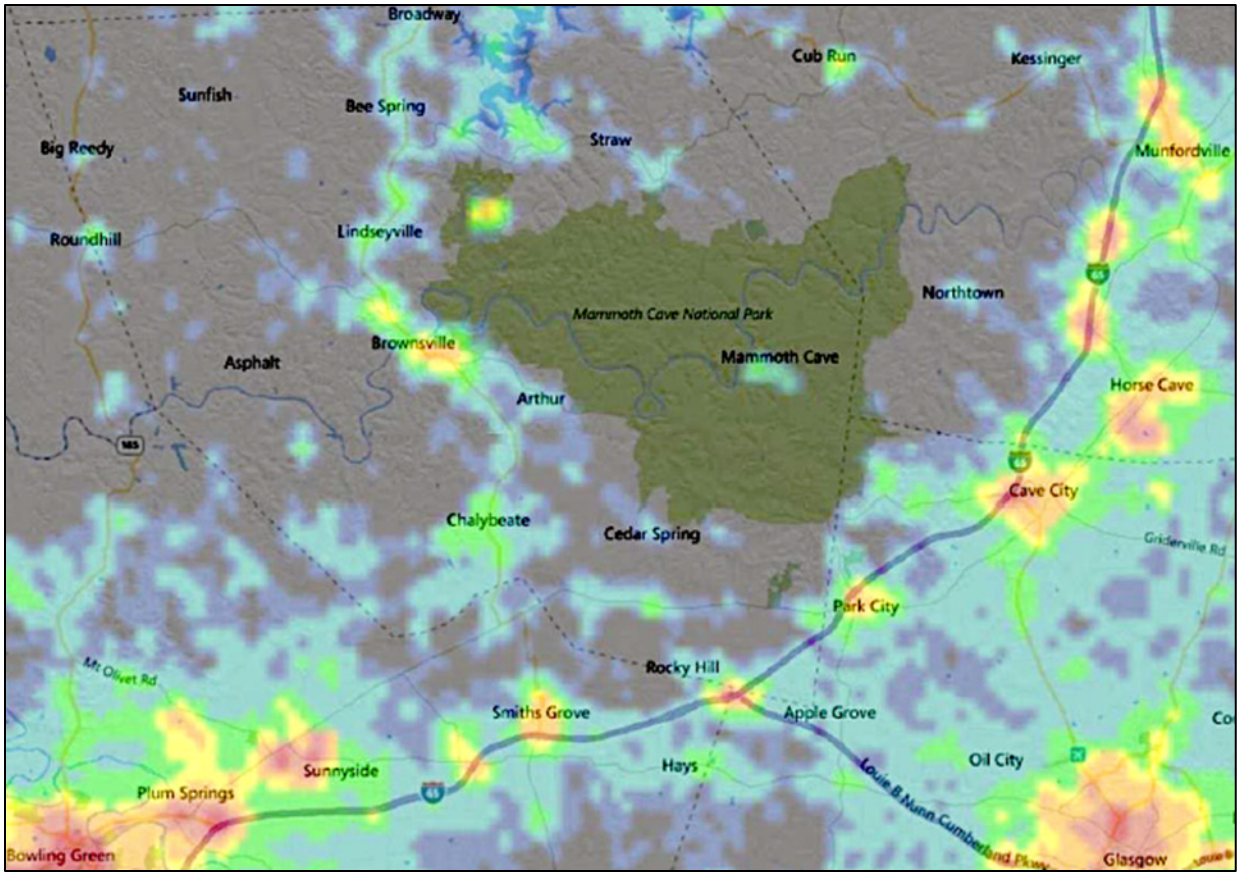


Figure 4.80. Sky darkness in the vicinity of MACA in March 2016 based on Visible Infrared Imaging Radiometer Suite (VIIRS) data from NOAA's Suomi NPP satellite (NPS 2018c, www.lightpollutionmap.info).

Data and Methods

Since 2001 the NPS has been working to enhance the development of sophisticated methods of *astonomical photometry* to accurately quantify the impacts of light pollution (Duriscoe et al. 2007, Duriscoe 2013). It is important that such measurements cover the entire sky from horizon to horizon in all directions because even light in a small portion of the sky, say the glow from the lights of a distant city, can degrade the natural night sky. Earlier systems for measuring night sky darkness had typically been been made at astronomical observatories using equipment that measures certain regions of the sky in a way that calibrates the measurements to objects of known brightness, (e.g., Nawar 1998, Pilachowski et al. 1989), or were able to make whole-sky observations but that were difficult to calibrate (e.g., Schwarz et al. 2003). A system developed and now used by NPS scientists to make calibrated, full-sky images includes a computer driven, research grade digital camera (Figure 4.81) using an approach that scans across the entire sky making 45 high-resolution imagesfrom horizon to zenith, and then stiches together the files to produce a mosaic whole-sky image that can be viewed in either a panoramic or fisheye perspective (Duriscoe et al. 2007, Duriscoe 2013, NPS 2016d). The images are calibrated with reference to known stellar objects in a way that can have sufficient accuracy and precision to allow comparison of subsequent images to assess trends.



Figure 4.81. Sweeping valley view across the City of Wenatchee, WA from atop Burch Mountain shows NSNSD resource specialist Ashley Pipkin installing the specialized NPS CCD camera used for night sky monitoring (NPS photo by Li-Wei Hung; NPS 2018d).

Using these methods (NPS 2015) a sky survey was made by the staff of the NPS Night Skies program on October 25, 2008 at the relatively remote Houchin's Meadow Atmospheric Monitoring site just south of the MACA boundary (Figure 4.1) and this gave the highly detailed information summarized below (see NPS 2018c) (Table 4.31). A dark sky survey at MACA was also made by Theo Wellington of the Barnard-Seyfert Astronomical Society on a clear night on January 18, 2018 using a Pentax K-3 DSLR camera (Figure 4.79), although due to calibration challenges data from the two methods are not directly comparable.

There are several parameters for quantifying the quality of night skies that were utilized in the current assesment (NPS 2018c). The Bortle Scale (Bortle 2001) synthesizes a number of factors with a nine-value scale based on the darkness and the magnitudes of different objects that can be seen with the unaided eye or various telescopes. A value of one is pristine and only still accessible at a few locations in the US.

Table 4.31. Results of the 2008 MACA sky survey at Houchin's Meadow (NPS 2018c).

Category	Details
Park:	Mammoth Cave NP
Site Name:	Houchin's Field
Longitude:	−86.15
Latitude:	37.13
Elevation (m):	245
Date (LMT):	28-Oct-2008
Time (LMT hours):	21.07
Camera:	IMG 2
Lens:	Nikon 1.8
Observers:	K. Magargal
Air Temp. (°C):	8.9
R.H. (%):	76.0
Wind Speed (MPH):	–
Extinction Coeff. (mag/airmass):	0.21
NELM:	6.5
Bortle Class:	4
Synthetic SQM:	20.69
SQI All-sky	41.
SQI to Z.A. 70°	51.3
Number of stars visible:	2020

NARRATIVE: A very calm, humid and clear night. Dewfall occurred during data collection, however dew heater prevented lens fog. Multiple light domes visible from site, as well as a continuous glow along horizon in all directions. Airglow was present. Andromeda Galaxy easily visible, Beehive (Pegasus) was visible with medium effort. Predominant dust lanes in Milky Way visible at zenith, but not below ~50o. Limiting magnitude found in Pegasus.

Another measure utilizes the Unihedron Sky Quality Meter (SQM). This is a type of light meter but with the ability to measure selective wavelengths to simulate what would be seen by human night vision. Each reading measures the value at a single location, pointed straight at the zenith. MACA staff made SQM readings at 52 locations in the park between January and May, 2017 (NPS 2018c).Another source of information is available in the form of maps from satellite data that have been made publically available through web sites such as that at www.lightpollutionmap.info). There are also separate products including the World Atlas of Artificial Light, which was first developed in 2001 (Cinzano et al. 2001) using US Defense Department weather satellite data from the Defense Meteorological Satellite Program (DMSP). Although the satellite only images a small part of the sky at a time, the atlas was constructed by combining images taken on clear nights, and carefully

calibrating the data, taking into account the way the light is transmitted through the atmosphere (IDA 2016). This provided the first measurements of light produced by human activities at a global scale. These data had been gathered for weather forecasting and the resolution of the maps was relatively coarse. In 2011, a new satellite—the Suomi National Polar-orbiting Partnership, or Suomi NPP satellite—was launched by the National Oceanic and Atmospheric Administration. The Suomi NPP deploys a much higher resolution camera called the Visible Infrared Imaging Radiometer Suite (VIIRS), with a resolution of one kilometer compared with three kilometers for the DMSP data.

Reference Conditions/Values

For the reference conditions to evaluate the night sky quality at MACA we use the standards of the International Dark Sky Association (IDA 2016) and apply them to the three typical NRCA condition assessment levels—good condition, moderate concern, or significant concern. IDA recognizes four levels of nighttime sky quality: Gold, Silver, and Bronze Tiers and then skies that fall below these designations in quality. These are described in Table 4.32 and associated with the NRCA levels, where Gold and Silver indicate good quality, bronze moderate concern, and skies of lesser quality indicate significant concern. The tiers are assigned based on a range of considerations, which include quantitative evaluation of night sky quality using both the Bortle Scale and SQM data (Figure 4.82).

Table 4.32. Criteria for dark sky quality condition.

Dark Sky Condition	Tier Level	Brief Description
Warrants Significant Concern	Below Bronze Tier	Does not meet threshold criteria for Bronze Tier.
Warrants Moderate Concern	Bronze Tier	Areas not meeting the requirements of Silver, yet still offering people, plants, and animals a respite from an otherwise degraded nocturnal environment.
Resource is in Good Condition	Silver Tier	Nighttime environments that have minor impacts from light pollution and other artificial light disturbance, yet still display good quality night skies and has exemplary nighttime lightscapes.
	Gold Tier	Natural, non-polluted or near natural light.

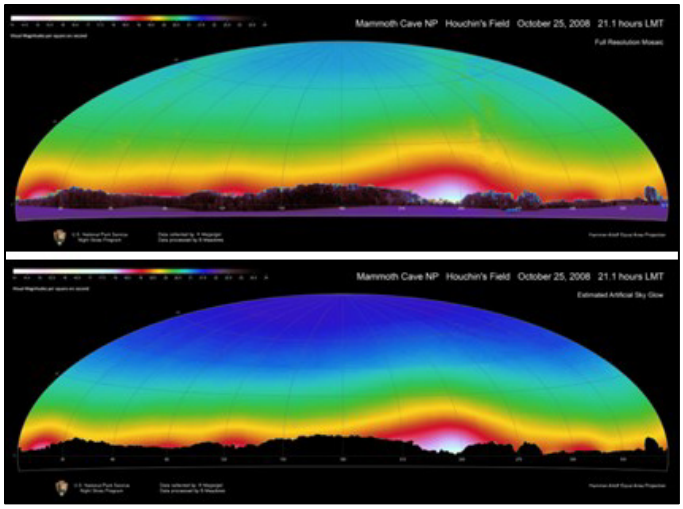


Figure 4.82. Observed and Estimated Artificial Sky Brightness Mosaics (NPS 2018c).

Condition and Trend

We conclude that that MACA's dark sky quality is in good condition based in the IDA's criteria which have allowed MACA to be assigned to Silver Tier Status (Table 4.33). Overall the collective data from these surveys taken over ten years agree that most of MACA is in Bortle Class 4 with small areas in the southern part of the park in class 5. Most SQM readings in the 2017 survey were over 21.00 (Figure 4.83) and with these considered together, the park has qualified as a Silver Tier Status (IDA 2018) based on the following criteria:

- Nighttime environments that have minor impacts from light pollution and other artificial light disturbance, yet still display good quality night skies and have exemplary nighttime lightscapes;
- Point light sources and glary lights do not dominate nighttime scene (Figure 4.84). Light domes present around horizon but do not stretch to zenith;
- Brighter sky phenomena can be regularly viewed, with fainter ones sometimes visible. Milky Way is visible in summer and winter;
- Areas that have minor to moderate ground illumination from artificial skyglow. Lights that may cause disorientation to wildlife are distant. Disruption of ecological processes is minor with no impairment to plants or wildlife;
- The visual limiting star magnitude is 6.0 to 6.7 under clear skies and good conditions;
- The Bortle Sky Class is from 3–5;7. Unihedron Sky Quality Meter Readings are from 21.00–21.74.

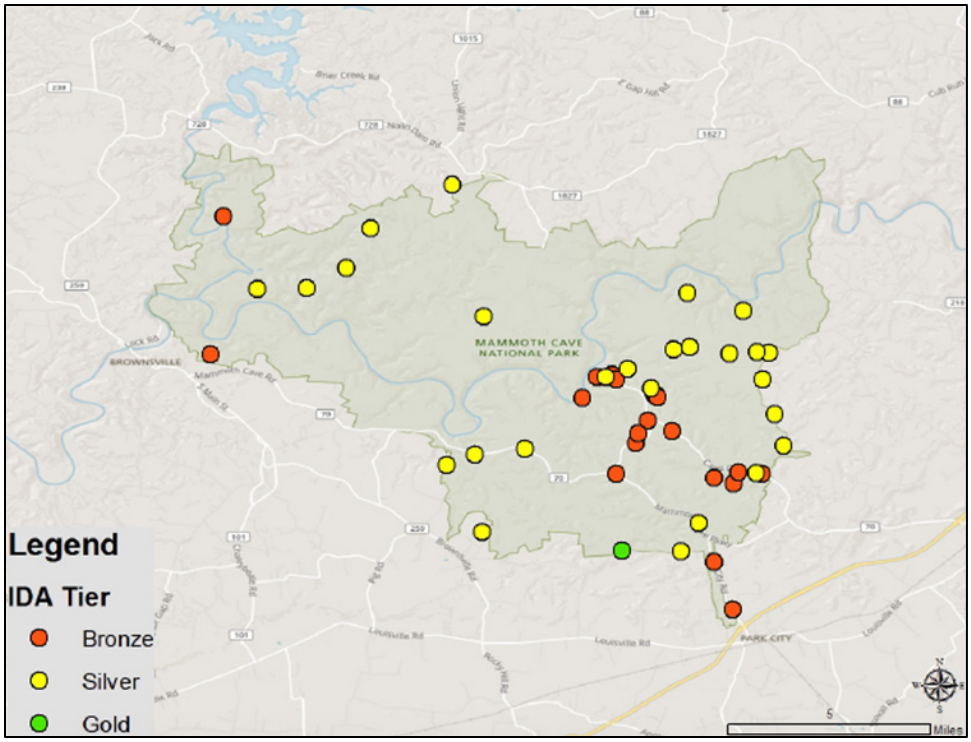


Figure 4.83. Results of the 2017 SQM survey at MACA (NPS 2018c).



Figure 4.84. Demonstration project showing impacts of light retrofitting at the MACA campground kiosk (Photos by Dave Spence).

Condition Summary

Table 4.33. Graphical summary of status and trends for visibility.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Night skies	Bortle Scale		Most of the park has a rating of Bortle scale 4 with some areas with values of 5. This supports IDA Silver Tier Designation. The conditions are expected to improve.
	Sky Quality Meter (SQM)		Average SQM values from 52 locations in the park in 2017 are greater than 21.00. This supports IDA Silver Tier Designation. The conditions are expected to improve.

Sources of Expertise

Information for this section came from Vickie Carson and Superintendent Barclay Trimble of MACA's Office of the Superintendent, along with Scott McFarland, Ashley Pipkin, and Bob Meadows of NPS Natural Sounds and Night Skies Division. Ms. Theo Wellington of the Barnard-Seyfert Astronomical Society also provided helpful information and insights.

4.7. Native Communities

Native communities for a given region or ecosystem are comprised of those indigenous or native species that have arrived there through natural processes as opposed to having been influenced by human intervention. These are opposed to non-native species, whose behaviors and influences can be defined in a number of ways. With respect to plants, for example (USDA NRCS 2018), non-native species are those intentionally or accidentally introduced by humans to a habitat where it was not previously found. Non-native species are not necessarily invasive, since some species cannot spread readily on their own without continued human help. Invasive species are non-native ones that are able to establish in a new area and spread quickly, often to the point of creating ecological or economic damage, or harm to human health. An example of an invasive species is the tree of heaven (*Ailanthus altissima*), which is a native of China and was introduced in the US as an ornamental tree in Pennsylvania in 1784 (Jackson 2018). It is now widespread throughout much of the US including in MACA, grows quickly, and can reach 25 m in height.

The purpose of this section is to evaluate the conditions of selected native plant and animal species at MACA based on available data, and to describe threats to these resources. In this particular NRCA, because of the specific nature of the ecosystem and environmental conditions at the park, we have pulled out several taxa in their own sections for more detailed treatment, including bats, birds, herpetofauna (reptiles and amphibians), surface fish and freshwater mussels, and species that live underground in the park's caves. Readers are referred to those sections and the information is not repeated here. Although most discussion of the park's invasive species appropriately is found in this section, one group of organisms limited to parks with electrically lit caves is lampenflora, which are green plants including ferns and algae that can locally colonize damp cave walls and floors near tour light fixtures. Lampenflora are discussed in the Cave Communities Section 4.13.

This chapter analyzes conditions through two sets of related resource indicators:

- 4.7.1 Native Plant Communities, and
- 4.7.2 Native Animal Communities

4.7.1. Native Plant Communities

There is a rich community of native plants at MACA (Figure 4.85), and clearly one of the principal functions of any national park is to protect and to the extent necessary, rehabilitate these species to historical and/or pre-European settlement conditions. Although NPS land management practices work to reduce or eliminate threats from development and other human impacts, there are still threats to native plant communities from invasive plant species that compete with native species for space and resources, as well as exotic pests and diseases, such as the Emerlad Ash borer, introduced into the US in 2002, that has killed hundreds of millions of ash trees (USDA 2018a), and was confirmed at MACA in 2018 (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, September 2018, personal communication).



Figure 4.85. The varied hydrologic, geologic and landscape conditions at MACA support a diverse community of native plants. This yellow lady's slipper orchid (*Cypripedium parviflorum*) is found in the park's rich mesic forests (NPS photo by Milo Pyne).

Description

Being positioned in a transition zone in temperature, precipitation, and latitude on a karst landscape with moderate topographic variation creates a variety of localized conditions that allow for greater biodiversity as the park encompasses the boundaries of many species' natural ranges (NPS 2018i). This diversity is not only recognized by species richness (number of species) but also the ecological community types that are present within the extensive forested uplands and the Green and Nolin River corridors at MACA. In describing the native plant communities at MACA for this assessment, we discriminate between the three major, relatively homogenous landscape units that each create certain common ecological characteristics. These are 1) uplands, which dominate the park, 2) riparian areas, and 3) wetlands. However, it should be noted that 28 natural and 12 human-modified or successional vegetation associations (unique assemblages of plants) have been identified across these three general landscape types within the park boundary (Pyne et al. 2010). Wetlands are distinct vegetation communities that generally occur on upland ridges due to specific hydro-geologic conditions. They are listed separately here due to the unique plant and animal communities they support within the upland forests. These surface habitats support diverse plant communities including over 1,200 documented species, subspecies, and varieties (Pyne et al. 2010, Bledsoe 2017). Of those 1,279 species, 87% are considered native to the region (Pyne et al. 2010, Bledsoe 2017).

The uplands (Figures 4.86 and 4.87) consist of relatively dry areas of hillslopes developed on limestones and sandstones, and the typically flat ridge tops generally formed from sandstones primarily of the of the Big Clifty, Hardinsburg, and Caseyville Formations, with some areas underlain by thin, heterogeneous upper Mississippian clastic rocks. The common feature, in comparison to the other landscape units, is that these areas are relatively dry with the exception of the rare occurrence of wetlands. The species distributions for plants that make up the upland forest communities are functions of the physical conditions such as geology, slope position, and slope aspect (Bledsoe 2017). The upland geology at MACA has additional influence as the areas lower on the carbonate rock slopes with buffered, more alkaline soils tend to have higher numbers of species than the more acidic forest types. Considering the range of permutations of basic and acidic soils and the high degree of topographic variation within MACA, it is not surprising that the park has high species diversity, with the second-highest plot-level plant diversity of the 14 CUPN parks (Bledsoe 2017).



Figure 4.86. Upland forests on the limestone slopes and sandstone ridgetop of the Green River Valley in MACA. (NPS Green River air quality webcam photo).

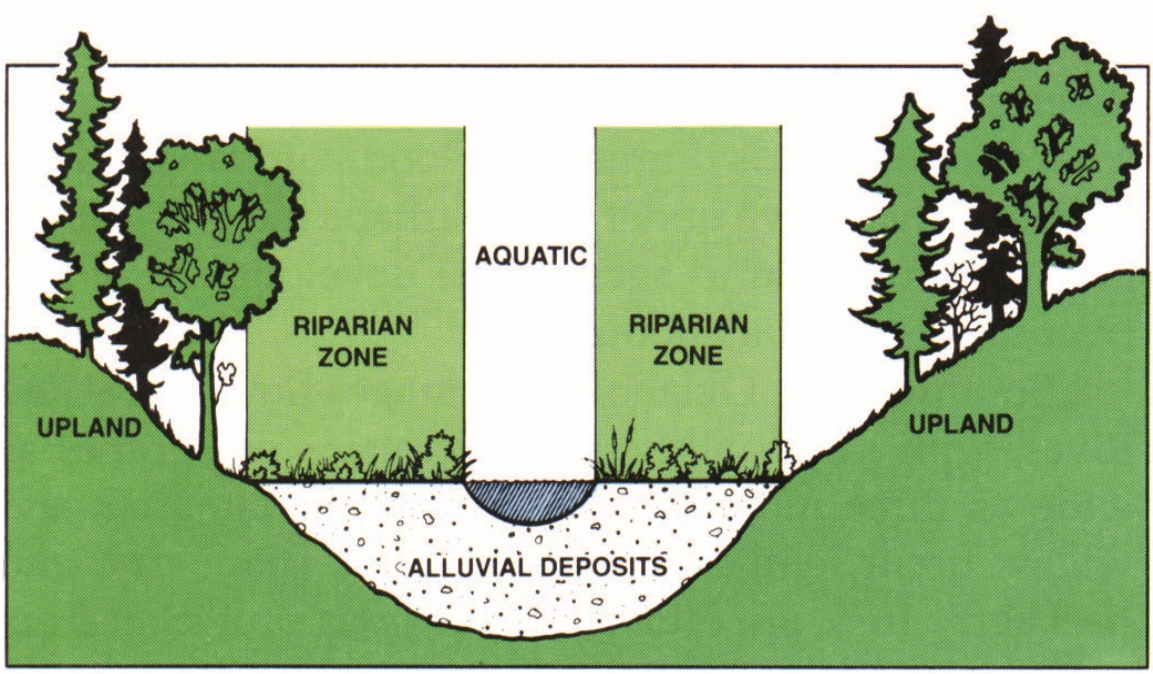


Figure 4.87. Diagrammatic cross-section of typical riparian and upland landscape zones representative of the Green and Nolin Rivers and their non-karst tributaries. The riparian zone is that adjacent to, and impacted by, the stream itself. These areas, and particularly the floodplains, are periodically inundated (Oklahoma Cooperative Extension Service 2017).

Based on the 2011 vegetation map of MACA and primarily for fire management, more than 20 categories were condensed into four natural and four successional or human-modified habitat types. The most prevalent upland habitat type is the Oak Forest-Woodlands which cover over 40% of park lands. It should be noted that MACA is home to one of the largest continuous hardwood forests in the region and continued maintenance of all of these habitats, rare or common, is critical to sustaining diversity at MACA (Pyne et al. 2010). A more recent study by Yahn (2018) points out even rarer vegetation communities at MACA—the Barrens and Prairie Plantation—and highlights the need to preserve the "incredible prairie-plant diversity" found in small woodland openings and roadside stands. While the Prairie Plantation represents disturbed areas where grasses and herbs have been planted, the Barrens are remnants of a vegetation type that was much more prevalent at MACA prior to European settlement and fire suppression (Olson 2017b; See Fire Management Section 4.8).

Moreover, it is these barren remnants and planted prairies and the associated rare plant species that deserve attention for preservation of the habitat types themselves but also the greater ecological community they support and the potential for increased species richness and diversity if maintained (Yahn 2018).

Riparian areas, in contrast, are those adjacent to streams and rivers (Figure 4.87). Plant communities within riparian zones often have characteristics of both aquatic and upland habitats, requiring or tolerant of relatively large amounts of water and being adapted to shallow water table conditions (Oklahoma Cooperative Extension Service 2017). They may also be periodically inundated with

floodwaters. These areas often have high productivity due to the abundance of water in combination with rich alluvial soils. Riparian vegetation can fulfill numerous ecological functions with respect to aquatic habitats (Richardson et al. 2007) that may include the provision of food, moderation of stream water temperature via evapotranspiration and shading, providing a buffer zone that filters sediments and controls nutrients, and stabilization of stream banks (Barling and Moore 1994, Hood and Naiman 2000). It also provides a corridor for the movement of biota (Naiman and Décamps 1997) and serves many important roles for humans (Kemper 2001). Ewel et al. (2001) coined the term "critical transition zones" for ecosystems such as riparian zones that serve as conduits for substantial fluxes of materials and energy from one adjacent, clearly defined ecosystem to another.

Wetlands are areas that spend some or all of their time in saturated conditions in which the local water table is above the ground surface. At MACA, they occupy a very small proportion of the park's area but may have outsized importance by providing homes to unusual and rare plant species. They occur on the broad, flat ridgetops, often underlain by nearly horizontal sandstone, and result from a variety of hydrogeologic conditions, including ponds, marshes, shrub swamps, and wet forests (Yahn et al. 2014).

These are areas where the protection afforded by MACA land management is especially critical. In addition to the fact that wetlands can have rare plant communities, the mere existence of these upland wetlands is rare in Kentucky as many were drained or cleared with European settlement and subsequent development (Yahn 2015). Although many wetlands have been heavily modified, Yahn (2015) identified 17 high-quality wetlands at MACA which is impressive as there are only 25 of these types of wetland recorded in the entire state. In fact, most of the wetland community types are ranked as state rare. Since inventory and monitoring has been limited at MACA, it is uncertain if additional common or rare wetland-dependent species may occur in these areas. It is known, however, that these areas provide important breeding habitat for amphibians and with declines in some species at MACA and generally worldwide (See Surface Aquatics Section 4.12), wetland restoration may be needed to protect both the flora and fauna of these unique habitats (Yahn 2015). Wetlands are considered separately in this assessment as they have been identified as areas with a high density of rare species that require the most undisturbed conditions (Yahn et al. 2014, Yahn 2015).

Most often habitat type or landscape unit can be linked to local hydrogeology and resulting soil conditions as well as position in regard to slope and aspect. As soil type is largely influenced by bedrock geology, the Kentucky State Nature Preserves Commission (KSNPC) and the MACA Fire Management Plan (NPS 2001) classify habitats on calcium-containing bedrock such as limestone as "calcareous" and those on non-calcareous bedrock as "acid". Calcareous habitats are generally more xeric (i.e., dry; Figure 4.88), due to the potential for subsurface drainage development, compared to acid habitats (See Fire Management Plan Section 4.8 for detailed information on habitat classes and types). In fact, according to Pyne et al. (2010) four out of the six most globally rare communities identified at MACA "are related to exposures of limestone or other habitats favorable for light-demanding plants" and suffer decreased species diversity due to lack of fire or other natural disturbances (Yahn 2018). These communities warrant special attention as highly ranked rare

habitats as well as for the globally rare and/or locally vulnerable species they support (Pyne et al. 2010). Two such distinct and localized upland vegetation communities directly related to geology include the Central Limestone Glade and the East-central Hemlock Hardwood Forest (Pyne et al. 2010). One extensive limestone glade is along Dennison Ferry Road where limestone exposures occur on south-facing slopes; many of the plants in this community are found nowhere else at MACA. The Hemlock forest are restricted to sandstone-capped areas in the northwestern portion of the park. Yahn (2018) also points out that of the nine communities recognized by KSNPC, eight of them are considered globally rare according to the Vegetation Monitoring Protocol for the Cumberland Piedmont Network and the International Vegetation Classification, with barrens, prairies, and glades ranking from special concern to threatened at the state level. The globally rare plant community types identified at MACA are listed in Table 4.34.

The preservation of diverse plant communities is an important component of overall ecological health at MACA in maintaining habitat and energy sources for surface and subsurface wildlife communities. Indeed, forest vegetation communities were selected as a high priority in the Vital Sign Monitoring program within the Cumberland Piedmont Network and long-term monitoring of forest communities began at MACA in 2011. Initial results from the first five years of monitoring show MACA to be the second highest across the CUPN in regard to monitoring plot diversity, averaging 70 species per plot (Bledsoe 2017). Monitoring efforts in recent years by CUPN and others (Pyne et al. 2010, Bledsoe 2017, Yahn 2018) have continued to find and confirm additional species including rare species, once again revealing the importance of MACA to local and global biodiversity. White et al. (2011) points out that monitoring community vital signs allows for not only keystone or rare species status to be evaluated but also ensures preservation of common species as threats and stressors can be identified and addressed before conditions become critical.

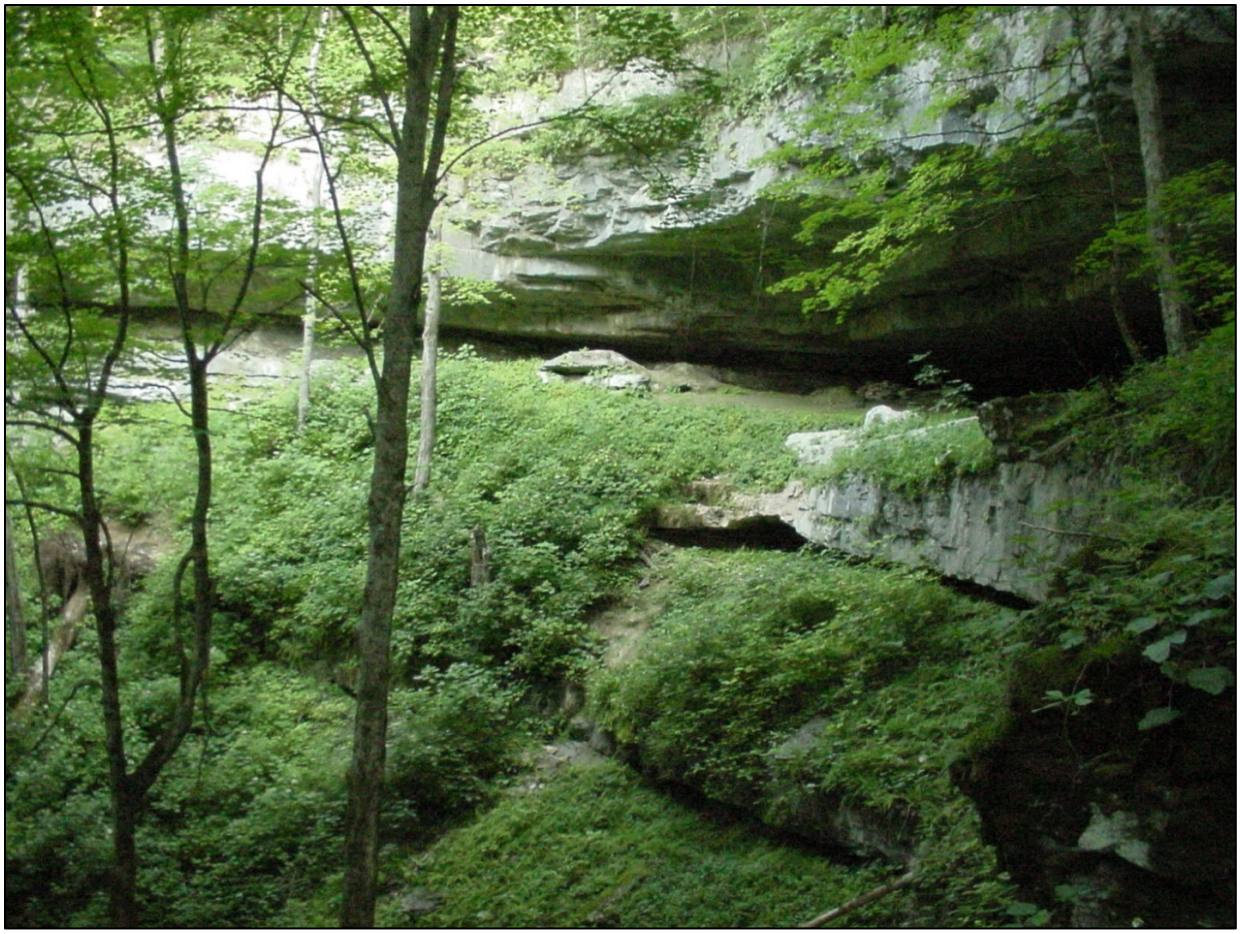


Figure 4.88. A characteristic of karst landscapes is that soils are often thin. Here at Cedar Sink vegetation clings to steep slopes, in many places with little soil (NPS photo by Erin Lunsford Jones).

Table 4.34. Globally rare plant community types that have been identified at MACA (Yahn 2018).

Rare Natural Community	NatureServe Status	Type	MACA Community
East-central Hemlock Hardwood Forest (CEGL005043) [A.413G3?]	G3?*	rich forest	occurs
Interior (Nashville Basin) Mesic Sugar Maple – Hickory Forest (CEGL004741) [A.1912]	G3G4	rich forest	occurs
Rich Appalachian Red Oak / Sugar Maple Forest (CEGL007698) [A.251]	G3	rich forest	occurs
Shumard Oak – Chinquapin Oak Mesic Limestone Forest (CEGL008442) [A.1912]	G2G3	rich forest	occurs
Appalachian Low-Elevation Mixed Pine / Hillside Blueberry Forest (CEGL007119) [A.131]	G3 dry (to mesic)	forest	occurs

* The NatureServe Status indicators in Table 4.34 are defined as follows: G1: Critically Imperiled, G2: Imperiled,G3: Vulnerable, G4: Apparently Secure. Two indicators listed together indicates a range of uncertainty, and a question mark denotes an inexact numeric rank. A full description can be found at NatureServe (2018).

Table 4.34 (continued). Globally rare plant community types that have been identified at MACA (Yahn 2018).

Rare Natural Community	NatureServe Status	Type	MACA Community
Chinquapin Oak Unglaciated Bluff Woodland (CEGL004267)	G2G3	xeric forest–woodland	potential
Eastern Red-cedar – Blue Ash / Can. Leafcup – (West. Daisy) Woodland (CEGL003754)?	G3	xeric forest–woodland	potential
Nashville Basin Shingle Oak – Shumard Oak – Chinquapin Oak Forest (CEGL003876) [A.1912]	G2G3	xeric forest–woodland	occurs
Central Limestone Glade (CEGL005131) [A.1919]	G2G3	prairie/barren/glade	occurs
Kentucky Mesic Tallgrass Prairie (CEGL004677) [A.1192]	G1G2	prairie/barren/glade	potential
Little Bluestem – (Ashy Sunflower, Fewleaf Sunflower, Whorled Rosinweed) Grassland (CEGL007805)	G2G3	prairie/barren/glade	occurs?
Western Highland Rim Escarpment Post Oak Barrens (CEGL004686) [A.625]	G2G3	prairie/barren/glade	occurs
Southern Red Oak Flatwoods Forest [CEGL004412]	G2?	flatwoods	occurs
Southern Oak Flatwoods Highland Rim Limestone Cliff/Talus Seep (CEGL004708) [A.1905]	G3	wetland	occurs

* The NatureServe Status indicators in Table 4.34 are defined as follows: G1: Critically Imperiled, G2: Imperiled,G3: Vulnerable, G4: Apparently Secure. Two indicators listed together indicates a range of uncertainty, and a question mark denotes an inexact numeric rank. A full description can be found at NatureServe (2018).

Data and Methods

Five programs provided the data considered in this analysis.

1. NatureServe Vascular Plant Inventory and Plant Community Classification (Pyne et al. 2010), 2002–2004

   This program had a two-fold purpose: 1) to establish a system of plots for future research, and 2) to complete a vegetation classification of all the vegetation associations within the park. In this study a grid system was used to identify 34 permanently marked, one hectare circular plots, as well as 31 other non-grid plots based on certain ecological criteria. Another 85 non-permanent "quickplots" were used to study unusual or ecologically significant associations (Pyne et al. 2010). The scientists then identified all the park's unique vegetation associations (Figure 4.89). There was a total of 40, with 28 natural and 12 human modified or successional associations, as well as two that may have existed earlier (Interior Mid- to Late-Successional Sweetgum-Oak Forest confirmed in 2017) and may return depending on the details of future management practices. Details of the methods used in the study were provided by Pyne et al. (2010).

2. CUPN Forest Vegetation Monitoring Program Phase I, 2011–2015 (CUPN 2013, Bledsoe 2017)

A general description of the methods used is provided in the associated Resource Brief (Bledsoe 2017).

In the first phase of vegetation monitoring, permanent plots were established across all CUPN parks over a five-year period (2011–2015). These plots will be revisited every five years in order to monitor changes and trends in forest vegetation conditions. By the conclusion of the 2015 field season, 52 permanent plots had been established at MACA. In 2016, four additional monitoring plots were established at MACA, and in 2017 four more, bringing the total number of plots at MACA to 60.

Monitoring plots are 20 × 20 meters with multiple nested sampling frames ranging in size from 1 to 100 square meters. Data collection is intensive, with data being grouped into the following broad categories: plot characteristics (slope, landform, etc.); species presence; frequency and cover (tree, sapling, seedling and herb layers); canopy cover; tree growth and health; evidence of forest pests, snags, and coarse woody debris (CWD); and community characterization/classification.

3. Wetland surveys by the Kentucky State Nature Preserves Commission (KSNPC), 2012–2014.

   In Phase I of this work the KSNPC vegetation ecologist evaluated the community significance of 22 sites based on native community composition and structure, and combined this with information on hydrologic and geologic conditions as well as the abundance of non-native species. Then the sites were surveyed for wetland-dependent rare species populations. Because rare species were being studied, collection of specimens was for the most part avoided, and documentation was accomplished through field notes, GPS location, photographs and/or visual observation. Altogether, 23 sites were identified as wetlands and surveyed, with eight considered as Tier 1 (good to excellent condition), seven were Tier 2 (fair to good condition), and eight Tier 3 (poor to fair condition). Yahn et al. (2014) provided additional details about the methods used in these phases.

   A supplemental survey using similar methods was conducted (Yahn 2015) in the 2014 growing season. Out of a total of 39 initially selected, 25 sites were evaluated. Of those, 17 were identified as natural wetlands and another two that had been wetlands but have since been significantly impacted, but still have high quality vegetation and were thus included in the analysis. Of these 19, five were determined to be Tier 1, eight were Tier 2 and six were Tier 3.

4. Survey of Select Upland Communities and Associated Rare Species by KSNPC, 2016–2017.

   Following the wetland survey described above, the upland survey began with the selection of potential sites through analysis of NatureServe data, recent and historical air photos, and discussion with MACA and CUPN staff, using methods detailed in Yahn (2018). Of 36 sites initially selected, five were labeled as Tier 1, five were Tier 2, and five were Tier 3. Other sites were eliminated for having less than significant vegetation.

5. Preliminary ecological assessment of the Green and Nolin rivers in MACA, Kentucky, following the removal of Lock and Dam #6 by KSNPC, 2017.

Scientists with KSNPC evaluated changes in riparian vegetation along the Green River associated with the removal of Lock and Dam #6 and the subsequent gradual restoration of the free-flowing river sections. Compton et al. (2017). assessed physical conditions and the floral diversity and relative species abundances along the Green and Nolin rivers. Their methods involved a systematic approach to "obtain adequate coverage and account for the potential variability of the riparian zone along the 24 river kilometers within the study area" (Compton et al. 2017). Thirteen plots on the Green River and two plots on the Nolin River were surveyed; detailed methods are described in Compton et al. (2017). Species composition and richness within the riparian zone was relatively similar between the hydrological sections (free-flowing versus impounded). However, with dam removal and the associated bank erosion and canopy loss, invasive herbaceous species such as Oriental lady's thumb (Persicaria longiseta) and Japanese stiltgrass (Microstegium vimineum), indicative of disturbed habitats, were common (Compton et al. 2017).



Figure 4.89. Lindsay Smart (left, NatureServe) and Leslie Meng (NPS) survey a vegetation plot within the park (NPS photo by Milo Pyne).

Reference Conditions/Values

There are a number of reference values with regard to plant communities that have been generated in the various survey and resource analysis projects at the park and can vary depending on landscape

unit and habitat type (upland, riparian area, wetlands). For example, certain upland plant communities such as Oak-Forest Woodlands and Barren/Prairie Plantations could consider pre-European settlement conditions as a reference of which to compare current condition and trend. For wetlands species, Yahn et al. (2014) used the Coefficient of Conservatism (Table 4.35) to quantify how native plant species in an area adapt to anthropogenic alteration and found it to be in the 6–10 range for the species evaluated. Yahn et al. (2014) also, at the site level, evaluated environmental quality and ranked wetland sites as either Tier 1 (good to excellent condition), Tier 2 (fair to good condition), and Tier 3 (poor to fair condition). Yet, as we are rating the overall native plant community, there is a not a single metric that we can draw on to quantify the whole picture. In this case, we have evaluated the available information and use professional judgment and discussions with both MACA S&RM and CUPN staff to arrive at our conclusions.

Table 4.35. Description of the Coefficient of Conservatism that describes how plants adapt to anthropogenic alteration, which in turn can be used to evaluate the quality of natural habitats. Taxa in the highest range have very low tolerance for human landscape alteration, and so their presence is restricted to high-quality natural areas (Yahn et al. 2014).

CoC value range	Description
0–1	Taxa adapted to severe anthropogenic habitat alteration, occurring so frequently that often only brief periods are available for growth and reproduction of the species. These species are also able to colonize areas with high degrees of anthropogenic alteration.
2–3	Taxa associated with somewhat more stable, though degraded, environments.
4–6	Taxa that persist with moderate alteration, but which decline with more intense, long-lasting, or frequent anthropogenic alteration. Many are also present in natural areas, and may be dominant or matrix species with broad habitat tolerance.
7–8	Taxa associated mostly with well-established natural areas, but that can be found persisting where the habitat has been degraded somewhat.
9–10	Considered to be restricted to high-quality natural areas, including those which show high frequencies of natural disturbance such as flooding or fire. These species often exhibit a high degree of fidelity to a narrow range of habitat requirements, but may be tolerant of a broader range of high-quality natural habitats.

Condition and Trend

Native plant communities play a crucial role in maintaining the services rendered by vegetation to the ecosystem. The most significant stressors on native plant communities include non-native plants, insect and fungal pests, climate change, and fire suppression (NPS 2001, NPS 2017c). Because vegetation resources are so valuable to humans and wildlife and equally vulnerable to a number of stressors, long-term monitoring efforts have been established throughout the park system with the goal of better management of said resources. In general, changes in plant communities at MACA resemble regional trends in the central Mississippi Valley (NPS 2017c). Pyne et al. (2010) added 79 either new or previously un-confirmed species to the overall count in 2010. According to statistical analysis, more than 90% of the vascular flora of MACA has been documented which shows species

richness between 837 and 945 using data from full plot surveys (Pyne et al. 2010). Condition for each landscape unit is discussed below.

Uplands

The NPS ranks forest vegetation as a high priority resource for monitoring at MACA. Forest vegetation resources are valuable in terms of recreational environments, wildlife habitat, soil and water protection, influence on weather patterns, and their status as carbon stores (NPS 2017c). In 2011, CUPN began a program of forest vegetation monitoring. Findings indicate that MACA is dominated by oak and hickory forest types representing much of the upland areas of the park. Together, these species represent 46% of tree basal area among sampled plots and dominated in the canopy strata. Results from fire effects monitoring indicate that forest succession to a closed canopy is occurring as shade-tolerant species still dominate the understory even though the preferred oak-hickory overstory remains intact (Burton 2013). Shade tolerant species such as red (*Acer rubrum*) and sugar maples and beech trees dominate in the sapling strata (CUPN 2013). Scientists did not observe any distinct issues with tree health or decline during this period. However, 13 new species were added to the park species list because of 2011–2015 monitoring and a previously unknown vegetation community of "Interior Mid- to Late-Successional Sweetgum-Oak Forest" was discovered during Phase I (Bledsoe 2017). Yahn (2018) also reports a first-time record of globally rare, cream ticktrefoil (*Desmodium ochroleucum*) in the park found during recent KSNPC surveys.

Riparian Zones

In 2017, scientists with KSNPC evaluated changes in riparian vegetation along the Green River associated with the removal of Lock and Dam #6 and the subsequent gradual restoration of the free-flowing river sections. Among the riparian habitats, Japanese stiltgrass and Oriental lady's thumb, Indian woodoats (*Chasmanthium latifolium*), and mild water-pepper (*Polygonum hydropiperoides*) dominated banks. Although still frequently encountered, lower abundances of Virginia cutgrass (*Leersia virginica*), Canada clearweed (*Pilea pumila*), and American hog-peanut (*Amphicarpaea bracteata*) were also observed. The comparatively lower frequency of observations for these last three species could indicate deteriorating habitat conditions as these are native riparian species commonly found in Kentucky (Compton et al. 2017). While important to the overall plant diversity, the vegetation in these zones also protects water quality through reduction of sedimentation, maintaining lower water temperature, nutrient sequestration, bank stabilization, and providing food and habitat for both terrestrial and aquatic life (Third Rock Consultants LLC 2010). Additional long-term monitoring is recommended to assess the condition and evolution of the riparian zones in respect to dam removal and modified dam operations. As riparian zones within the park are protected, return to a natural flow regime with modified dam operations could minimize disturbance of these areas, which in turn could inhibit invasive species, potentially the greatest threat to the vegetation in this landscape unit.

Wetlands

Recent surveys show several rare native plants in MACA wetlands as well as in surrounding areas, although other previously known species have not been identified in more recent surveys.

Kentucky State Nature Preserves Commission (KSNPC) surveyed wetland communities in MACA during 2012–2013 and reported the occurrence of three rare native plants including cypressknee sedge (*Carex decomposita*), spotted pondweed (*Potamogeton pulcher*), and sessile-fruited arrowhead (*Sagittaria rigida*). Since the initial record of its occurrence in 1987, the only population of sessile-fruited arrowheads in Kentucky was in MACA. Park botanists observed the species during surveys in 2006 and 2007, but 2013 surveys failed to produce any specimens. Drought conditions in the preceding year may have accounted for the absence, and the species was discovered in a new location on the park in 2014. Also of interest is a partial, unconfirmed specimen collected during wetland surveys that appears to be Rafinesque's seedbox (*Ludwigia hirtella*). The possible occurrence of Rafinesque's seedbox is significant as the species is native to MACA, but no records exist for Hart County and the most recent record from Chalybeate, in Edmonson County, dates to 1897 (Yahn 2015). The same survey demonstrated that several rare plant species native to the park were not present during Yahn's wetland surveys.

Rare, native plant species not observed in surveyed wetlands, but present in surrounding areas include blue mudplantain (*Heteranthera limosa*), crossleaf milkwort (*Polygala cruciata*), grassleaf arrowhead (*Sagittaria graminea),* straw sedge (*Carex straminea*), sharp scaled manna grass (*Glyceria acutiflora*), shorts hedgehyssop (*Gratiola viscidula*), pickeralweed (*Pontederia cordata*), and tall beaked rush (*Rhychospora macrostachya*). In addition, the giant sedge (*Carex gigantea*) was observed on the park during 2012–2013 wetland surveys, representing a new record for Hart County. Further studies may yield additional occurrences of other rare species known to exist in MACA and will likely generate new records of wetland dependent species not previously known to the park. The wetland survey report notes that temporarily-saturated meadow grass areas are of importance as these are rare in Kentucky and they provide habitat that serves a number of rare species, such as crossleaf milkwort (*Polygala cruciata*), which is gone from Edmonson County, but may still be found in other sections of the park. Such rare species may benefit from the inclusion of short-saturated meadow grass areas in prescribed burns (Yahn 2015).

Threats from Non-native Species

The destructive impacts of non-native and invasive plant species on habitats within the park and elsewhere merits some discussion when considering changes in species richness observed among the native plant communities of MACA (Figure 4.90). In most cases, species richness is increasing among exotic and invasive plant species at the expense of native plant communities. Native species are those that historically occurred or presently exist in a given ecosystem by means other than introduction. Non-native (also referred to as exotic or non-indigenous) species are capable of propagating in habitats where the species is not native (Executive Order 13112 1999). Because these species are introduced in habitats where they are not naturally present, they often have few or no natural controls or predators. This lack of natural control can allow non-native species to outcompete and displace native communities, thereby becoming an invasive species. Invasive species are non-native species whose introduction creates, or is likely to cause economic or environmental harm or harm to human health (Executive Order 13112 1999).

As of 2017, 174 species of non-native plants were documented in MACA (Appendix B), and any of these can have adverse effects on growth of native plants (Olson 2017c). Phase I of CUPN's forest vegetation monitoring at MACA provided some useful information regarding the threat posed to native plant communities by non-native and/or invasive species and pests. Preliminary results from 2011–2012, reported the presence of seven non-native plant species in the sixteen sample plots, with at least one non-native species being found on 12 of the plots. Compared to other CUPN parks, the average number of non-native species per plot was higher at MACA than other CUPN parks for this time period. During the two years, Japanese honeysuckle (*Lonicera japonica*) (62.5% of plots), Japanese stiltgrass (62.5%), Chinese privet (*Ligustrum sinense*) (12.5%), and Chinese lespedeza (*Sericea lespedeza*) (12.5%) were the most common non-native species encountered (CUPN 2013). Similar results can be observed from the entirety of the Phase I monitoring at MACA, which included 52 monitoring plots. Only twelve of 411 (2.9%) species identified from plots during Phase I were non-native. In addition, non-native species composed only approximately 1.4% of overall average plot species diversity at MACA (Bledsoe 2017). This may suggest that the impact of non-native plants on native forest vegetation might be less severe at MACA than in other CUPN parks (Figure 4.90).



Figure 4.90. Volunteers from the Mammoth Job Corps Center near park clear Chinese bush clover (*Lespedeza cuneata*). With limited resources, MACA relies on student interns and volunteers to help with exotic species control (NPS photo by Brice Leech).

Other non-native plants found on the park, but outside of monitoring plots include European privet (*Ligustrum vulgare*) and the invasive common reed (*Phragmites australis*) (Bledsoe 2017). Callery pear (*Pyrus calleryana*), a highly invasive non-native tree, was also found in the park during vegetation monitoring in 2017 at a roadside location (Clare Bledsoe, Biologist, CUPN, September 2018, personal communication). Both the common reed and Callery pear are ranked as a "severe threat" by the Kentucky Invasive Plant Council (CISEH 2013). The population of common reed was eradicated from the park in 2016, and a tree-sized individual of the Callery pear was treated and removed in 2018 (Claire Bledsoe, Biologist, CUPN, September 2018, personal communication).

Botanists conducting KSNPC wetland surveys in 2012–2013 noted that nearly all park wetlands were infested with non-native Japanese stiltgrass. This exotic has displaced native plants and consequently, species composition no longer reflects the natural conditions of these wetland habitats. To conserve natural fauna, KSNPC also recommended targeting other invasive plants, including barnyard grass (*Exhinochloa crusgalli*), Japanese honeysuckle, and multiflora rose within the park.

Recent evaluation of riparian vegetation on the Green River notes that the invasive species Oriental lady's thumb and Japanese stiltgrass were common in the riparian zone, indicating a disturbed habitat. Oriental lady's thumb is considered a "significant threat" by the Kentucky Invasive Plant Council (CISEH 2013) and its dominant growth is predicted to continue along unstable banks and areas where mature canopy is absent (Compton et al. 2017). Some native plants, such as Indian woodoats and mild water-pepper are capable of competing with Oriental lady's thumb and may slow the progression of the spread. During a recently completed survey of upland vegetation in the park, Yahn (2018) noted that limited stands of buffer forest can render vegetation at greater risk for invasion by exotic plant species.

Insects and Fungal Pests

Changes in native plant communities in MACA associated with insect and/or fungal pests have been evaluated in MACA over recent years. The emerald ash borer (EAB) is an insect pest native to Asia that is responsible for the destruction of millions of ash trees in the United States and Canada (Poland and McCullough 2006). EAB was confirmed at MACA in 2018. Working with the state of Kentucky entomologists and forest managers, it is the park's plan to introduce the biological controls for EAB (Brice Leech, Resource Management Specialist, October 2018, personal communication). The biological controls would consist of three species of small, non-stinging wasps that prey on the EAB at different stages of its life cycle. These wasp predators are also native to Asia and through studies are found to be highly specific to preying on the EAB. The hemlock woolly adelgid (HWA), though not currently known to be present in the park, is established in Kentucky and has been confirmed within 160 km of the park in Pulaski and Wayne counties (University of Kentucky 2018a). HWA has the potential to eliminate the micro-ecosystem of the hemlock forests, a rare plant community at MACA primarily located in the northwest portion of the park extending beyond park boundaries. The disappearance of these canopy trees would increase temperature within these microecosystems, eliminating the conducive nature of hemlocks repopulating these habitats. There is not a present plan in place at MACA to protect these trees from HWA, albeit searching for HWA at any time

employees are in the vicinity (Brice Leech, Resource Management Specialist, October 2018, personal communication).

The European gypsy moth (EGM) is another insect pest of concern and following early detection protocol, MACA has been actively monitoring for them for over a decade and luckily, they have not been found to date (Larry Johnson, Resource Management Specialist, October 2018, personal communication). However, the gypsy moth is established and decimating forests in border states. In West Virginia, for example, the gypsy moth was responsible for defoliation of over 1.5 million hectares between 2000 and 2002. Male gypsy moths are caught in Kentucky each year, the closest capture to the park being in Meade County (University of Kentucky 2018b). The USDA considers Kentucky at a particularly high risk for this pest (USDA 2018b).

Exotic diseases such as chestnut blight (*Cryphoctria parasitica*) and butternut canker (Sirococcus clavigignenti-juglandacearum) have already had serious impacts on park forests (Olson 2017c). Thompson et al. (2006) reports that surveys show a "drastically reduced" butternut population at MACA, a species that was once considered abundant in the park and surrounding areas (Bailey et al. 1933). Butternut trees were noted by John Muir (1916) at the Historic Entrance in the late 19th century and Lucy Braun (1950) noted that the butternut was over 10% of the forest community of the lower slopes and flats during her studies in the mid to late 20th century. Though more recent surveys are needed, records show just over 100 butternut trees in and around the park's boundaries with many succumbing to butternut canker (Brice Leech, Resource Management Specialist, October 2018, personal communication). Observations at MACA show that trees suffering from the canker disease do not sprout successfully and the entire tree dies. Unfortunately, according to Dr. Scott Schlarbaum, a forest researcher at University of Tennessee, efforts to preserve the nuts from the butternut tree for future planting has failed (Brice Leech, Resource Management Specialist, October 2018, personal communication). The work of Thompson et al. (2006) does indicate hope for possible restoration of the species but additional research is necessary before field implementation is possible.

Chestnut blight fungus decimated American chestnut populations during the early 20th century (McCormick and Platt 1980). The loss of this historically dominant forest species is considered one of the most important events in the history of the eastern North American forest (McEwan et al. 2005). The American chestnut was a prominent component of forests in and around MACA based on records of European explorers in the area prior to establishment of the land as a national park (e.g., Hussey 1876) and witness tree data (McEwan et al. 2005). The blight drastically reduced chestnuts within the park during the 1930s and 1940s, and nearly all large chestnuts were dead in MACA by the late 1940s. Optimum conditions for sustaining American chestnut growth within MACA have been modeled as part of efforts to breed and cultivate this species in the wild (Fei et al. 2007). This type of spatial modeling not only highlights the habitats chestnut sprouts are most successful in, but it also provides information about areas in MACA that could sustain a comeback of the American chestnut. In fact, there has been an effort to both reintroduce the American chestnut back into the landscape, and find surviving chestnut trees across the park. The reintroduction effort placed over 7,000 American chestnut trees in 53 different locations throughout the park between 2002 and 2010. Surveys in 2009 found 21% of those surviving. Dr. Joe Shebig and staff from Tennessee Tech found

over 2000 living American chestnut trees in the Big Woods and Dennison Ferry, though most were seedlings and saplings (Brice Leech, Resource Management Specialist, October 2018, personal communication). Subsequent searches have found two larger living specimens, a 20 cm diameter at breast height (dbh) and a 32 cm dbh with several sprouts at its base. Unfortunately, the larger of the two died two years after being found.

Another exotic fungal disease of concern is the dogwood anthracnose (*Discula destructive*) which appears to be affecting the flowering dogwood (*Cornus florida)* population at MACA. First identified in the US in the late 1970s, dogwood anthracnose is an aggressive fungus that can cause mortality in one to three years and kill saplings in a single season (Daughtrey et al. 1996). Park staff began to notice an inordinate number of dead or dying dogwoods in the early 2000s and a preliminary survey was conducted in 2004 (NPS 2004a). Over 2,000 dogwood trees were identified in ten randomly selected plots throughout the park; 29%, were classified as alive and healthy, 38% were alive but stressed or impacted, 5%, were classified as dying (50% dead), and 28% were found dead (NPS 2004a; Table 4.36). Though not laboratory confirmed, experts from the University of Kentucky and University of Tennessee identified dogwood anthracnose during the 2004 survey by physical examination (Larry Johnson, Resource Management Specialist, October 2018, personal communication). As the disease has been present in the region since 1994, it is possible that dogwood populations have suffered dramatically, however more research is needed to confirm the cause of dogwood deaths and assess current status of this native species (Daughtrey et al. 1996).

Condition Summary

Table 4.36. Graphical summary of status and trends for native plants.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Native plants	Species richness and diversity		Overall, MACA protects a very rich and diverse assemblage of native plants, over a heterogeneous range of landscape conditions, including important rare plants. We have high confidence following a number of systematic surveys by MACA and CUPN. There is concern because of the current and expected influences of invasive plants and exotic insect pests and disease.

Sources of Expertise

Brice Leech (Resource Management Specialist, MACA Division of S&RM), Rick Toomey (Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM), Shannon Trimboli (Citizen Science Coordinator, MACA Division of Interpretation and Visitor Services/Western Kentucky University Ogden College), Clare Bledsoe (Biologist, CUPN), Bill Moore (Supervisory Ecologist/Data Manager, CUPN), Steve Thomas (Monitoring Program Leader, CUPN), and Milo Pyne (Senior Regional Ecologist, NatureServe) provided expertise for this section.

4.7.2. Native Animal Communities

Description

There are numerous animal species that are native to the park area, many of which have been discussed in other sections of this report including reptiles, amphibians, birds, fish, mussels, and all representatives of cave life. With regard to mammals, woodrats have been discussed in the cave communities section, bats were discussed in their own section, and deer will be given additional treatment as a resource in themselves within this section. Several other native mammals are present in the park and may represent important parts of the community. However, study of these organisms has been very limited, and data to evaluate trends in species diversity, distribution, threats/stressors, species changes, etc. are insufficient. This assessment of native animals at MACA should be considered qualitative with the need for additional study to fill existing data gaps.

Additionally, although insects are not included in the framework for this limited assessment of native communities, some mention of these is appropriate as numerous species of flying insects, particularly of the order Lepidoptera (butterflies and moths) are important prey to birds and bats. Other insects are food sources for some of the small mammals and fish present at MACA. Furthermore, several insects are pollinators that are vital to reproductive processes of native plants, while other insects are pests that may threaten native trees and plants at MACA. The role of insect pests among native plants is discussed in the preceding section, 4.7.1 Native Plant Communities. There has been relatively little research into the condition of insects at MACA and most recent studies have focused primarily on flying insects, specifically members of the order Lepidoptera (butterflies and moths) (Covell 1998; Dodd et al. 2012, 2015; Griffitts 2016; Fulton 2017). Multiple recent studies have evaluated insects as prey for insectivorous bats at MACA to better understand connections between bat foraging behaviors, WNS, and prescribed burn areas.

Dodd et al. (2012) found Lepidopterans were the most frequently detected prey among bat fecal samples in traditional morphological as well as DNA-based techniques. Lepidoptera were surveyed during this study using blacklight traps to develop a relative index of insect prey abundance. Noctuids (owlet moths) were most abundant, but a number of other Lepidopteran families were common including Geometridae (geometer moths), Arctiidae (tiger moths), Notodontidae (prominent moths), Pyralidae (snout moths), Lasiocampidae (lappet moths), Saturniidae (wild silk moths), Oecophoridae (concealer moths), Limacodidae (cup moths), Tortricidae (tortrix moths), and Lymantriidae (tussock moths). Dodd et al. (2012) documented predation of several Lepidopterans that are important agricultural and forest pests including Torticidae larvae (leaf rollers and tiers, as well as root, stem, and fruit borers of broad economic importance) and the eastern tent caterpillar (*Malacosoma americanum*), a defoliator of rosaceous trees (Covell 2005). Dodd et al. (2012) concluded that the diversity of Lepidopteran consumed across bat species is reason to orient conservation goals towards promoting land management and forest stewardship practices that contribute to a diverse prey base. Griffitts (2016) documented substantial changes with respect to bats and insect prey community composition pre- and post-WNS detection, and in relation to prescribed burn areas. Total insect abundance was found to be greater after WNS ($P<0.01$). Abundance was greater post-WNS and in unburned areas for Lepidoptera ($P < 0.01$). Coleopterans (beetles) were in greater abundance following the arrival of WNS at MACA and among burned areas

($P<0.05$). Abundance of Dipterans (flies) was unchanged throughout the study and did not show a significant interaction with either WNS or prescribed burning ($P\geq0.05$). Fulton (2017) assessed the insect assemblage at MACA pre- and post-WNS in addition to energetic value of various Lepidopteran species as prey for bats. Only minor differences in caloric value of Lepidopteran prey were observed, such that Lepidopterans among various size classes may be of similar prey quality. The orders Lepidoptera and Coleoptera comprised a smaller percent of the insect assemblage relative to Diptera and other orders prior to WNS. However, following detection of WNS, the percentage of Lepidopteran and Coleopteran insects increased whereas Dipteran and other orders decreased. Concurrently, bat assemblage composition shifted from mostly *Myotis* and mid-frequency species prior to WNS to low-frequency bat species post-WNS detection. This suggests that Lepidopteran and Coleopteran insects, which are preferred prey for mid-frequency and *Myotis* species, have experienced increases in relative abundance that are inversely proportional to the decrease in said bat species following detection of WNS. Diptera and other insect orders have decreased proportionally to decreases in mid-frequency species following WNS at MACA. Greater diversity among Lepidopteran prey size was also observed post-WNS detection. Fulton concluded that although WNS was a primary driver impacting bat abundance and distribution, prescribed fire and the composition of insect communities are also important contributors to observed patterns in bat assemblage diversity and composition.

Data and Methods

The data that supports this limited assessment of the native animal communities draws heavily on the Inventory of Terrestrial Wild Mammals at MACA (Thomas 2013). This natural resource technical report represents the most recent assessment of the presence, abundance, and distribution of the various mammal species on the park.

Reference Conditions/Values

Large, Herbivorous Mammals

Thomas (2013) documented white-tailed deer primarily from remote "trail" cameras placed at 25 locations in the park, supplemented by a few visual records.

White-tailed deer

White-tailed deer are found throughout Kentucky in a wide range of habitats (Barbour and Davis 1974, Whitaker and Hamilton 1998). White-tailed deer have historically been part of the natural wildlife at MACA. Unfortunately, by the 1930s, the native subspecies of whitetail deer in the area that would be eventually established as MACA had been extirpated. No historical population numbers are available and no recent study of the current population of white-tailed deer in the park exists. In the 1960s, a conservation project designed to repopulate white-tailed deer at MACA was successfully initiated with a systematic reintroduction of northern white-tailed deer from a population in Michigan, which are genetically related to the native subspecies. Within a decade, the reintroduction resulted in an explosion in the population of white-tailed deer and notable damage to native plant communities was observed. Deer are robust herbivores and, because of the lack of natural predators and hunting, consumed many native plant species to local extinction within the park (Larry Johnson, Resource Management Specialist, MACA Division of S&RM, November 2017,

personal communication). Thomas (2013) documented white-tailed deer in Barren, Edmonson, and Hart counties from 101 records consisting of 97 remote camera photo records, three sightings, and one specimen found dead and collected (Williamson 2009). This species is considered widespread and abundant on the park (Thomas 2013).

Several internal NPS projects in the 1980s evaluated over-population and damage to the native plant communities by white-tailed deer (Larry Johnson, Resource Management Specialist, MACA S&RM, November 2017, personal communication). These collectively resulted in an NPS management decision to address the over-population in the park with a relocation program. Hundreds of animals were captured and redistributed throughout Kentucky. The state population, managed primarily for hunting resources through the Deer program of the Wildlife Division of the Kentucky Department of Fish and Wildlife Resources, is funded from the sale of hunting and fishing licensees as well as boating registration fees and other federal funds.

No current or recent study of the MACA deer population exists. This is a significant data gap as over-population of deer may act as a stressor for plant communities. Decreasing the current population, which lacks natural predators, would gradually improve the ecosystem and altered regime of the forest ecosystem. While an accurate current count is unavailable, NPS staff indicated concern with potential over-population, particularly regarding the negative impacts on native plant communities.

There is a complete lack of knowledge of current population density. However, a multiple-year estimate of population using a flat, fixed survey plot could effectively address this gap. This would establish a baseline inventory. The current population, suspected to be too high, may be beyond sustainability. Additionally, a population index could also be estimated with a selected transect to monitor groups of deer pellets each week. This would provide a correlation index that is easily measured and consistent.

Small and Medium-sized Non-carnivorous Mammals

Thomas (2013) observed 22 species of small-sized, non-carnivorous mammals on the park. Four orders (Didelphimorpha, Soricomorpha, Lagomorpha, and Rodentia) were represented from this study including one opossum, five shrews, one mole, one rabbit, five squirrels, one beaver, and nine members of the mouse/rat/vole family.

Nine-banded armadillo

The nine-banded armadillo (*Dasypus novemcinctus*) has recently expanded to the park. Although the species is not currently included in the park species list generated by NPSpecies, several unconfirmed observations of armadillo sign reported in and the park have been deemed reliable, and dead armadillos have been seen on the road within a couple of miles of the park. However, but no confirmed sightings or other observations currently exist for MACA (John MacGregor, Herpetologist, KDFWR, October 2018, personal communication, Steve Thomas, Monitoring Program Leader, CUPN, October 2018, personal communication). The armadillo is a native species that has been expanding its range since the late 1800s. While this organism represents a change in park fauna, it should not be considered as a threat to existing populations. Current data regarding

distribution and abundance at MACA is limited, and will deserve additional consideration in future evaluations of park fauna.

Virginia opossum

The Virginia opossum is an omnivorous mammal that exhibits distribution among a wide range of habitats in Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to the inventory conducted by Thomas (2013), the species was represented by two museum records collected in the mid 1930s, and more recent records of tracks observed at scent stations along the Green and Nolin rivers in 2002–2003 (Asmus 2004). Thomas (2013) collected four records of the species including a specimen that was found dead, two remote camera photos, and a sighting. The species is considered widespread and common at MACA.

Northern short-tailed shrew

The northern short-tailed shrew (*Blarina brevicauda*) is considered ubiquitous and can be found in a wide variety of habitats in Kentucky with the exception of the Jackson Purchase area of far western Kentucky where it has been replaced by the smaller southern short-tailed shrew (Barbour and Davis 1974, Whitaker and Hamilton 1998). Barbour and Davis (1974) described that species as perhaps the most common mammal in Kentucky. During an inventory by Thomas (2013), the species was documented in Barren, Edmonson, and Hart counties by 42 records from 40 specimen collections and a pair of sightings. The northern short-tailed shrew is considered common and widespread on the park.

A single specimen was collected in October 2005 in Edmonson County exhibiting morphological measurements intermediate between the northern and southern short-tailed shrew. It was identified to the genus-level (*Blarina*) and assigned as an "unconfirmed" southern short-tailed shrew for its "Park Status in 2013".

Least Shrew

The least shrew (*Cryptotis parva*) is a small shrew that occurs almost exclusively in grasslands and can be found throughout Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to the inventory by Thomas (2013), the least shrew was known on the park from one visual sighting and one museum specimen, both taken during the 1930s, and a more recent sighting in 2004 observed beneath a piece of tin in 2004 by John MacGregor. The least shrew was documented during Thomas (2013) by 17 records in Barren, Edmonson, and Hart counties including 12 collections and five sighting. The species distribution is restricted to grassy, open areas (which are becoming less available as forested areas increase), and is considered uncommon at MACA.

Smoky Shrew

The smoky shrew (*Sorex fumeus*) seems to prefer moist, shady woodlands where moss-covered rocks and logs are present and can be found in eastern and south-central Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998, Thomas 2001). Prior to the inventory by Thomas (2013), the species had not been reported from Barren or Hart counties. Four specimens were captured in Edmonson County during the early 1930s at the Historic Entrance to Mammoth Cave (Bailey et al. 1933, Barbour and Davis 1974), one specimen in the park museum was collected in 1934, and more recently a skull was found in 2003 by Steven Thomas in Edmonson County. During the inventory by

Thomas (2013) the smoky shrew was documented from 22 records of collected specimens in Barren, Edmonson, and Hart counties. The species is restricted to mesic woodlands and is considered rare on the park.

Pygmy Shrew

The pygmy shrew (*Sorex minutus*) is the smallest shrew found on the park and is among the smallest mammals in the world. It seemingly prefers to inhabit the slopes of wooded ravines with fallen logs and leaf litter, and can be found in eastern, western, and south-central Kentucky (Whitaker and Hamilton 1998, Thomas 2001). Previous to the Thomas (2013) inventory, the species had not been reported at MACA, or in Barren, Hart, or Edmonson counties. During the Thomas (2013) inventory the pygmy shrew was represented in Barren, Edmonson, and Hart counties by 13 records, all made as specimen collections. The pygmy shrew displays restricted distribution in rich woods, particularly where topographic relief is present, and is considered rare on the park.

Southeastern Shrew

The southeastern shrew (*Sorex longirostris*) is a medium-sized shrew that occurs in a relatively wide variety of habitats, but is most abundant in lowlands (Barbour and Davis 1974, Whitaker and Hamilton 1998). It is present throughout most of Kentucky (Barbour and Davis 1974, Thomas 2001). The species had not been documented in the park, Barren, Edmonson, or Hart counties prior to the inventory by Thomas (2013) but was represented by 24 records, all specimen collections, in Barren, Edmonson and Hart counties by Thomas (2013). Although the species is widely distributed, it is rare on the park.

Eastern mole

The eastern mole (*Scalopus aquaticus*) is a fossorial creature that can be found statewide in Kentucky among a wide range of habitats where loose, well-drained soils exist (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past, the species was represented by a single specimen in the park museum collected in 1934, and more recently two visual and two sign records taken in 2004. Thomas (2013) documented the eastern mole in 11 records from Barren, Edmonson, and Hart counties including six collected specimens, and five visual observations. The species is considered widespread and common on the park.

Eastern cottontail

The eastern cottontail (*Sylvilagus floridanus*) can be found throughout Kentucky among a wide range of open or sparsely forested habitats (Barbour and Davis 1974, Whitaker and Hamilton 1998). The species had not been documented from MACA based on collected specimens or specific sightings, although it was included in two general checklist reports from 1934 and 1969. Thomas (2013) documented it in Barren and Edmonson counties by six records including one photographed dead specimen, one live capture, an observed dead specimen, and three live sightings. The species is restricted to thick, brushy openlands and areas with few trees. It is considered common on the park.

Eastern chipmunk

The eastern chipmunk (*Tamias striatus*) is a ground-dwelling squirrel species that occurs statewide in Kentucky among a wide variety primarily-forest habitats (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past the species was known to the park from one museum specimen collected

in 1934, and 13 live captures from 1997 to 1999 (Thomas 2003). Thomas (2013) documented the eastern chipmunk in Edmonson County from a single live capture. The species mainly uses wooded areas or woodland margins, and is common on the park.

Woodchuck

The woodchuck occurs throughout Kentucky but is more common in the eastern portions of the state. The species is found in a wide variety of habitats, but is most abundant in sparsely wooded areas (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past, the species was known to the park from one specimen in the park museum that was collected in 1935, and a more recent sighting by Steven Thomas in 1997. Thomas (2013) documented the woodchuck from seven records in Barren and Edmonson counties including one collected dead specimen, one live capture, and five sightings of live individuals. Woodchucks are considered widespread and common on the park.

Eastern gray squirrel

The eastern gray squirrel (*Sciurus carolinensis*) is a species of tree squirrel that occurs throughout Kentucky in a wide variety of forested habitats (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to the inventory by Thomas (2013), the species was represented at MACA by a specimen in the park museum collected in 1935, a visual record from the same time period, and another sighting reported in 1978. Thomas (2013) documented the gray squirrel from eight records in Edmonson County including one dead collected specimen, two other dead specimens which were not collected, two remote camera records, and three live sightings. The species is considered widespread and abundant on the park.

Eastern fox squirrel

The eastern fox squirrel (*Sciurus niger*) is a species of tree squirrel found statewide in Kentucky, particularly in the Bluegrass and far west, across a wide variety of sparsely forested habitats (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past the species was not documented on the park based on any specimen collection or specific sighting, but was included in two general checklist reports in 1934 and 1969. Thomas (2013) documented the eastern fox squirrel in four Edmonson County records including one collected dead specimen, and three sightings of live individuals. This species tends to use half-open oak or hickory stands and similar areas where few trees are present, and is considered uncommon on the park.

Southern flying squirrel

The southern flying squirrel (*Glaucomys volans*) is a species of tree squirrel that occurs throughout Kentucky in a wide variety of forested habitats (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to the inventory by Thomas (2013) the species was represented by one specimen collected near Mammoth Cave in the early 1930s (Bailey et al. 1933), two specimens in the park museum collected in 1934, a sighting from the same time period, and more recently from one auditory record by Steven Thomas in 2004. Thomas (2013) documented the southern flying squirrel in two Edmonson County records including one live capture in a mist net intended for bats, and one auditory record by Steven Thomas. This species is considered widespread and common on the park.

American beaver

The American beaver is the largest rodent species in North America and can be found throughout Kentucky in a wide range of forested habitats where adequate water bodies exist (Barbour and Davis 1974, Whitaker and Hamilton 1998). Bailey et al. (1933) reported a lack of the species in the Mammoth Cave area for a generation or more in 1933. In the past, the species was represented at MACA from three specimens in the park museum collected on an unknown date, and more recently from two sighting in 1978 and 1980, and by six spotlight survey records in 2002 (Asmus 2004). Thomas (2013) documented the American beaver in 58 records from Edmonson County consisting of 55 spotlight survey records, one live capture, one remote camera photo, and one sign observation (Williamson 2009). The species is restricted to areas where suitable bodies of water are present, but is common on the park.

Allegheny woodrat

The Allegheny woodrat (*Neotoma magister*) is a native rat species found in eastern and south-central Kentucky in a wide variety of forested habitats where sufficient rocky habitat exists (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to the inventory by Thomas (2013), the species was known to the park from two specimens in the park museum, one collected in 1934 when the species was known as the eastern woodrat (*Neotoma floridana*), and one collected by Steven Thomas in 1997 after the name had been changed (Hayes and Harrison 1992, Hayes and Richmond 1993). Additional documentation included live trapping records from woodrat monitoring 1997–2003 (Thomas 2003), and 16 live trapping records [one report from 1987 (Hayes 1987), and 15 from 2004 woodrat monitoring (Woodman et al. 2007)]. Thomas (2013) documented the species in Barren and Edmonson counties by 86 records including 83 live captures from longterm woodrat monitoring, two collected dead specimens, and one sighting (Woodman et al. 2007). The species is restricted to forested areas with appropriate rocky habitat (e.g., cliffs, caves, boulders), but is common on the park.

Eastern harvest mouse

The eastern harvest mouse (*Reithrodontomys humulis*) is found almost exclusively in grasslands and occurs throughout Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past the species had not been documented from the park based on a collected specimen or specific sighting, but was included in two general checklist reports in 1934 and 1969. Thomas (2013) documented the species from 10 records in Barren and Edmonson counties including six collected specimens, and four live trap capture/releases. The species is restricted to tall, dense grassy open areas and is uncommon in the park as these habitats are mostly being replaced by forested environments.

White-footed mouse

The white-footed mouse (*Peromyscus leucopus*) is one of the most abundant and widely distributed mammals in Kentucky, occurring statewide in a wide variety of forested habitats (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to the inventory by Thomas (2013) the species was known to the park from several individuals captured in the entrance to Mammoth Cave in the early 1930s, one specimen in the park museum collected in 1934, by 16 specimens in the University of Illinois Museum of Natural History collected in 1960, and more recently by 19 sighting records beneath pieces of tin in 2004 (MacGregor 2007). Thomas (2013) documented the white-footed mouse in

Barren, Edmonson, and Hart counties from 72 records consisting of 12 collected specimens, five sightings of live individuals, 54 live trap captures/releases, and one individual found dead but not collected (MacGregor 2007). The species is considered widespread and common on the park.

Prairie vole

The prairie vole (*Microtus ochrogaster*) is found exclusively in grasslands and occurs nearly statewide in Kentucky except for the mountainous areas in the southeast, where it is absent (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past the species was represented by one specimen in the park museum collected in 1935, and one more recent sighting record beneath tin (MacGregor 2007). Thomas (2013) documented the prairie vole from 17 records in Barren and Edmonson counties including 5 collected specimens, and 12 live trap captures/releases. Although the species is restricted to grassy, open areas, it is common on the park.

Woodland vole

The woodland vole (*Microtus pinetorum*), distinguished by its short tail, is found in a wide range of habitats throughout Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). Previous to the inventory by Thomas (2013) the species was known to the park from three specimens in the park museum collected in 1934, and more recently by one specimen found dead and collected by Steven Thomas in 2002, as well as 17 sighting records beneath tin in 2003 and 2004 (MacGregor 2007). Thomas (2013) documented the woodland vole in Barren, Edmonson, and Hart counties by 11 records consisting of 5 collected specimens and six sighting records beneath tin (MacGregor 2007). The species is considered widespread and common at MACA.

Southern bog lemming

The southern bog lemming (*Synaptomys cooperi*) is a short-tailed lemming that can be found in a variety of grassland habitats throughout most of Kentucky, except for the far western part of the state (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to Thomas (2013) the species was not reported from the park or from Edmonson County (Thomas 2001). Thomas (2013) documented a single record for the southern bog lemming—a sight record underneath tin in Edmonson County (MacGregor 2007). This species is restricted to grassy, open areas, is patchy in its local distribution, and is rare on the park.

Muskrat

The muskrat (*Ondatra zibethicus*) is found throughout Kentucky wherever sufficient bodies of water are present (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past, this species was not documented on the park based on a collected specimen, however Bailey et al. (1933) mentioned they had been considered common in the Green River in the 1920s but were scarce in the 1930s due to the value of their pelts. More recent records include 33 spotlight survey records on the Green River in 2002 (Asmus 2004). Thomas (2013) documented 112 records in Edmonson County including 111 spotlight survey records from the Green and Nolin rivers, and one live capture from the Nolin River (Williamson 2009). This species is restricted to areas where adequate bodies of water exist and is common on the park.

Meadow jumping mouse

The meadow jumping mouse (*Zapus hudsonius*) is long-tailed mouse with large hind feet that can be found in tall, weedy grasslands near streams and occurs throughout central and western Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). In the past, the species had not been documented on the park (or from Barren, Edmonson, or Hart counties) (Thomas 2001). Thomas (2013) documented the meadow jumping mouse from two collected specimen records, one each from Barren and Edmonson counties. The species is restricted to tall-weedy grasslands or open woodlands near streams or moist lowlands, and is considered to be rare on the park.

Medium-sized Carnivores

Red fox

The red fox (*Vulpes vulpes*) occurs throughout Kentucky, predominantly in open areas, agricultural lands, and forest edges, such as the habitat adjacent to much of MACA (Barbour and Davis 1974, Whitaker and Hamilton 1998). This species had not been documented on the park prior to 2012, when a specimen was found dead on Highway 70, approximately 1 km inside the Brownsville Entrance to MACA. This species is considered rare on the park. Additionally, a sighting of an adult occurred in 2017 within the park boundary near the vicinity of Diamond Caverns (Cory Fish, Park Ranger, MACA Division of Interpretation and Visitor Services, September 2018, personal communication).

Gray Fox

The gray fox (*Urocyon cinereoargenteus*) inhabits hardwood forests throughout Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). This species was initially documented in the park in 1959 when an individual exhibiting signs of rabies was shot by a ranger and subsequently tested positive for the disease. During the inventory conducted by Thomas (2013), three records were collected from Edmonson County including one found skull, one specimen found dead on Highway 70, and one sighting record. The species is considered to have widespread distribution in the park but is not common.

Coyote

The coyote (*Canis latrans*) is broadly distributed throughout the eastern United States and occupies a variety of habitats (Whitaker and Hamilton 1998). The species was originally restricted to western North America but has expanded its range to the east through natural and both accidental/intentional transplants (Whitaker and Hamilton 1998). Prior to the start of the Thomas (2013) inventory in 2005, this species was known to the park from a single sighting record and several tracks identified at scent stations along the Green and Nolin Rivers in 2002–2003 (Asmus 2004). During the recent inventory, the coyote was documented in Edmonson and Hart counties from 14 remote camera records, two live trapping captures, and three sighting records. The species is considered widespread and common on the park.

Raccoon

The raccoon prefers wooded habitats and is present throughout Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). Historic records for the species in MACA include one specimen in the park museum collected in 1938, one report of a specimen shot by hunters in 1957, three spotlight

survey records in 2002, and several records of tracks at scent stations along the Green and Nolin rivers in 2002–2003 (Asmus 2004). During the inventory conducted by Thomas (2013) 50 records for raccoons were collected from Barren and Edmonson counties within the park including 32 spotlight survey records, 9 remote camera photo records, 7 live captures, one specimen found deceased, and one found skull (Williamson 2009). The species is considered widespread and common at MACA.

Long-tailed Weasel

The long-tailed weasel (*Mustela frenata*) can be found throughout Kentucky in a wide variety of forested habitats, but preferentially occupies forest edges (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to beginning of the 2013 Thomas inventory, the species was represented by one specimen in the park museum collected in 1935, and one specimen captured live (Thomas 2003). Recent park records come from two sight records on subsequent days in a cave in Edmonson County. Although the wooded and forest edge habitats are preferred by this species exist in MACA, it is considered rare on the park.

Mink

The mink (*Neovison vison*) is found in diverse wetland habitats with permanent water and exhibits statewide distribution (Barbour and Davis 1974, Whitaker and Hamilton 1998). Prior to the inventory by Thomas (2013), this species was known to the park from spotlight survey records and records of tracks and scent stations along the Green and Nolin rivers in 2002–2003 (Asmus 2004). During the recent inventory, the mink was documented in Edmonson County by three spotlight survey records (Williamson 2009). The species exhibits restricted distribution where appropriate habitat exists and is considered rare at MACA.

River Otter

The river otter (*Lontra canadensis*) occurs in diverse wetland habitats where much water is present and is locally distributed throughout Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). The river otter was believed to be extirpated from the state by the early to mid-1900s. During early surveys of park fauna, Bailey et al. (1933) reported that the latest record for the species at MACA was from a specimen caught around 1910. A river otter restoration project was conducted by KDFWR from 1991–1994 in eastern Kentucky (Cramer 1995). During this effort, 25 otters (15 males, 10 females) were released at the Bacon Creek boat ramp along the upper Nolin River in Hart County in February 1994. In early 2001, KDFWR relocated five nuisance otters (2 males, 3 females) from the Wax marina on Nolin Lake to the Green River at the US Route 31E bridge in eastern Hart County approximately 48 km upstream of the park boundary. Prior to the inventory by Thomas (2013) the species was known to MACA from spotlight surveys and tracks identified at scent stations along the Green and Nolin rivers in 2002–2003 (Asmus 2004). During the recent inventory, the river otter was documented from 77 records in Edmonson and Hart counties, including 61 records of sign at live traps and scat sign, 10 remote camera records, 5 live captures, and one spotlight survey record (Williamson 2009, Thomas 2013). The species distribution is restricted to areas where appropriate very wet habitat is present and is considered rare on the park.

Striped Skunk

The striped skunk (*Memphitis memphitis*) occurs statewide in Kentucky in a wide variety of non- to sparsely forested habitats, especially farmland and woodland edge (Barbour and Davis 1974, Whitaker and Hamilton 1998). Historic records of the species on the park were based on sighting and sign in the early 1930s (Bailey et al. 1933). During the inventory by Thomas (2013) the species was documented by two Edmonson County records including a dead specimen, and one sighting of a live individual. This species generally occupies open lands and areas with few trees and is considered common on the park.

Bobcat

The bobcat (*Lynx rufus)* is found in a wide variety of habitats and exhibits sporadic distribution throughout Kentucky (Barbour and Davis 1974, Whitaker and Hamilton 1998). Historic records include sighting tracks in 1934, a sighting of a live specimen in 1980, and spotlight survey records, and records of tracks at scent stations along the Green and Nolin rivers during 2002–2003 (Asmus 2004). More recently, the bobcat was documented from three records in Edmonson County including one remote camera photo record, and two live capture records (Williamson 2009, Thomas 2013). The species occupies a range of habitats, but is considered rare on the park.

Large-sized Carnivores

At least two large carnivores including the mountain lion (*Puma concolor*) and black bear *(Ursus americanus)* may be important considerations for the park as these species begin returning to the Mammoth Cave area. Both species have been reported near the park (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, October 2018, personal communication) and there have been several unconfirmed reports of large long-tailed cats and the American black bear at MACA. Attempts to verify these reports have proven unsuccessful. However, a black bear was confirmed outside the park in Barren County by KDFWR in June 2013 (Thomas 2013). In 2006 park ranger Larry Johnson reported a sighting of a mountain lion crossing KY 255 near Park City, but the species is considered unconfirmed in the park. Since adequate habitat and food sources for both these large carnivores exists at MACA, it is only a matter of time before these animals are back on the park. They will require special management and it may be in the park's best interest to begin developing some intermediate term plans to help control the impact of these species as they return the park.

Condition and Trend

A lack of sufficient long-term data prevents true trend analysis of the condition of the native mammal resources at MACA. However, some qualitative statements can be drawn from the results of the inventory by Thomas (2013). Many native mammals were found to be common, abundant, or very abundant at MACA and exhibited widespread distribution and these organisms are considered to be doing well on the park. This includes the majority of the medium-sized carnivores (striped skunk, raccoon, and coyote), many small and medium-sized non-carnivorous mammals (woodland vole, eastern mole, northern short-tailed shrew, white-footed mouse, eastern chipmunk, Allegheny woodrat, southern flying squirrel, eastern gray squirrel, Virginia opossum, eastern cottontail, woodchuck, American beaver, and muskrat), and white-tailed deer. White-tailed deer were once extirpated from the park area, yet currently represent a population that is becoming overly abundant

and the condition of this resource is improving. However, there is evidence to suggest that the success of the deer population comes at the expense of some native plant communities due to over-grazing.

Among the rare or uncommon native animals, most are medium-sized carnivores (bobcats, red and gray foxes, mink, river otters, and long-tailed weasels) with a few small non-carnivorous species (meadow jumping mouse, southern bog lemming, eastern harvest mouse, least shrew, and eastern fox squirrel). It is difficult to categorize organisms reported by Thomas (2013) as rare or uncommon on the park to improving, unchanging, or declining resource status as many of these creatures, (e.g., bobcats and red foxes) exhibit reclusive, solitary, or territorial behaviors which would be expected to result in fewer observations of these organisms or their sign. Likewise, some rare or uncommon mammals on the park occupy habitats that are not easily surveyed and thus may be underrepresented by surveys despite intensive efforts. The fact that these organisms are not commonly encountered in surveys is not necessarily an indication these species are struggling on the park. An exception may be rare or uncommon native animals that exhibit restricted distribution among habitats that are becoming less available at MACA. For example, the meadow jumping mouse (rare at MACA), eastern harvest mouse (uncommon), and least shrew (uncommon) each demonstrate restricted distributions in open grasslands, the changes in such vegetation types and habitats has been referenced throughout this report (e.g., Campbell 1999, MacGregor 2007, Thomas 2013; Bill Moore, Supervisory Ecologist/Data Manager, CUPN, May 2018, personal communication).

Exotic and invasive species present a threat to the native animals of MACA through competition, and niche disruption. The Norway rat has been documented on the park. This organism is a pest and potentially a threat to the park ecosystem that may prove to be an important consideration in protecting native animal resources on the park. There have also been reports of feral cats, feral dogs, feral hogs, an in one case an emu, and it is assumed that most come from local families & communities (Brice Leech, Resource Management Specialist, MACA Division of S&RM, December 2018, personal communication).

Level of Confidence and Data Gaps

The level of confidence in the assessment is low as significant data gaps exist in research and monitoring among most native animal groups discussed in this section (Table 4.37). The impact of deer on native vegetation is an important data gap that merits attention as some speculate these herbivores have consumed some native plant species to local extinction. The inventory of park mammals by Thomas (2013) provides some idea of the presence, abundance, and distribution of several mammals known to the park, including addition of some species records to the list of park fauna. However, reference conditions and long-term monitoring are lacking for most groups except for a 5-year woodrat monitoring study from 1997–2002 (Thomas 2003), the results of which are discussed in detail in Section 4.13 Cave Communities of this report.

Condition Summary

Table 4.37. Graphical summary of status and trends for native animals.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Native Animals	• White-tailed deer • Small, non-carnivorous mammals • Medium-sized carnivores • Large carnivores		The condition of native animals at MACA appears to be improving slightly but still warrants need for moderate concern. Sufficient data is not available for trend analysis, but a few qualitative inferences can be drawn. There are no quantitative data on deer or the impacts they may be having on native vegetation, but this population is suspected of being over-populous. Several species of small, non-carnivorous mammals are present on the park, many of which are considered rare or uncommon including the meadow jumping mouse, southern bog lemming, eastern harvest mouse, eastern fox squirrel, southeastern shrew, pygmy shrew, smokey shrew, and least shrew. All other small, non-carnivorous mammals discussed are common or abundant where suitable habitat exists (Thomas 2013). The nine-banded armadillo has recently expanded its range to include the park and will need to be considered in future evaluations of park fauna, although at present data is limited. The park also hosts a reasonable diversity of medium-sized carnivores, although many are considered rare on the park including the red fox, long-tailed weasel, mink, river otter, and bobcat. Raccoons, coyotes, and skunks are considered common on the park and are present where suitable habitat and food sources exists. Efforts to restore river otters to the area in the early 1990s appear to have been successful, with numerous records of this species collected from the park in recent years although the species is still considered rare at MACA (Thomas 2013). Some species that have been long extirpated from the park (e.g., mountain lion and American black bear) are returning to the area. The return of these large carnivores will require specific management approaches to preserve park resources. Exotic and invasive species present a threat to the native animals of MACA through competition, and niche disruption. The Norway rat has been documented on the park. This organism is a pest and potentially a threat to the park ecosystem that may prove to be an important consideration in protecting native animal resources on the park. The level of confidence in this assessment is low, due to several data gaps. Research on these groups has been fairly limited. Additional study and long-term monitoring of these and other native animal species is recommended for more accurate characterization.

Sources of Expertise

Brice Leech (Resource Management Specialist, MACA Division of S&RM), Rick Toomey (Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM), and Shannon Trimboli (Citizen Science Coordinator, MACA Division of Interpretation and Visitor Services/Western Kentucky University Ogden College), Clare Bledsoe (Biologist, CUPN), Bill Moore (Supervisory Ecologist/Data Manager, CUPN), and Steve Thomas (Monitoring Program Leader, CUPN), and Milo Pyne (Senior Regional Ecologist, NatureServe) provided expertise for this section.

4.8. Fire Management

There is a significant amount of evidence that supports the existence of pre-settlement fire-adapted landscapes at MACA (Ray 1997, NPS 2001, Olson 2002, Burton 2013, Frost et al. 2013). Historic and current accounts of fire-adapted or fire-tolerant plant species, known fire use by Native Americans and early European settlers, pre-historic artifacts (torches, slippers, paleo-feces), pollen core analysis, potential for natural fire regime via lightning, forest succession ecology, and pre-settlement vegetation models provide the basis for the reintroduction of fire as a tool for maintenance and restoration of ecological processes at MACA (Ray 1997, Olson and Franz 1998, NPS 2001, Olson 2002, Olson and Noble 2005, Olson et al. 2013a, Frost et al. 2013). Therefore, restoration objectives are based on these assumed pre-settlement conditions as well as currently identified and mapped or modeled vegetation types (Olson and Franz 1998, NPS 2001, Burton 2013, Olson et al. 2013a). According to NPS (2016f), restoration objectives are being met with minimal uncertainty, with the exception of Indian Grass grasslands, as specified in Table 4.40. Overall, there has been preservation of preferred overstory canopy, reduced shade-tolerant species, increase in native herbaceous cover, and reduction in total fuel load. Fire effects monitoring results suggest that continued prescribed burning and non-fire actions can indeed restore historic pyrogenic vegetation communities while maintaining and/or improving biodiversity and increasing safety to visitors and infrastructure. Confidence in assessment is moderate as sample size for statistical analysis was limited, additional burns may be needed to fully realize restoration objectives, and more detailed information about prescribed burn and non-fire treatment is not available.

4.8.1. Description

Some of the plant and forest communities that currently exist, or have been known to exist at MACA, appear to be dependent on fire for preservation or prefer open-canopy habitats that fire supports (NPS 2001, Olson 2002, Burton 2013). With European settlement, subsequent development (agricultural, residential, park infrastructure), and fire suppression, habitats that developed under a natural and/or Native American induced fire regime appear to have decreased in extent and diversity, or all but disappeared, with forest succession to non-pyrogenic communities (NPS 2001, Olson 2002, Burton 2013, Frost et al. 2013).

Prescribed burning and wildland fire control can affect communities above and below ground in the types of vegetation present, the fauna that vegetation supports, and the quality and quantity of organic matter, air, and water that enter the cave system (Olson 2002, 2017a). As such fire plans restrict burning to November through April and only when ambient atmospheric conditions would not draw smoke into caves in consideration of sensitive and endangered species such as Indiana (*Myotis sodalis*) and gray bats (*M. grisescens*) (NPS 2009). Griffitts (2016) found that prescribed burning may be especially beneficial in response to WNS in bat populations at the park (See Section 4.8) as affected bats tend to prefer open canopy foraging in response to limited wing mobility caused by the infection. Griffitts (2016) also found increases in Coleoptera species (beetles) in burned areas and proposed that infected bats favored burned areas not only for ease of foraging but also the increase in food sources. Indeed, the NPS (2009) biological assessment determined there were minimal to no anticipated detrimental effects to federal threatened, endangered, proposed and/or candidate species, or general ecological integrity in the evaluation of the 2001 MACA Fire

Management Plan which assessed planned implementation for fires during 2002–2009. Therefore, restoration and preservation of these fire-dependent communities is critical to the overall ecological health of MACA.

Until the late 1990s, MACA's approach to fire management was total suppression following NPS policies outlining this as the best strategy for protection of natural and cultural resources and safety of people and infrastructure (NPS 2001, 2018f). Necessary modifications to this approach were made evident as studies have shown the ecological importance of fire especially in regard to plant and animal diversity as well as increased safety to people and property (Campbell 1999, Burton 2013, Frost et al. 2013, NPS 2018g). Burton (2013) reports that almost one third of the park is covered in upland oak and oak-hickory forest communities which are on the decline due to fire suppression as these forests require disturbance processes for continued existence. In 2002, after an almost 200 year absence or rare occurrence of fire on parklands, MACA implemented the 2001 Fire Management Plan and thus began prescribed burning, mechanical removal of hazard fuels, spot herbicide treatment, and fire effects monitoring using an adaptive management strategy to restore native habitats to pre-settlement conditions, ultimately to protect rare species, promote diversity, inhibit exotic and/or invasive species, and improve safety through reduced fuel loads (NPS 2001, 2009, 2018f).

Current fire management strategies are based on vegetation in the context of fuel type and restoration objectives and rely heavily on previous classification and mapping by Olson and Franz (1998) and subsequent map and model improvements in both 2009 and 2011 (Olson et al. 2013a, NPS 2018h unpublished). These authors classified vegetation considering both regional geology and hydrology, as well as slope and aspect, to outline nine habitat types present at MACA (Table 4.38). As soil type is largely influenced by bedrock geology, the Kentucky State Nature Preserves Commission, and the Mammoth Cave Fire Management Plan (Campbell 1999) following their standard, classify habitats on calcium-containing bedrock such as limestone as "calcareous" and those on non-calcareous soils as "acid". Calcareous habitats are generally more xeric (dry), due to the potential for subsurface drainage development, compared to acid habitats. However, slope and aspect often dictate soil moisture levels and are therefore used, in addition to geology, in classifying habitat types from xeric to mesic (moist).

Table 4.38. Habitat types and areal extent at MACA. Modified from Olson 2017b.

Habitat Type	Potential natural vegetation	Hectares	% of Total Hectares
Calcareous Xeric	Cedar Glade	60.7	<1
Calcareous Sub-Xeric*	**Forest–Woodland**	**3,739**	**18**
Calcareous Sub-Mesic*	**Forest–Woodland**	**3,857**	**18**
Calcareous Mesic	Mesic Hollow Forest	3,662	17
Calcareous Supra-Mesic	Mesic Hollow Forest	53	<1
Acid Xeric	Pine Cliff Edge Forest	24	<1
Acid Sub-Xeric*	**Forest–Woodland**	**1,012**	**5**
Acid Mesic*	**Forest–Woodland**	**7,284**	**34**
Acid Supra-Mesic	Hemlock–Yellow Birch Forest	405	2
Alluvium	Floodplain Forest	1093	5

* Habitat types capable of carrying fire under normal conditions during fire seasons, also shown in bold.

The relation of hydrogeology to fire management is especially important in modeling of pre-settlement conditions for restoration considering the history of disturbance on park lands and current vegetation communities present (NPS 2001). Habitat modeling shows that 16,200 hectares or "about 75% of park lands are capable of carrying fire under the normal range of weather conditions during either of the two fire seasons" (Olson 2002). However, significant restoration efforts will be needed to achieve that percentage as more recent NPS report (2018g unpublished) states that only 42% of parklands have fire-dependent or tolerant vegetation. The two fire seasons at MACA are February 15 to April 30 (spring), and October 1 to December 15 (fall); however, the spring season is preferred for prescribed burning due to lower fuel moisture levels and benefits for seed germination and wildlife food sources (NPS 2001). Additionally, limiting fire to only November 15 through April 30 ensures that fires will not interfere with arboreal roosting Indiana bats and their fall swarming activity (NPS 2009, 2018f). Further condensing these fire dependent/tolerant vegetation categories by plant community for prescribed fire planning and post-burn monitoring, Table 4.39 shows specific measures for each vegetation type. As for fire frequency, grasslands require frequent fire such as one to three years, yet return frequency for oak-hickory stands is approximately 12 years (NPS 2018h unpublished). The Indian Grass Grassland and Big Bluestem Grassland categories, though separated in classification of burn plots as shown in Table 4.39, are not considered separate or autonomous stands but rather occur in mixed grasslands. Future classifications should group these under the combined title of "Barrens" as categorized and shown in the 2011 vegetation map (Figure 4.91; Olson et al. 2013a).

Table 4.39. Vegetation types and restoration objectives. Modified from Olson (2002) and NPS (2016f).

Vegetation Type	Restoration Objective
Oak Hickory Forest (Calcareous Subxeric)	Decrease density of shade tolerant pole-size trees Limit mortality of overstory trees Increase native herbaceous cover
Red Cedar Glade Forest (Calcareous Xeric to Subxeric)	Reduce litter, duff, and downed woody fuel load Reduce pole-sized trees Limit mortality of overstory trees
Chestnut Oak Woodland (Acid Subxeric)	Decrease density of shade tolerant pole-size trees Limit mortality of overstory trees Increase native grass and forb cover Reduce total fuel load
Indian Grass Grassland (Calcareous Subxeric)	Reduce the density of shade tolerant species Reduce density of shrubs Cause no net gain in percent cover of exotic plants Increase relative cover of Indian Grass
Big Bluestem Grassland (Calcareous Subxeric)	Cause no net gain in percent cover of exotic plants Decrease invading woody species
Old Field (Acid Mesic)	Increase density of oak and hickory seedlings Reduce density of shade tolerant pole-size trees Reduce total fuel load

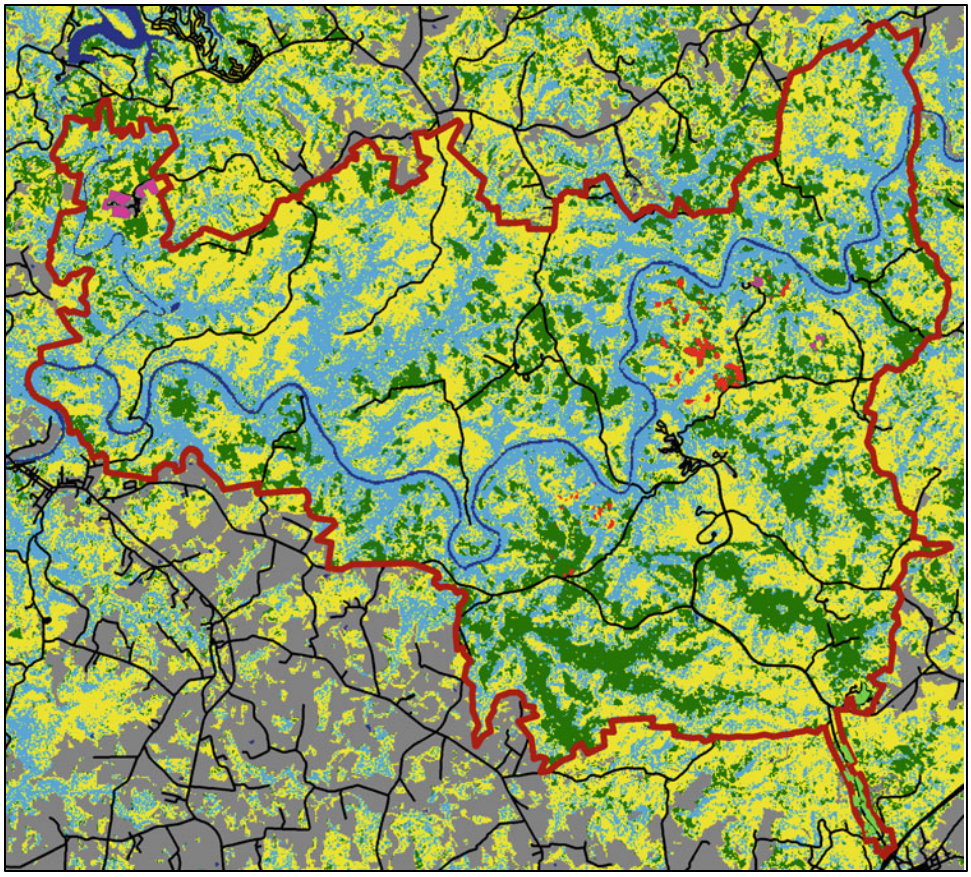


Figure 4.91. Vegetation map of the park. Yellow: Oak Forest–Woodland, Blue: Mesic Hollow Floodplain-Forest, Green: Coniferous-Deciduous Successional Forest, Red: Fire-Killed Coniferous Forest, Fuchsia: Planted Prairie, Lime Green: Barrens (Olson 2017b).

4.8.2. Data and Methods

This assessment relied heavily upon the technical plans and reports provided by the National Park Service (2001–2015), The Nature Conservancy (Campbell 1999), and a detailed report by Burton (2013) which reviewed select results on fire management activity from 2002–2012. Pre-settlement conditions are largely supported by peer-reviewed scientific papers and historical accounts that provide evidence for reconstruction of pre-settlement vegetation and fire use, both regionally and at MACA, and are considered the target conditions for prescribed burning. However, for assessment purposes, reference conditions are considered those immediately prior to burning as described in pre-burn monitoring and used in statistical analysis of fire effects per monitoring plot type (NPS 2016e).

Fire effects monitoring protocol for MACA was adapted from the NPS Fire Monitoring Handbook (NPS 1992, Switky 2003). Fire effects monitoring consists of installation of permanent vegetation monitoring plots in representative monitoring types, also referred to as habitat or vegetation types in this assessment (NPS 2016e). There are currently 38 permanent monitoring plots at MACA across the six different monitoring types (Burton 2013). Monitoring plots are 20 meters by 50 meters, however subsampling within these plots is used depending upon the variable being measured. Measures for prescribed burning, as a method for habitat restoration and improved safety through

fuel reduction as previously were determined per fire management unit and are presented in annual reports (NPS 2004b, 2005, 2006c, 2008). Sampling design, field protocol, and data analysis methods can be found in the NPS Fire Monitoring Handbook (Switky 2003) and for select burns and measures as detailed in Burton (2013).

Assessment of current condition and trend are based on results of fire effects monitoring as they relate to management objectives as reported by the Barrens to Bayous Fire Monitoring Network that conducts and monitors effects of the prescribed burning program for several parks including MACA. Outcomes of prescribed burning are reported as percentages, within an 80% confidence interval of the mean, of a particular measure per vegetation type across all units burned from 2000–2015. Trend assessment considers if objectives of prescribed burning have been met.

4.8.3. Reference Conditions/Values

As the current fire management plan (NPS 2001) is built on restoration targets of pre-settlement conditions which could be considered "reference" in that regard, supporting research is presented in this section, along with measurable reference conditions provided through pre-burn monitoring of vegetation plots. However, only conditions immediately prior to implementation of prescribed burning were used in the statistical analysis to evaluate restoration objectives and as such the status and trend of fire management at MACA.

There is a significant amount of evidence, especially when considered collectively, that supports the existence of pre-settlement fire-adapted landscapes, particularly savannas and prairies, at MACA (Ray 1997, Campbell 1999, NPS 2001, Olson 2002, Wilder 2011, Burton 2013, Frost et al. 2013). Early descriptions of the region and the Mammoth Cave Plateau in particular, by botanist Francois Michaux in the early 1800s, include accounts of savanna and Native American fire use (Campbell 1999, NPS 2001). Campbell (1999) also cites several other writers (Davidson 1840, Drake 1850, Ross 1882, Sargent 1884, Shaler 1884) that describe grasslands and attribute the presence of those to annual fires on the greater Pennyrile Karst Plain set by Native Americans for centuries prior. Though post-settlement, other early authors (Bullitt 1845, Hussey 1876, DeFriese 1880) as cited by NPS (2001) give similar descriptions of karst plain prairie, upland oak-hickory-chestnut forests, fire-adapted/tolerant species such as buffalo clover (*Trifolium stoloniferum*) and post oak, and accounts, or hypothesis, of fire-maintained grasslands and open-canopy forests (NPS 2001). Today, Michaux would not find the savanna he observed but rather a solid canopy along the Chester Escarpment; nor would Hussey or DeFriese find the same abundance of buffalo clover, post-oak, or the fire-dependent plant communities that were once present (NPS 2001).

In addition to historical accounts, palynological and archaeological studies in the region support the hypothesis for the presence of grasslands at MACA long before European settlement of the region. In Wilkins et al. (1991) and Delcourt et al. (1998), pollen analysis from soil cores indicate that there was a mix of open grassy barrens and closed forests prior to a shift to more mesophytic and hydrophytic tree species around 3,000 to 3,500 years before present (Campbell 1999). Campbell (1999) also points to evidence by Schoenwetter (1974) looking at pollen from Salt's Cave, that there was an increase in cultivation by Native Americans during this time as populations grew and became more settled during the shift from the Archaic to Woodland cultural period. The presence of charcoal

particles and increased grass pollen also suggests that there was increased fire frequency during this time, which would of course improve conditions for cultivation of herbaceous species with increased light and enriched soils (Campbell 1999, NPS 2001, Wilder 2011). Olson (1996) and Campbell (1999) also note that the practice of burning to clear areas for cultivation, ease small game hunting and possibly promote grazing by large game, and/or promote edible species is consistent with practices elsewhere in eastern North America at that time. A study by Wilder (2011) agrees and points out that for much of human history "fire has been a natural and anthropogenic disturbance throughout the world."

Other archaeological evidence to support pre-settlement vegetation can be found in the abundant plant remains left by Native Americans in the form of torch remnants, woven slippers, and paleo feces (NPS 2001). During both Archaic and Woodland periods, native peoples explored Mammoth Cave and burned torches made of plant material to light their way. Olson (1998) found that false foxglove (*Aureolaria* sp.*)* and goldenrod (*Soligado* sp.*)* were the most common material used for torches with cane being less so; all are species that are generally more common in border environments and open woodlands rather than the closed, dense forests within the park currently. Another key point that supports these findings is the rarity of false foxglove on park lands post fire suppression (Seymour 1997). Similarly, remains of woven slippers from the Mammoth Cave area (Watson and Yarnell 1969, King 1974 as cited in Campbell 1999) are most often made from rattlesnake master fiber (*Eryngium yuccifolium)* which grows primarily in open grassy woods and grasslands, and is also considered very rare within the park today (Campbell 1999). Edible annual plant species found in paleo feces including lamb's quarters (*Chenopodium album*), sunflower (*Helianthus* sp.), sumpweed (*Iva annua*), amaranth (*Amanthus* sp.), panic grass (*Panicum* sp.), and maygrass (*Phalaris caroliniana*) which corroborate the postulation of pre-settlement conditions other than closed canopy forest where light intensity would have been inadequate to support these species (Schoenwetter 1974, Campbell 1999).

Along those same lines but looking at current vegetation, Campbell (1999) listed the species that occur either in MACA or the greater Mammoth Cave region as rare at global to local scales and typical of "native grassland or open, non-hydric oak woodland" and "clearly dependent on disturbance." While not listed as endangered, considering the known ecology of the globally rare species, these plants have probably declined greatly since settlement (Campbell 1999). Buffalo clover (*Trifolium reflexum)* in particular is identified as highly fire-dependent and needs soil disturbance for proper seed germination and growth, making its presence one of the strongest indicators for loss of grasslands and open woodlands in the upland habitats of MACA (Campbell 1999, NPS 2001). The state-rare species, identified as fire-dependent with only two or three records within the park are most likely in danger of further declines or local extinction if closed, dense forests continue to develop with fire suppression (Campbell 1999). He also identified 34 species of concern which are known to occur in upland habitats characterized by grassland and non-hydric oak forests and only seven in closed, non-disturbed forests. Luckily, many of these 34 species appear to have viable populations within the park and/or region with only a few (e.g., purple coneflower, hairy phlox *[Phlox amoena],* and eastern gammagrass [*Tripsacum dactylodes*]) at risk of decline or local extinction. While these species represent a small portion of the overall plant community, maintaining

environments for these species should be considered important not only for local, regional, and global plant diversity but also the insect, avian, and mammal communities they potentially support, directly and indirectly, in both surface and subsurface environments. Similarly, ecological restoration and consideration of rare species in fire management, serves to maintain a level of biodiversity recognized as internationally important through the United Nations Education, Scientific, and Cultural Organization's International Biosphere Reserve program. One illustration to the significance of ecological restoration for preservation of diverse plant communities is that the park is the only site in Kentucky where the western dwarf dandelion has been documented. Though it is common in western prairie states it is another example of the importance of proper management to protect our natural resources and to maintain MACA as a biological hotspot (NPS 2018j).

One of the best lines of evidence of past forest conditions, according to Campbell (1999), is the increasing knowledge and understanding of fire ecology and its effects on forest succession, particularly in regard to oak ecosystems which have co-evolved with fire (Abrams 1992, Olson 1996). Without disturbance processes such as fire, invasive species can change forest composition. Three such invasive species are garlic mustard (*Alliaria petiolata*) Japanese honeysuckle, and Japanese grass (*Microsteqium vimineum*), all of which thrive in shaded, dense forests such as those currently observed at MACA and developed during decades of fire suppression (NPS 2001). Fortunately, fire which can create open canopy conditions, has been shown to effectively decrease coverage and/or disrupt life cycles of the above mentioned plant species (NPS 2001).

According to Burton (2013), upon completion of the 2012 spring fire season, approximately 6400 hectares had been burned one to four times. Including plots with multiple treatments, more than 8900 hectares at MACA had been treated with prescribed fire at that time. Evaluating data from April 2002 to May 2012 on 12 monitoring plots over a total of nine prescribed fires, Burton (2013) further describes treatment effects. These twelve plots were predominantly oak-hickory forest with total overstory basal area greater than 50%. Burton (2013) used two-tailed paired t-tests for pre- and post-burn comparison with a confidence interval of 95 percent. Restoration objectives were to limit mortality of overstory trees to 20% while decreasing understory (pole-sized) trees, increase native ground cover, and reduce total fuel loads. Specific goals depend on monitoring type (Table 4.39). Burton found that even though the average prescribed burn was classified as intermediate, overstory density was not significantly decreased and mortality was limited. Unfortunately, in contrast to stated objectives, understory basal area did not decrease either, even though density of trees with diameter at breast height (dbh) of less than 15 cm decreased by 30%. Burton notes that this is typical of areas burned only once with a relatively low-intensity fire; a study by Wilder (2011) at MACA, though it predates Burton supports that conclusion. These results suggest that forest succession to a closed canopy is occurring as shade-tolerant species still dominate the understory even though the preferred oak-hickory overstory remains intact (Figure 4.92). Continued prescribed burning and additional post-burn fire effects monitoring is recommended in these areas and it should be recognized that such large-scale landscape restoration may take decades (Burton 2013, Olson 2017b).

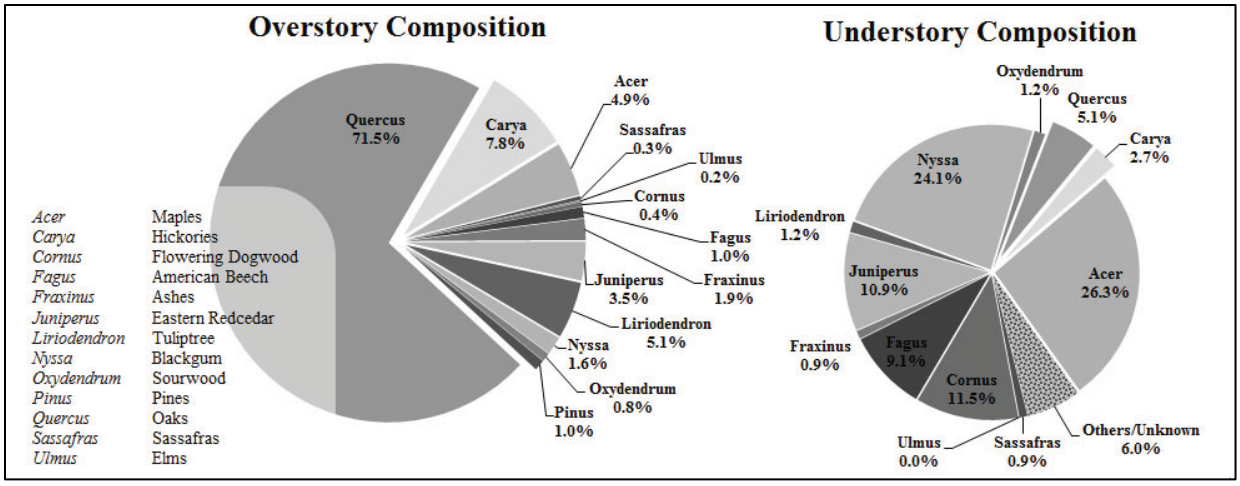


Figure 4.92. Tree composition of oak-hickory monitoring plots. Overstory composition is based on mean basal area for trees ≥ 15.0 cm at dbh. Understory composition utilizes stem density of trees ≥ 2.5 < 15.0 cm dbh (Burton 2013).

Although understory effects appear minor, there was a significant change in herbaceous ground cover. Graminoid species (grasses, sedges, and rushes) appear to thrive with fire disturbance as this group of species was completely absent in several monitoring transects prior to prescribed burning and a modest increase of approximately 5% mean cover was observed post burn (Burton 2013). With fire, barriers to seed germination are removed, allowing preferred plant communities to develop while inhibiting invasive woody species. Wilder (2011) also points out that fire use can stimulate herbaceous cover and support the microbial community by warming the soil allowing for increased nutrient cycling. Another positive change for ecological restoration through fire use was observed in that wildland fuel loading was reduced by 18% (Burton 2013). Mean total fuel loads were reduced from 34.9 metric tons/hectare prior to 28.4 metric tons/hectare after a single treatment (Burton 2013). However, this reduction was only statistically significant in litter compared to duff (leaf, needle, herbaceous litter), fine woody debris (dead woody stems < 7.62 cm), and coarse woody debris (dead woody steam >/= 7.62 cm.) Figure 4.93 shows changes in fuels loads after a single fire.

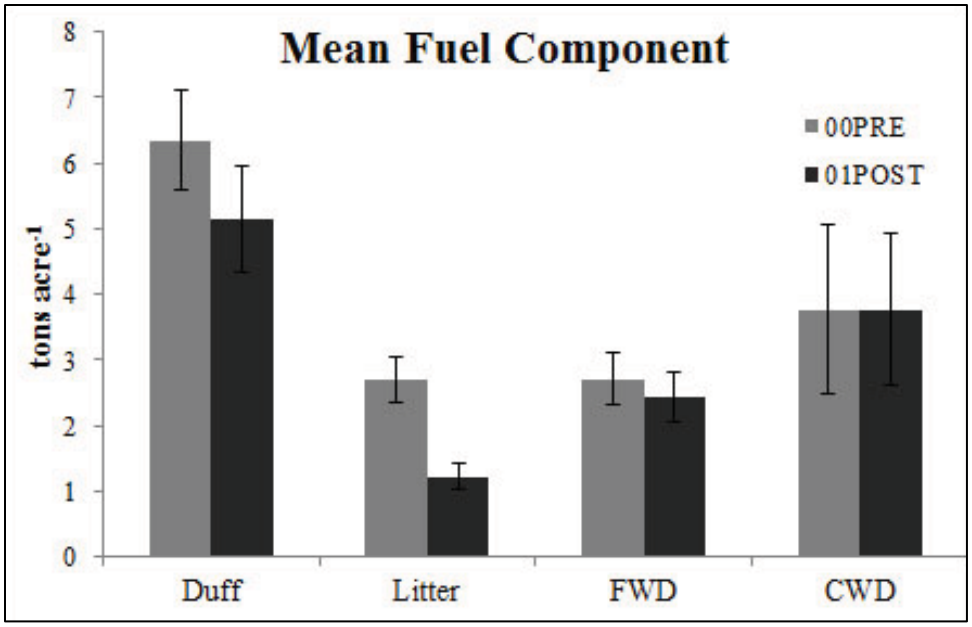


Figure 4.93. Changes in wildland fuels per fuel type after a single prescribed fire. FWD=fine woody debris, CWD=coarse woody debris (Burton 2013).

Based on known and modeled pre-settlement conditions as well as the limited analysis by Burton (2013), the use of prescribed burning for ecological restoration and improved safety is warranted and initially appears to be improving conditions for oak-hickory forests. Indeed, Burton (2013) citing Hutchinson et al. (2012) points out that repeated burns at appropriate intervals would likely support reduction of shade tolerant species and promote open canopy conditions. These conclusions also reveal that large-scale restoration goals involving the reintroduction of fire regime across the landscape of MACA will require long-term treatment and management (Olson 2017b).

4.8.4. Condition and Trend

Certain plant communities at MACA appear to have developed within a natural and/or anthropogenic fire regime and with suppression, mostly to support and protect human use (residential, agriculture, visitor use, other infrastructure), the barrens and forest landscapes have been changed and diversity threatened (Olson 2002, Burton 2013). Subsequent fire management at MACA however seems to be creating shifts in community composition while meeting safety objectives for people, property, and cultural resources (NPS 2016f). Results of prescribed burning from 2000–2015 for the specific measures for each habitat type are shown in Table 4.40 below. It should be noted that the number of burns or units burned within each vegetation type varied from year to year as well as the frequency of post-burn monitoring. Details for select prescribed burns can be found in NPS Barrens to Bayous annual reports (NPS 2010c, 2011, 2012b, 2016f).

Overall the results show positive ecological changes in all vegetation types in relation to restoration objectives. However, there is a great deal of uncertainty as there have been very few fires and/or required post-burn growing seasons (3–5 burns in several cases) compared to the specific objectives of each monitoring type so sample size is limited and additional burns are needed. With that said,

results should be considered preliminary in those cases where results are specified as “Uncertain” (Table 4.40) until the suggested or required number of burns and/or growing seasons are met for full and proper evaluation of fire effects. Non-fire treatments such as mechanical removal and/or spot herbicide treatment were not described nor included in the report which provided the above evaluation of all fires at MACA from 2000–2015. Those management actions could potentially have reduced fuel loads, shade tolerant species, and/or exotic species enhancing overall effects of fire management at MACA. Details of those activities and/or results were not available for this review. This could be considered a data gap as those actions could have significant effects especially on coarse woody debris and overall fuel loads.

Noteworthy to this assessment are suggested modifications to vegetation classification as well as what has been learned in the time since inception of the prescribed burning program at MACA. As noted previously, the Indian Grass Grassland and Big Bluestem Grassland categories, though separated in classification of burn plots, are not considered separate or autonomous stands but rather occur in mixed grasslands. Future classifications should group these under the combined title of “Barrens” as categorized and shown in the 2011 vegetation map (Olson et al. 2013a). Also, though previously burned at MACA, calcareous xeric cedar oak glades often experience drought like conditions caused by rapid karst drainage and location in regard to slope and aspect which tends to create conditions not suitable for mesic species, therefore maintaining community composition without fire (Olson et al. 2013a). Eastern red cedar is not fire-adapted and these areas typically have rock outcrops and thin soils that do not support fire well either, thus the use of fire in areas with non-tolerant species should be reevaluated (Olson et al. 2013a, NPS 2016f).

Table 4.40. Combined fire effects monitoring results from all prescribed burns at MACA from 2000–2015. Note: An underlined number of plots denote that minimum sample sizes have been achieved. Estimations of minimum sample size were conducted in 2010 with the "SS Two Samples" tool created by Ken Gerow (available online at www.statsalive.com). Sample sizes needed with current variance are given in brackets when minimum size has not been achieved. When brackets are not given, variance and correlation of samples do not yet allow for an estimate of minimum sample size (NPS 2016).

Vegetation Type	Management Objectives (Restoration)	Monitoring Results (80% Confidence Intervals)	Objective Achieved?	Year Analysis Completed (Range)
Oak Hickory Forest (FOAHI1D09)	Decrease density of shade tolerant pole trees by 30–90%[a] $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = **58.5% (± 15%) after 1st fire n = 7 [9], *5 burn units***	**Yes** Density of shade intolerant species significantly reduced by > 30%, All plots must burn and be monitored during annual read to meet min sample size	**2010** (2005–2010)
	Limit mortality of overstory trees to less than 20% $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = **7.4% (± 5%) after 1st fire n = 7, *5 burn units***	**Yes**	**2010** (2005–2010)
	Increase native herbaceous cover by 10–25% by 1 year after the 3rd burn $\frac{\beta\ YR02 - 00Pre}{00Pre}$	Increase in cover = **148.3% (± 63%) after 1st fire n = 7, *5 burn units***	**Yes** All plots have experienced increases in herbaceous cover; however, plots have not burned 3 times	**2010** (2005–2010)
	Reduce total fuel load by 25–50% immediately postburn $\frac{\beta\ Post - before\ \beta}{before\ \beta}$	Decrease in total fuels = 33.3% (± 10%) after 1st fire n = 7, *5 burn units*	**Yes** Reduction objective does not fall outside range of confidence	**2010** (2005–2010)

[a] Shade intolerant species include *Carya, Pinus, and Quercus* genera. Density analyzed for all other species.

[b] Density analyzed for *Acer*, *Juniperus*, *Sassafras*, and *Ulmus* genera.

[c] Exotics in SONU plots include; *Digitaria* spp., *Kummerowia* spp., *Lespedeza cuneate*, *Lonicera japonica*, *Microstegium vimineum*, *Ligustrum* spp., and *Setaria* spp.

Table 4.40 (continued). Combined fire effects monitoring results from all prescribed burns at MACA from 2000–2015. Note: An underlined number of plots denote that minimum sample sizes have been achieved. Estimations of minimum sample size were conducted in 2010 with the "SS Two Samples" tool created by Ken Gerow (available online at www.statsalive.com). Sample sizes needed with current variance are given in brackets when minimum size has not been achieved. When brackets are not given, variance and correlation of samples do not yet allow for an estimate of minimum sample size (NPS 2016).

Vegetation Type	Management Objectives (Restoration)	Monitoring Results (80% Confidence Intervals)	Objective Achieved?	Year Analysis Completed (Range)
Redcedar Glade Forest (FJUVI1D09)	Reduce litter, duff, and downed woody fuel load by 25–50% $\frac{\beta\ Post - before\ \beta}{before\ \beta}$	Decrease of Duff = +24.1% (± 32%) after 1st fire n = 7 [9], *4 burn units* 25.7% (± 32%) after 2nd fire n = 3 [25], *1 burn units* Decrease of Litter = **46.3% (± 10%) after 1st fire n = 7 [21], 4 burn units** 31.3% (± 27%) after 2nd fire n = 3 [27], *1 burn units* Decrease in Total Wood = 3.4% (± 19%) after 1st fire n = 7 [8], *4 burn units* 36.5% (± 27%) after 2nd fire n = 3 [4], *1 burn units*	**No/Uncertain** Significant reductions in litter fuel loading; however, duff and downed woody fuels do not yet show responses to treatment [Objective to be changed in 2013]	**2010** (2002–2010)
	Reduce pole-sized trees by 40–60% $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = 12.3% (± 12%) after 1st fire n = 6, *3 burn units*	**No** This objective is being reevaluated as very low fire intensities are advised for this ecotype	**2010** (2002–2010)
	Limit mortality to overstory species to less than 20% $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = +2.2% (± 4%) after 1st fire n = 6, *3 burn units*	**Yes**	**2010** (2002–2010)

[a] Shade intolerant species include *Carya, Pinus, and Quercus* genera. Density analyzed for all other species.

[b] Density analyzed for *Acer*, *Juniperus*, *Sassafras*, and *Ulmus* genera.

[c] Exotics in SONU plots include; *Digitaria* spp., *Kummerowia* spp., *Lespedeza cuneate*, *Lonicera japonica*, *Microstegium vimineum*, *Ligustrum* spp., and *Setaria* spp.

Table 4.40 (continued). Combined fire effects monitoring results from all prescribed burns at MACA from 2000–2015. Note: An underlined number of plots denote that minimum sample sizes have been achieved. Estimations of minimum sample size were conducted in 2010 with the "SS Two Samples" tool created by Ken Gerow (available online at www.statsalive.com). Sample sizes needed with current variance are given in brackets when minimum size has not been achieved. When brackets are not given, variance and correlation of samples do not yet allow for an estimate of minimum sample size (NPS 2016).

Vegetation Type	Management Objectives (Restoration)	Monitoring Results (80% Confidence Intervals)	Objective Achieved?	Year Analysis Completed (Range)
Chestnut Oak Woodland (FQUMO1D09)	Decrease density of shade tolerant pole trees by 30–90%[a] $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = 33.3% (± N/A%) after 1st fire n = 1, *1 burn units*	**Yes/Uncertain** Limited sample size	**2010** (2000–2010)
	Limit mortality of overstory trees to less than 20% $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = 4.0% (± N/A %) after 1st fire n = 1, 1 burn units	**Yes/Uncertain** Limited sample size	**2010** (2000–2010)
	Reduce total fuel load by 25–50% after 3 burns $\frac{\beta\ Post - before\ \beta}{before\ \beta}$	Decrease in total fuels = **20.2% (± 7%) after 11st fire n = 3, *2 burn units*** +14.4% (± N/A %) after 2nd fire n = 1, *1 burn units*	**Yes/Uncertain** Significant reduction in total fuels; however, fuels not reduced by > 25% after first treatment	**2010** (2000–2010)
	Increase native grass and forb cover by 10–25% after 3 burns $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Increase in cover = **−68.3% (± 18%) after 1st fire n = 2, *1 burn units*** 21.7% (± N/A %) after 2nd fire n = 1, *1 burn units*	**Uncertain** Limited sample size and plots have not burned three times	**2010** (2000–2010)

[a] Shade intolerant species include *Carya, Pinus, and Quercus* genera. Density analyzed for all other species.

[b] Density analyzed for *Acer*, *Juniperus*, *Sassafras*, and *Ulmus* genera.

[c] Exotics in SONU plots include; *Digitaria* spp., *Kummerowia* spp., *Lespedeza cuneate*, *Lonicera japonica*, *Microstegium vimineum*, *Ligustrum* spp., and *Setaria* spp.

Table 4.40 (continued). Combined fire effects monitoring results from all prescribed burns at MACA from 2000–2015. Note: An underlined number of plots denote that minimum sample sizes have been achieved. Estimations of minimum sample size were conducted in 2010 with the "SS Two Samples" tool created by Ken Gerow (available online at www.statsalive.com). Sample sizes needed with current variance are given in brackets when minimum size has not been achieved. When brackets are not given, variance and correlation of samples do not yet allow for an estimate of minimum sample size (NPS 2016).

Vegetation Type	Management Objectives (Restoration)	Monitoring Results (80% Confidence Intervals)	Objective Achieved?	Year Analysis Completed (Range)
Indian Grass Grassland (BSONU1T02)	Reduce density of shade tolerant seedlings 30% to 60% one year after second fire[b] $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = 39.1% (± 21%) after 1st fire n = 3 [20], 1 burn unit **45.8% (± 25%) after 2nd fire n = 2 [4], *1 burn unit***	**Yes/Uncertain** Reductions are occurring; however, > 30% is not outside, the confidence interval	**2010** (2002–2010)
	Reduce density of shrubs 30% to 60% one year after second fire $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = **35.% (± 9%) after 1st fire n = 3**, ***1 burn unit*** 23.2% (± 54%) after 2nd fire n = 2 [43], *1 burn unit*	**Uncertain** Significant reduction occurred after first treatment; however, all plots must burn 2 two times	**2010** (2002–2010)
	Cause no net gain in percent cover of exotic plants after five years of burning[c] $\frac{\beta\ YR02 - 00Pre}{00Pre}$	Increase in cover = 156.1% (± 136%) after 1st fire n = 3, *1 burn units* 371.2% (± 550%) after 2nd fire n = 2, *1 burn units*	**Uncertain** Plots have not burned 5 times and minimum sample size not met	**2010** (2002–2010)
	Increase relative cover of Indiangrass (*Sorghastrum nutans*) 15% after five years of burning $\frac{\beta\ YR02 - 00Pre}{00Pre}$	Increase in cover = 534.6% (± 319%) after 1st fire n = 3, *1 burn units* 81.9% (± 142%) after 2nd fire n = 2, *1 burn units*	**Uncertain** Plots have not burned 5 times and minimum sample size not met	**2010** (2002–2010)

[a] Shade intolerant species include *Carya, Pinus, and Quercus* genera. Density analyzed for all other species.

[b] Density analyzed for *Acer*, *Juniperus*, *Sassafras*, and *Ulmus* genera.

[c] Exotics in SONU plots include; *Digitaria* spp., *Kummerowia* spp., *Lespedeza cuneate*, *Lonicera japonica*, *Microstegium vimineum*, *Ligustrum* spp., and *Setaria* spp.

Table 4.40 (continued). Combined fire effects monitoring results from all prescribed burns at MACA from 2000–2015. Note: An underlined number of plots denote that minimum sample sizes have been achieved. Estimations of minimum sample size were conducted in 2010 with the "SS Two Samples" tool created by Ken Gerow (available online at www.statsalive.com). Sample sizes needed with current variance are given in brackets when minimum size has not been achieved. When brackets are not given, variance and correlation of samples do not yet allow for an estimate of minimum sample size (NPS 2016).

Vegetation Type	Management Objectives (Restoration)	Monitoring Results (80% Confidence Intervals)	Objective Achieved?	Year Analysis Completed (Range)
Big Bluestem Grassland (BANGE1D02)	Cause no net gain in percent cover of exotic plants as measure one year and five years post burn $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Decrease in cover = ***56.4% (± 12%) after 1st fire n = 2, 1 burn units 96.3% (± 1%) after 2nd fire n = 2, 1 burn units***	**Yes** Limited sample size and all plots must burn	**2010** (2000–2010)
	Decrease invading woody species by 30% as measured 1-year post burn $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = +38.5% (±135%) after 1st fire n = 4 [13], *1 burn unit* ***49.7% (± 5%) after 2nd fire n = 2 [4], 1 burn unit***	**Yes/Uncertain** Limited sample size and all plots must burn	**2010** (2000–2010)

[a] Shade intolerant species include *Carya, Pinus, and Quercus* genera. Density analyzed for all other species.

[b] Density analyzed for *Acer*, *Juniperus*, *Sassafras*, and *Ulmus* genera.

[c] Exotics in SONU plots include; *Digitaria* spp., *Kummerowia* spp., *Lespedeza cuneate*, *Lonicera japonica*, *Microstegium vimineum*, *Ligustrum* spp., and *Setaria* spp.

Table 4.40 (continued). Combined fire effects monitoring results from all prescribed burns at MACA from 2000–2015. Note: An underlined number of plots denote that minimum sample sizes have been achieved. Estimations of minimum sample size were conducted in 2010 with the "SS Two Samples" tool created by Ken Gerow (available online at www.statsalive.com). Sample sizes needed with current variance are given in brackets when minimum size has not been achieved. When brackets are not given, variance and correlation of samples do not yet allow for an estimate of minimum sample size (NPS 2016).

Vegetation Type	Management Objectives (Restoration)	Monitoring Results (80% Confidence Intervals)	Objective Achieved?	Year Analysis Completed (Range)
Old Field (FOLFI1D08)	Increase density of oak and hickory seedlings after three burns, as measured one year post-burn $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Increase = +73.7% (± 169%) after 1st fire n = 2, *1 burn unit*	**Yes/Uncertain** Limited sample size, but initial monitoring shows an increase after first treatment	**2015** (2011–2014)
	Reduce density of shade tolerant pole-sized trees by greater than %50 after three burns* $\frac{\beta\ YR01 - 00Pre}{00Pre}$	Density Reduction = N/A	**No/Uncertain** Plots have only burned one time, and have increased from a mean of 0 to 80 poles/ha	**2015** (2011–2014)
	Reduce total fuel load by > 25% after 3 burns $\frac{\beta\ Post - before\ \beta}{before\ \beta}$	Decrease in total fuels = 7.1% (± 19%) after 1st fire n = 2, *1 burn units*	**Uncertain** Plots have not burned 3 times and fire had very limited spread into OLFI plots	**2012** (2011–2012)

[a] Shade intolerant species include *Carya, Pinus, and Quercus* genera. Density analyzed for all other species.

[b] Density analyzed for *Acer*, *Juniperus*, *Sassafras*, and *Ulmus* genera.

[c] Exotics in SONU plots include; *Digitaria* spp., *Kummerowia* spp., *Lespedeza cuneate*, *Lonicera japonica*, *Microstegium vimineum*, *Ligustrum* spp., and *Setaria* spp.

Challenges to fire management include the potential for excessive fire (too frequent) or extreme fire severity (high temperatures) which can be more detrimental than helpful to restoration efforts (Olson 2017b). One such example was the 2010 prescribed fire where over 1,620 hectares of native Virginia pines (not fire adapted) were killed. As such, these areas will require intensive management to return these areas to preferred conditions and inhibit invasive exotic species (Olson 2017b). Also, climatic events which produce either more moisture or unfavorable fire conditions during specified fire seasons could delay or constrain fire management decisions and actions, potentially negatively affecting ecological restoration progress in grasslands as that vegetation types needs more frequent (1–2 years) fire.

4.8.5. Level of Confidence and Data Gaps

The level of confidence in this assessment is moderate as there is comprehensive data on all prescribed burns in relation to specific restoration objective of each vegetation type (Table 4.41). However, it appears based on references by Burton (2013) and NPS (2018h unpublished) more recent fire management plans and data on prescribed burning efforts and non-fire application methods may be available that were not accessible to the author for evaluation. Data gaps in fire effects monitoring appear to be mostly related to lack of actual fires conducted and number of post-burn growing seasons needed for stated objective or statistical sample size. Data on wildland fires on park lands could be seen as a data gap as this information could assist in identifying areas where natural fires are more likely occur and could be useful to current fire management decisions (Campbell 1999). Status of the current fire management program at MACA based on fire effect monitoring (NPS 2016) seems to be stable and generally making progress towards ecological restoration in respect to stated goals in identified areas of need.

4.8.6. Condition Summary

Table 4.41. Graphical summary of status and trends for Fire Management.

Indicator	Measure	Condition Status/ Trend	Rationale and Reference Conditions
Fire effects (prescribed burning)	Ongoing impacts		There is a significant amount of evidence that supports the existence of pre-settlement fire-adapted landscapes at MACA (Ray 1997, NPS 2001, Olson 2002, Burton 2013, Frost et al. 2013). Therefore, restoration objectives are based on these assumed pre-settlement conditions as well as currently identified and mapped or modeled vegetation types (Olson and Franz 1998, Olson et al. 2013a). According to NPS (2016) reports, restoration objectives are being met with minimal uncertainty, with the exception of Indian Grass grasslands, as specified in Table 4.40. Overall, there has been preservation of preferred overstory canopy, reduced shade tolerant species, increases in native herbaceous cover, and reductions in total fuel loads. Fire effects results suggest that continued prescribed burning and non-fire actions can indeed restore historic vegetation communities while maintaining and/or improving biodiversity and increasing safety to visitors and infrastructure.

4.8.7. Sources of Expertise

Jesse Burton (Ecologist, NPS Barrens to Bayous Fire Monitoring Network) and Rick Olson (Park Ecologist, MACA Division of S&RM) provided expertise for this section.

4.9. Bats

Bats represent one of the most imperiled resource groups found on the park. Compared to historic and pre-historic times, relatively few bats use the park today, although Mammoth Cave once served as one of the largest bat hibernacula in the world. The number of bat species now present at MACA is consistent with historical reports. During 2004–2005 13 out of 14 expected species were identified through various observation and capture methods (Foster et al. 2007). Anthropogenic modifications to cave bat habitat, and the effects of WNS have resulted in consistent declines in numbers of several bat species over recent decades. Significant declines (>50%) have been observed for Indiana, northern long-eared (*M. septentrionalis*), tri-colored (*Perimyotis subflavus*), and little brown (*M. lucifugus*) bat populations here. Declines more than 90 percent have been observed among some species at some sites. However, some species (e.g., gray bat, Rafinesque's big-eared bat (*Corynorhinus rafinsquii*), evening bat (*Nycticeius humeralis*), and eastern red bat (*Lasiurus borealis*), are increasing in abundance.

The majority of bat hibernation activity in the park appears to be concentrated within four caves (Dixon, Long, Colossal, and Hickory Flat), but numerous other caves in and around the park, including the Historic Entrance of Mammoth Cave also serve as important roosting, hibernating, maternity, or swarming locations. At least 12 bat species known to exist in the park are considered reproductively active as indicated by observations of pregnant/lactating females or juvenile bats. Seven of these are federally listed or regionally rare species including Indiana and gray bats (federally endangered), northern long-eared (federally threatened) and big-eared, eastern small-footed, and evening bats (regionally rare).

4.9.1. Description

Bats are critical components of surface and subsurface ecosystems. Cave-roosting bats import organic matter into the nutrient-deficient cave environment in the form of guano (Culver and Pipan 2009), and this supports highly specialized communities of cave invertebrates. Outside the cave, bats play a critical role in controlling nocturnal insects and serve as a major asset to pest management in agricultural and forest settings (Thomas 2015). The bat species that occur on the park are exclusively insectivores, and their consumption of insects is of great benefit to surface ecosystems (Thomas and Toomey 2017). Many bat species are experiencing population declines in association with a variety of threats. Several bat species that occur on the park are federally listed as endangered, threatened, or species of concern under the Endangered Species Act (Thomas et al. 2016). The park hosts three federally listed bat species including the gray bat, Indiana bat, and northern long-eared bat. In addition to federally-listed species, eastern small-footed bat (*M. leibii*), evening bat, and Rafinesque's big-eared bat are considered regionally rare, but have been observed on the park in recent years (Foster et al. 2007, Johnson 2012, Thalken and Lacki 2017, Thomas 2018). As with some other mammals, bats exhibit low reproductive rates, produce few offspring per event, and reach reproductive maturity later in life, rendering them particularly vulnerable to population declines. At one time, Mammoth Cave served as one of the largest bat hibernacula in the world, hosting both gray bat and Indiana bat colonies. Bone deposits from several bat species suggest heavy use of the Mammoth Cave over the past 11,000 years (Colburn et al. 2015, Jansky et al. 2016). Compared to historical counts, relatively few bats use Mammoth Cave today (Thomas and Toomey 2017).

The cave-roosting bats that occur on the park and elsewhere face a variety of challenges including human use of and disturbance in caves, physical changes to the cave environment, surface land use issues (including wind energy development), and disease. Much study has been dedicated toward understanding the specific microclimate requirements of certain bat species, and how these requirements may be reflected in bat distributions (e.g., Henshaw and Folk 1963, Freeman et al. 1973, Clawson 1983). Modifications, such as passage enlargement or installation of cave gates, have altered cave microclimates so that these areas no longer provide suitable roosting environment for some bat species (Thomas and Toomey 2017).

A major threat posed to many species of cave-dwelling bats in MACA and elsewhere is the deadly fungal disease known as WNS. Since discovery of the disease in the United States in 2006, and documentation in the park in 2013, WNS in bats has been an important issue related to cave and bat management at MACA (Toomey 2015). WNS has been documented in 7 of 8 cave-dwelling bat species that occur in MACA. The fungus responsible for causing WNS, *Pseudogymnoascus destructans* (hereafter, *Pd*), has been found on the eighth species, (Rafinesque's big-eared bat), but the disease has not been observed in this species (Thomas 2016). Multiple bat species including the federally protected Indiana bat and northern long-eared bat have shown substantial declines in response to WNS (Griffitts 2016). The declines observed in some winter-roosting species are as high as 93% (little brown bats at Colossal Cave since 2013) (Thomas and Toomey 2017). Summer capture rates for one listed species, the northern long-eared bat, have fallen by over 99% in one analysis (Thomas 2018). In response to the disease, monitoring and surveillance of bat populations has increased dramatically, colonial bat roosts were temporarily closed year-round (except for approved research), researchers have been required to decontaminate all gear when visiting caves that are not known to be WNS positive, and visitors leaving the cave are required to walk over biosecurity mats to remove/clean spores that may spread WNS (Toomey et al. 2013; Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, June 2018, personal communication). Other management techniques for WNS include cave microclimate monitoring to assess changes associated with human modification of some entrances.

Ecologically-based research is of great importance to resource management in national parks. Inventories of the bat species that are present on the park provide measures of community structure that may inform park management practices. Of special concern is the development of a better understanding of how the rare and endangered bat species use the caves and other resources of MACA. The combined toll of naturally low reproductive rates along with the high mortality rates associated with WNS and land use practices compound the potential for loss of species that are already rare, threatened, or (Thomas and Toomey 2017). Knowledge of critical roost locations and specific needs of maternity colonies helps to inform appropriate management of reproductive bat populations (Foster et al. 2007). Continued efforts toward monitoring and conservation of bat species is necessary as these organisms provide critical services to both surface and cave communities and the loss of such services could result in detriment to both cave and surface ecosystems. Since bat survival is closely linked to the availability and quality of cave habitat, continued monitoring of bats and roosts are essential for managing and protecting populations and habitats in MACA (Thomas 2015).

4.9.2. Data and Methods

The measures of community structure used to evaluate the status of MACA bats within the framework of this report include diversity, impacts of WNS, distribution, changing dynamics of habitats and roosts, reproductive success, species changes, and threatened and endangered species. These ecological parameters can be represented quantitatively which is important in evaluating how resource conditions change over time and space. Multiple datasets were used in evaluating the condition of the bat populations at MACA. Current conditions are based on the results of inventories conducted over recent decades with a focus on federally listed bat species in the park. Reference conditions are relative to geographic range maps and historical reports. Contributions to historical bat data include Lee (1835), Silliman (1851), Bailey et al. (1933), Komarek and Komarek (1934), Davis (1959), Jegla and Hall (1962), Barbour (1963), Hall (1963), Henshaw and Folk (1963), Jegla (1963), Davis et al. (1965), Freeman et al. (1973), and Clawson (1983). A summary of significant historical records is presented below. Thomas and Toomey (2017) present a thorough discussion of the previous work on bats within the Mammoth Cave system and other caves in the park. These historic reports provide information regarding species presence, where and when bats roosted in the park's caves and general comments regarding numbers of bats. Historic accounts are based on physical evidence of bat usage including direct observations of roosting bats, guano, and stains left on cave walls and ceilings. Bat remains found in the cave also provide information about what species were using certain areas of the cave. The results represent baseline conditions by which changes in bat population dynamics can be evaluated.

A great amount of study has been dedicated to understanding bat populations in the Mammoth Cave area. Lee (1835) referenced "clusters of bats" in the area of Mammoth Cave now known as Audubon Avenue and the presence of bats in Little Bat Avenue. Silliman (1851) estimated millions of bats roosted within a few kilometers of the entrance to Mammoth Cave. More recently, Tuttle (1997) estimated the same area to host 9–13 million bats at peak usage by studying the extent of bat stains. By the time Bailey et al. (1933) conducted a survey of park fauna, very few bats could be found in Mammoth Cave even during the winter. Geographic range maps used by Bailey et al. (1933) predicted 12 bat species that could occur in the park, nine species were reported. Not recorded in MACA were the hoary bat (*Lasiurus cinereus*), silver-haired bat (*Lasionycteris noctivagans*), and Rafinesque's big-eared bat (a big-eared bat was identified in nearby Bowling Green, Kentucky) (Bailey et al. 1933). Komarek and Komarek (1934) offered a generalized account of fauna in the area proposed for the park, and recommended the closure of Dixon Cave to the public to protect a large bat hibernaculum. Davis (1959) made several collections in the park, but these were focused on obtaining specimens of the eastern pipistrelle (*Pipistrellus subflavus*), (note that *P. subflavus* was more recently reclassified as the tri-colored bat (*Perimyotis subflavus*)) for comparison to determine the existence of subspecies variants over the distribution range of the organism. Davies and Chao (1959) added the free-tailed bat (*Tadarida brasiliensis*) to the list of historical bat fauna of the park when remains were recovered from guano deposits near the Chief City area approximately one kilometer from the Violet City artificial entrance to Mammoth Cave. The deposits were radiocarbon dated to be over 38,000 years old. Jegla and Hall (1962) studied free-tailed bats from these extensive guano deposits, and suggested the species probably existed in the park during the Sangamonian interglacial period, were forced southward as temperatures declined with the Wisconsin glaciation

and have not returned to MACA in the time since. Barbour (1963) made several collections in MACA and elsewhere in Kentucky to augment poorly understood distribution patterns for several bats. Barbour documented continued presence of the eastern small-footed bat (among the rarest bats in North America at the time) in the park. Bailey et al. (1933) had previously reported the species from the park during the 1930s. The big-eared bat population was evaluated by Hall (1963) and found to represent a small and isolated population in MACA. A total of five bat species were observed during Hall's study, all of which were previously described from the park. Henshaw and Folk (1963) studied microclimate requirements of hibernating little brown and Indiana bats in caves of northern and central Kentucky (including the park), increasing knowledge of distribution and habitat requirements for these two very similar species. The observations of Davis et al. (1965) enhanced knowledge of behavior and distribution of eastern small-footed bats in the Mammoth Cave area. Davis and his team reported a total of five species, all of which were previously documented by Bailey et al. (1933). Captured specimens were tagged and released, but no eastern small-footed bats individuals were recaptured, suggesting these bats were transient. A few members of the genus Myotis were observed roosting in Lee Cave during the summer and several dozen little brown bats were found hibernating here in 1972. Insufficient microclimate conditions are thought to explain why so few bats occupied this relatively undisturbed cave (Freeman et al. 1973). Clawson (1983) provided a status report on the condition of the Priority 1 Indiana bat hibernacula in the US including a census of approximately 30,000 Indiana bats in Dixon Cave within MACA. Aside from the Indiana bat, the gray bat was the only other species observed in the cave at that time.

4.9.3. Reference Conditions/Values

Diversity

Bats have been documented in Mammoth Cave dating back over 38,000 years (Jegla and Hall 1962, Colburn 2005, Colburn et al. 2015). Early surveys by Bailey et al. (1933) report the little brown bat and Indiana bat were by far the most abundant bat species observed. The big brown bat (*Eptesicus fuscus*), and tri-colored bat were also moderately abundant. Less common were the red bat, evening bat, gray bat, northern long-eared bat, and little brown bat (Bailey et al. 1933). Hall (1963) observed five species of bats in the park, all of which were previously described by Bailey et al. (1933). The author found the big-eared bat to be one of the least common bat species in the park, along with the big brown bat. The most abundant species at the time were the Indiana bat, little brown bat, and gray bat. Freeman et al. (1973) reported up to 20 individuals of the genus Myotis and dozens of little brown bats in Lee Cave in 1972. Clawson's census of the bats of Dixon Cave in 1983 reported only two species (Indiana and gray bat). Approximately 30,000 Indiana bats and about 125 gray bats were reported. A rare bat summer roost study examined six target species, including the federally endangered gray and Indiana bats, as well as regionally rare Rafinesque's big-eared bats, evening bats, southeastern bats (*Myotis austroriparius*), and eastern small-footed bats in 2004 and 2005 (Foster et al. 2007). Twelve of 14 possible species were collected from 32 sites using mist nets/harp traps, and bats were caught by hand at four more sites. Five of the six target species were captured, the southeastern bat was the only target species not observed during the inventory (Foster et al. 2007). Species composition results from this survey are shown in (Figure 4.94). Later, a report on the parkwide response to the arrival of WNS by Toomey et al. (2013) reported that in 2011 Long Cave,

the park's largest hibernaculum, sheltered about 12,000 gray bats, 1,000 Indiana bats and a few little brown, tri-color, and big brown bats. The report also noted that nearby Coach and James caves house approximately 300,000 gray bats.

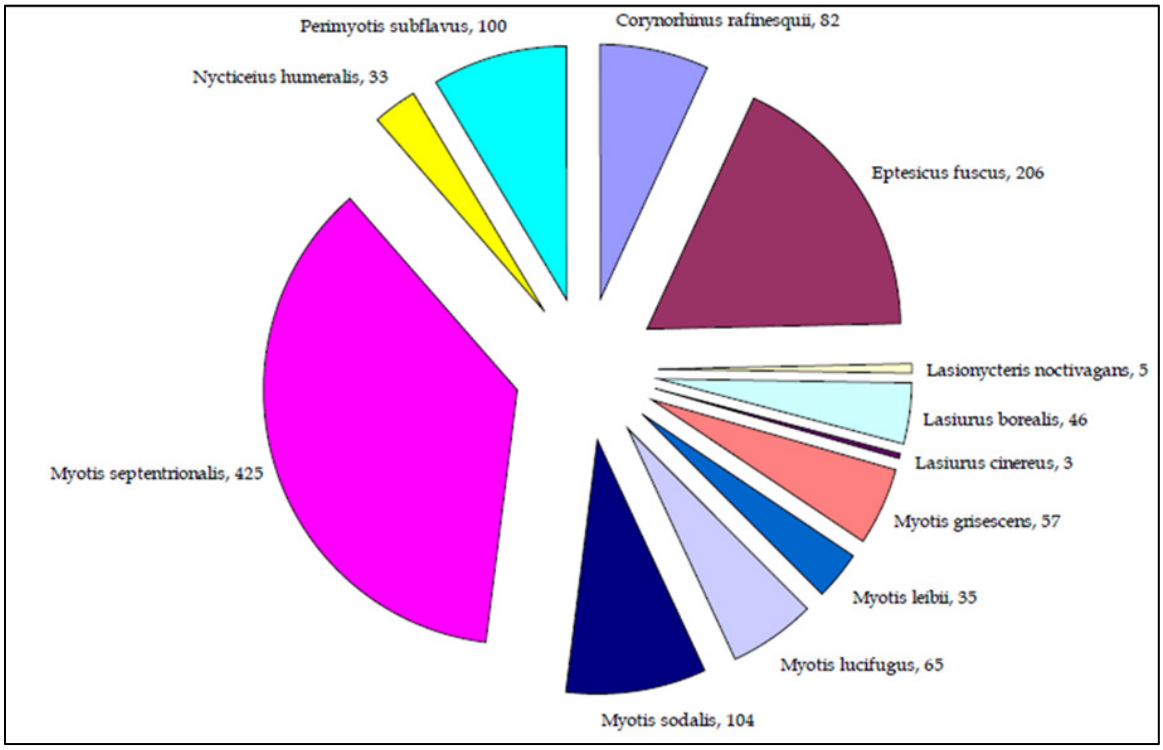


Figure 4.94. Species composition from captures taken over 25 nights of mist netting/harp trapping at 32 locations in MACA and five hand capture events in four sites in summer 2004 and 2005. (Foster et al. 2007).

Recent geochronological framework and taxa identification were used to assess the remains of Myotis bat species in a bonebed excavated in Bat Cave in 1999 by researchers from Illinois State Museum Research and Collections Center along with park employees Rick Toomey and Rick Olson (Colburn et al. 2015). Five species were identified and an estimated 1,322 individual bats were estimated from counting of distal humeri. Specimens able to be identified to the species level included eastern small-footed bats, little brown bats, Indiana bats, big brown bats, and one Corynorhinus species (Colburn et al. 2015). The estimated total of 1,322 bats is consistent with prior work done at the site (Jegla 1963). Size and configuration of humeri indicate mostly medium-size Myotis species, with several humeri of small and very small Myotis species, likely tri-colored and medium-size bats. None of the humeri examined were representative of large size Myotis bat species (Colburn et al. 2015). Sub-fossil dentaries of Myotis bats from these same collections from Bat Cave were later examined by Jansky and a team of colleagues using geometric morphometrics (Jansky et al. 2016). A total of 48 fossil specimens were examined, with most identified as either southeastern bats (33.3%) or Indiana bats (25%). Minor presence of gray bats (4.2%) and eastern small-footed bats (2.1%) was also detected, but no specimens representing little brown bats or northern long-eared bats were found. This is doubtfully a direct reflection of the species present in the cave at the time the

fossils were deposited—little brown bats and northern long-eared bats were likely present but simply composed a much smaller proportion of the bat assemblage in Bat Cave during the Holocene period (Jansky et al. 2016). Indeed, most of the radii deposits in Bat Cave have been radiocarbon dated to ~9510 to 2250 years before present (Colburn et al. 2015). Another 12 specimens (25%) could not be classified to any of the six Myotis species studied. Furthermore, 35.4% of specimens that were classified to the species level fell outside the 95% confidence interval for their assigned species. This would suggest that one or more groups not represented among the modern species included in the scope of the study were present in Bat Cave in the past. The relative proportions of bat species in Bat Cave are quite different now from when the fossils were deposited—although Indiana bats continue to use the site, numbers have been reduced in recent years, and the southeastern bat has essentially abandoned the site (Jansky et al. 2016).

Lacki et al. (2015) examined temporal changes in physiological characteristic of cave-hibernating bats during staging and swarming events for two years prior to detection of WNS (2011–2012) and two years following confirmation of the disease in MACA (2013–2014). A total of 1,232 bats representing 8 species were captured during sampling at Colossal Cave during this time. Tri-colored and northern long-eared were the most abundant species observed during sampling. Sex ratios of bat captures were male-dominated which is common at swarming caves in the fall, however it is unknown why sex ratios were male-dominated in spring/summer staging events (Piksa 2008, Suba et al. 2008, Vintulis and Suba 2010). Degree of wing damage associated with WNS infection was also examined, and the percentage of bats displaying fungal lesions increased during the final two years of samples (2013–2014), concurrent with substantial declines in bat capture rates. Body Mass Index (BMI) was also used as a tool for evaluating body condition in bats in this study and significant variation in body condition was observed among cave-hibernating bats at both the seasonal and annual scale. Significant temporal variation of body mass and BMI was observed for little brown bats, northern long-eared bats, and tri-colored bats. However, Indiana bats did not exhibit this same pattern. This work also identified an increase in BMI among little brown bats and northern long-eared bats in 2014. This observance is thought to be related to the overall better body condition of bats able to survive exposure to WNS (Lacki et al. 2015).

Steven Thomas (Monitoring Program Leader for CUPN) and others developed a monitoring protocol for cave-roosting bats in MACA and several other CUPN parks in 2015. In a resource brief, Thomas cited the importance of bats to surface and subsurface communities, the threat posed to bats by the presence of WNS, and the reliance of many bats on adequate cave habitat as evidence of the need for enhanced monitoring of bats and cave roosts to manage and protect critical bat and cave habitat at MACA and other CUPN parks. The resource brief reported steady declines in federally endangered Indiana bats during counts conducted at Dixon Cave within MACA from 1987 to 2013 (Figure 4.95) (Thomas 2015). Thomas conducted five winter counts from 2008–2016 among five caves used by the big-eared bat and the results indicated the species appeared to be increasing in numbers during this period (Thomas 2016). An updated version of the monitoring protocol was issued in 2016 by Thomas et al. to change sampling design and data analysis from a single-measure technique proposed in the initial version to a multiple-measure approach for summer bat monitoring (Thomas et al. 2016). Datasets produced via this monitoring system exist for several MACA hibernacula, but are not yet

available for publication. Thomas notes that these data are presently undergoing QAQC procedures and the information derived from this monitoring will be covered in reports issued later in 2018 (Steven Thomas, Monitoring Program Leader, CUPN, June 2018, personal communication).

Biennial hibernation counts of several colonial Myotis hibernacula in the park during 2015 revealed significant decreases among several bat species (Thomas 2015). Preliminary counts at the time of publication indicated over 80% declines in little brown bats, nearly 80% declines in Indiana bats, and declines near 70% for tri-colored bats. Mist netting efforts on several summer projects suggest that northern long-eared bat populations have declined substantially on the summer landscape at MACA, whereas gray bat and Rafinesque's big-eared bat numbers were stable or increasing in the park as of 2015 (Thomas 2016, Thalken 2017, Thomas 2018).

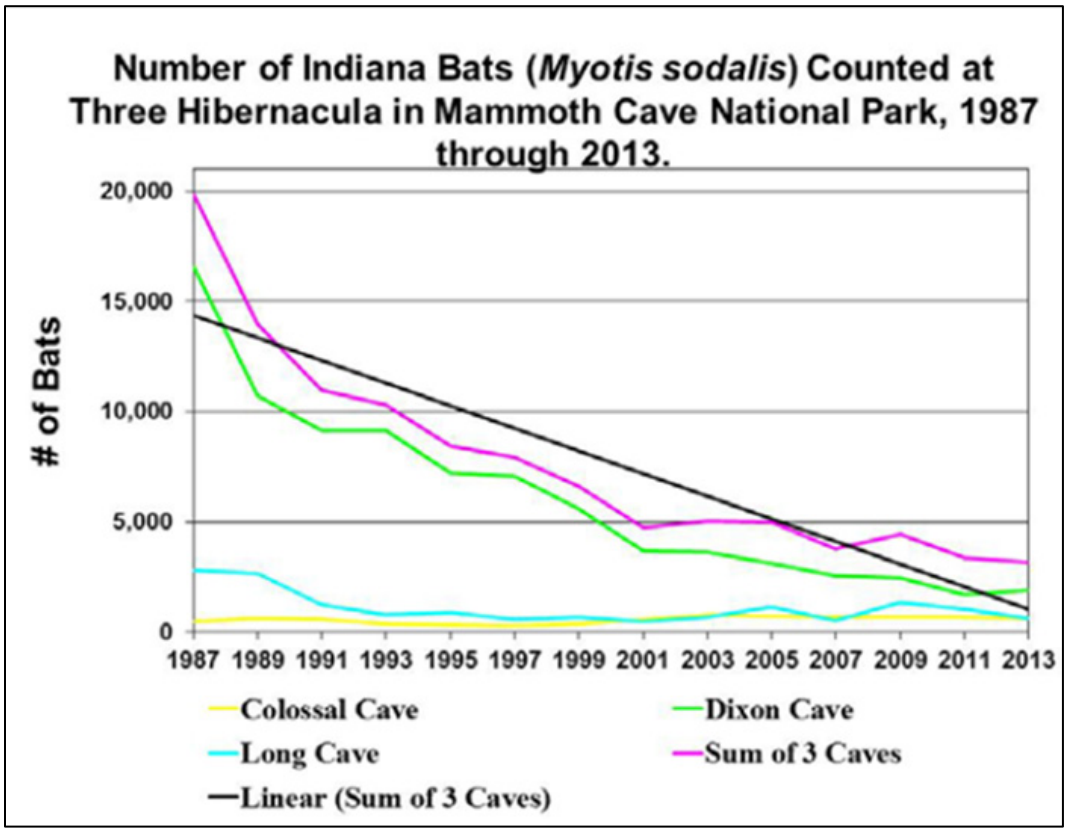


Figure 4.95. Counts of hibernating Indiana bats 1987 through 2013 in three important bat caves in MACA (Thomas 2015).

Thomas and Toomey (2017) provide a thorough description of the work that has been done to assess present-day bat abundance and species diversity among several important bat caves within and near to the park relative to historic and pre-historic conditions. This effort was conducted as part of a larger work dedicated to various facets of the park and the intersection of human and natural history that has shaped the current state of the park and its resources. The summarized results are presented hereafter according to location.

Historic Entrance to Mammoth Cave

Overall numbers and diversity have declined greatly in Mammoth Cave over the 20th and 21st centuries. The millions or even tens of thousands of bats that once used the area around the Historic Entrance in historic and prehistoric times have not been observed in the past 100 years. As part of the NPS Inventory and Monitoring Program, systematic biennial winter counts began at this location in 2015. The initial count produced records for 5 bat species including 122 tri-colored bats, 27 Indiana bats (federally endangered), 10 little brown bats, four big brown bats, and a single northern long-eared bat (federally threatened). In March of 2015 the first recent winter record of an eastern small-footed bat was found just inside the entrance gate. Use of the Historic Entrance itself has been assessed by various researchers in recent years (1997–2016) using mist nets or harp traps during late summer/fall swarming, and exit counts were conducted during summer 2010–2016. These records indicated use of the area by the same six species identified during biennial winter counts in addition to a seventh species, the red bat. Evening exit counts for the period 2010–2016 ranged from 5–50 bats during June to 70–170 in August. Several species visit the area and utilize it during fall swarming in numbers of a few hundred.

Dixon Cave

More bat survey and research effort has been conducted here during the 20th century than at any other cave in the park as this cave has typically been occupied by greater numbers of more species than any other major bat cave in MACA. At one time, Dixon Cave housed the largest known Indiana bat colony on the park and represented the park's most significant swarming site. Evidence of bat use here extends to dates well before counts and direct observations were recorded. Extensive saltpeter deposits here suggest that bats used this cave over an extended period, likely thousands of years, but pervasive mining of saltpeter from the cave has disturbed much of the floor and the number of pre-20th century bone deposits here are few. At minimum, the bone deposits indicate bat use in the cave over the past 1,000 years. Analysis of the bones that are present here suggest the cave housed numerous species with the most common species (in descending order) including Indiana, big brown, eastern small-footed, tri-colored, and little brown bats. A few gray, big-eared, and perhaps some southeastern bats were also present among bone deposits but these species are much less well represented (Colburn 2005). Counts of hibernating Indiana bats here date from 1957 to present and show that numbers have steadily decreased since their peak in the mid-1980s (Figure 4.96). However, counts before 1987 were irregular and focused on only listed bats. Regular counts for little brown, tri-colored, and big brown bats hibernating in Dixon Cave are available from 1987 to present and demonstrate that the number of hibernating bats tends to oscillate over time (Figure 4.97).

As of 2015, the cave is used by slightly over 1,000 bats of five species during the winter, fewer than 100 bats representing three species occupy the area during the summer, and around 1,000 bats of 8 species can be found here during late summer/fall swarming season. Bat use of the cave was assessed during bat workshops during August/September 1997, 2004, 2006, 2014, and 2015 using mist nets and/or harp traps. A total of 129 individuals representing eight species were captured from these efforts. Colburn et al. (2015) reported a cluster of 50–100 bats in the rear of the cave during summer 2000–2002, most appeared to be gray bats. This is supported by winter bat surveys extending to the late 1980s that report gray bats hibernating in the rear sections of the cave. Nocturnal exit counts

using external infrared lights at the entrance from 2010–2016 range from 28–340 bats during June/July to 30–129 bats in October. Dixon Cave is listed in the highest priority category for recovery of Indiana bats, and the continued decline of the species observed there represents a concern.

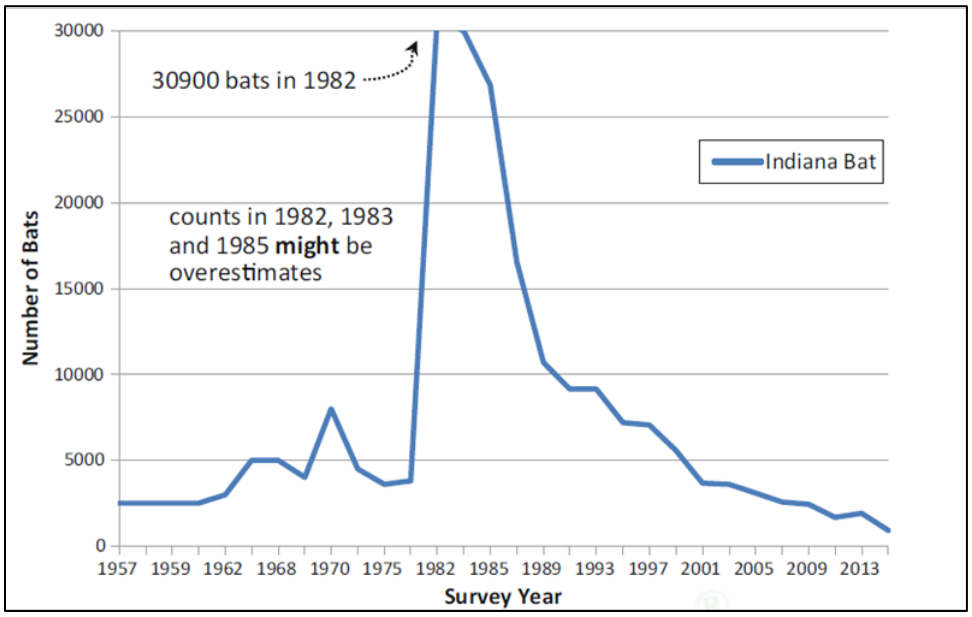


Figure 4.96. Number of hibernating Indiana bats counted in Dixon Cave, MACA from 1957 through 2013. (Thomas and Toomey 2017).

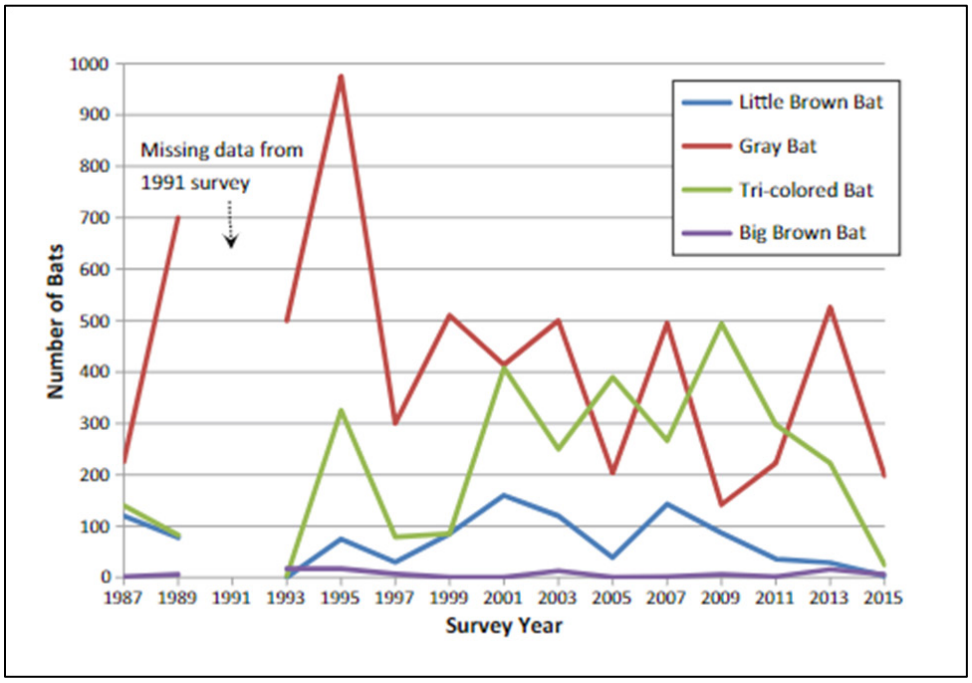


Figure 4.97. Number of hibernating bats counted in Dixon Cave, MACA from 1987 through 2015. (Thomas and Toomey 2017).

Colossal Cave Entrance

The entrance to Colossal Cave that is used by bats is an artificial entrance that was constructed in 1896 to allow the cave to be commercially developed. As such, this section of the cave had no known bat use prior to that time. Relatively little bat use is known from the cave prior to the 1950s (Thomas and Toomey 2017). Populations here have declined from the 1950s, when they were initially surveyed, particularly among Indiana and little brown bats (Figure 4.98). These species hibernated in numbers of several thousands in the 1950s, but now only a few hundred of each can be found here in the winter. Overall, less than 500 bats representing four species are present in Colossal Cave during winter, and a few hundred individuals of six species occupy the cave in summer. The entrance to this cave does not appear to serve as a fall swarming site. Counts of hibernating Indiana bats have been conducted by Kentucky Department of Fish and Wildlife Resources (KDFWR) and US Fish and Wildlife Service (USFWS) biologists during biennial censuses in the 1980s and 1990s.

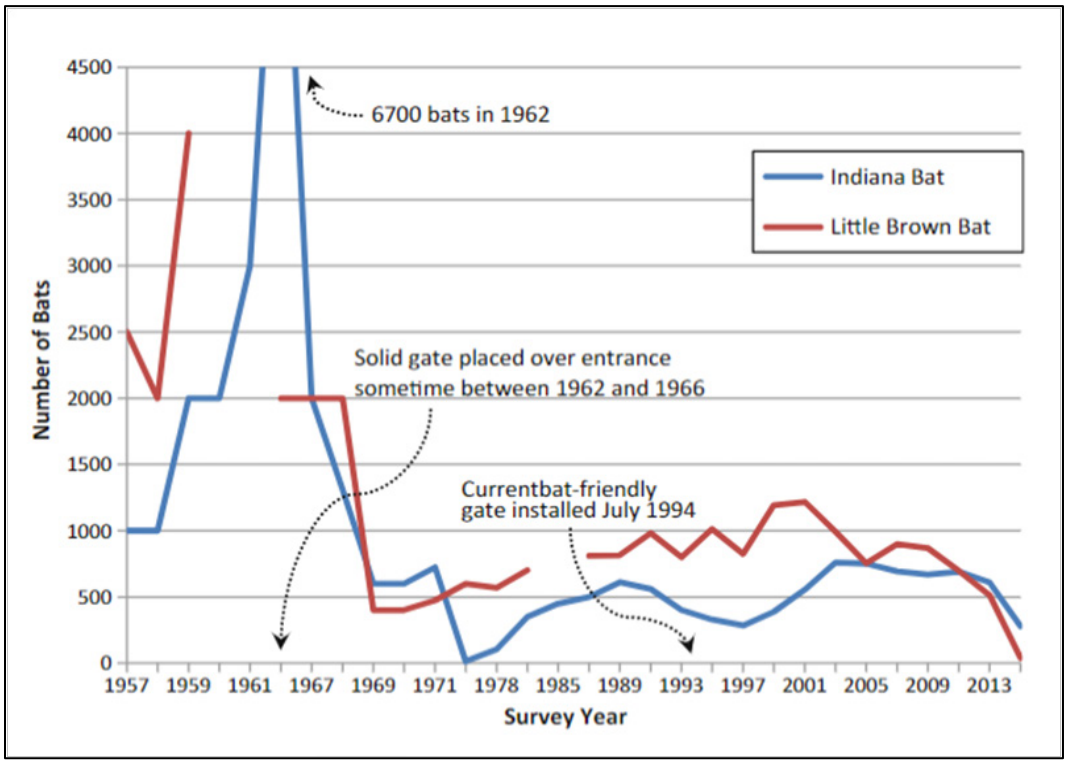


Figure 4.98. Indiana and little brown bats in Colossal Cave winter 1957–2015 (Thomas and Toomey 2017).

During this time, numbers of Indiana bats remained fairly stable, ranging from 284–610 individuals. In the same interval, little brown bat numbers at Colossal Cave increased to 1,192 individuals by 1999. Numbers of both species have yet to return to early 1960s levels, even post-installation of a bat-friendly gate at the entrance in 1994. Surveys during the early 2000s showed that Indiana bats were remaining fairly stable, with numbers ranging from 544–760, but as of January 2015, only 279 Indiana bats remained. Little brown bats declined during the early 2000s from 1,219 individuals in 2001 to just 515 in 2013. As of January 2015, only 38 little brown bats remained here, and 4 of these

exhibited symptoms of WNS. WNS was discovered at this entrance in February 2013 and as with other caves that have been affected by the disease within the park and elsewhere, it has produced devastating effects in terms of bat abundance and diversity at Colossal Cave. The marked declines observed since WNS was found at this entrance are likely related to the disease.

Long Cave

One of three major bat caves in the park over the past 100 years (along with Dixon Cave and Colossal Cave), Long Cave demonstrates a long period of bat use dating back to prehistoric times and has shown substantial year-round usage in modern times. In December 1947, up to 50,000 Indiana bats were reported here by H.B. Hitchcock, yet today that number more closely resembles 1,000 individuals of the species. However, it appears that species diversity here has increased; gray bats colonized the cave in 1997. Nocturnal exit counts and harp/mist netting during summer months indicate the cave houses over 500 bats of seven species. Unofficial counts from winter 2017 suggest that hibernating gray bats number over 100,000 in Long Cave (Steven Thomas, Monitoring Program Leader, CUPN, August 2018, personal communication).

Bat Cave

Substantial bone deposits found in Bat Cave were recently examined by paleontologists and bat and cave scientists (e.g., Jansky et al. 2016, Colburn et al. 2015). These studies suggest significant bat use of the cave over approximately the past 11,000 years. Since the 1970s, Bat Cave has hosted 200–400 bats during the winter representing four main species, as well as federally-listed species (Indiana, gray, and northern long-eared bats). Small numbers of male gray bats and tri-colored bats can also be found here during the summer months. Little brown and Indiana bats have declined significantly here in recent years (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Wilson Cave

Historically, Wilson Cave has been used by moderate numbers of bats. In February 1999, Steven Thomas documented a few hundred bats of five species. Little brown bats were observed in greatest abundance (207 individuals), followed by Indiana bats (65), tri-colored bats (33), big brown bats (5) and a single gray bat. Since 2000, four bat species have been observed hibernating in Wilson Cave in small numbers. Numbers of hibernating little brown bats range from zero to 123 individuals, Indiana bats from 3–140, tri-colored bats range from 5–68, and big brown bats have been observed hibernating in the single digits (1–7). The most recent counts (2015 and 2017) demonstrate precipitous declines of Indiana, little brown, and tri-colored bats, presumably due to WNS (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication; Steven Thomas, Monitoring Program Leader, CUPN, August 2018, personal communication).

Lee Cave

Lee Cave demonstrates evidence of prehistoric bat use, and is presently known to house several bats from five species, including three that are federally-listed (Indiana, gray, and northern long-eared bats). Significant pre-historic use evidence includes desiccated guano piles that indicate summer use by colonies of gray bats (Colburn 2005). Modern summer usage of the cave is thought to consist of

mainly gray bats. During the summer months a gray bat colony of approximately 75 male, or non-reproductive females use the cave. The first known winter bat count at Lee Cave was conducted in 2011 by Steven Thomas and Rick Toomey, where 164 little brown bats, 66 Indiana bats, 49 tri-colored bats, and three gray bats were found. Evidence in Lee Cave suggests historic summer use by gray bats (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). The most recent counts (2015 and 2017) demonstrate precipitous declines of little brown and tri-colored bats and smaller declines of Indiana bats, presumably due to WNS (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication; Steven Thomas, Monitoring Program Leader, CUPN, August 2018, personal communication).

Hickory Flat Cave

The largest known natural hibernaculum for Rafinesque's big-eared bats in MACA is present in this cave. More than 1,570 members of the species were documented here by Rick Toomey and Steven Thomas on January 30, 2014. This observation is unusual as the species typically hibernates in smaller clusters ranging from 70–270 among four other caves in the park.

Coach and James Caves

Although located just to the south of the park boundary, these two caves serve as important hibernacula and summer roosts for endangered gray and Indiana bats, and thus bear mention in this report. Together, Coach and James Caves act as winter roosts for approximately 300,000 gray bats. Coach Cave was reported to have housed up to 100,000 Indiana bats in the winter of 1960, but these numbers have fallen, likely in response to entrance modifications by humans and subsequent large increase in the number of gray bats using the cave. For example, decreases in Indiana bats in Coach Cave from 100,000 to 4,500 during the late 1960s and early 1970s was due to bat movement out of the cave after an observation platform and building were constructed in one entrance during the early 1960s. Subsequent increases in Indiana bat numbers were observed among caves in the park which accommodated Indiana bats that had left Coach Cave in response to modifications. Both caves also house several thousand male and non-reproductive female gray bats during the summer.

4.9.4. Impacts of White-nose Syndrome

Thomas (2016, 2018) provides an update on the current status of MACA bats in relation to WNS confirmation on the park. Biennial winter counts from 2007 to 2017 in selected caves on the park show increases in big brown, gray, and Rafinesque's big-eared bats and decreases in Indiana, little brown, and tri-colored bat (Thomas 2016). Summer bat capture rates from inventories conducted on the park in 2004–2005, prior to the arrival of WNS, were compared to post-WNS conditions in 2017 (Thomas 2018). Capture rates for big brown, eastern red, and evening bat increased by 25.0–326.9% whereas tri-colored, little brown and northern long-eared bats declined by 82.5–99.1% (Table 4.42–4.43) (Thomas 2018).

Table 4.42. Captures, capture rates, and percent changes in rates among six sites in MACA pre-WNS (2009–2011) and post-WNS (2014–2016) arrival (from Thalken 2017). Unequal effort (pre-WNA = 120 net-nights; post-WNS = 121 net-nights) between sampling periods standardized by capture per net-night. Asterisks (*) indicate small sample size both before and after WNS arrival (modified from Thomas 2018).

	Pre-WNS (2009–2011)		Post-WNS (2014–2016)		
Thalken Study Species	Total Captures	Captures per net-night	Total Captures	Captures per net-night	Percent Change (Capture Rate)
Myotis septentrionalis	130	1.08	24	0.20	−81.5
Eptesicus fuscus	10	0.08	19	0.16	100.0*
Perimyotis subflavus	13	0.11	9	0.07	−36.4*
Myotis lucifugus	4	0.03	13	0.11	266.7*
Lasiurus borealis	8	0.07	37	0.31	342.8
Mycticeius humeralis	7	0.06	41	0.34	466.7

Table 4.43. Summer bat captures, capture rates, and percent change in rates from MACA pre-WNS (2004–2005) and post-WNS (2017) arrival. Unequal effort (pre-WNS =125 net-nights; post-WNS = 79 net-night) between sampling events is standardized by capture per net-night. (modified from Thomas, 2018).

	Pre-WNS (2004–2005)		Post-WNS (2017)		
Bat Inventories Species	Total Captures	Captures per net-night	Total Captures	Captures per net-night	Percent Change (Capture Rate)
Myotis septentrionalis	425	3.40	2	0.03	−99.1
Eptesicus fuscus	205	1.64	162	2.05	25.0
Perimyotis subflavus	100	0.80	11	014	−82.5
Myotis lucifugus	65	0.52	7	0.09	−82.7
Lasiurus borealis	46	0.37	67	0.85	129.7
Mycticeius humeralis	33	0.26	88	1.11	326.9

4.9.5. Distribution

Historic Distribution Records

Prior to the last 100–200 years, the largest bat roost in the park was near the Historic Entrance to Mammoth Cave, where large numbers of several bat species could be found hibernating during the winter, and some species used the area as a summer roost as well. Extensive staining and guano deposits in the historic entrance area (Figure 4.99) suggest this part of the cave was once heavily used by numerous bat species. Prior to 2015, when the NPS Inventory and Monitoring Program began long-term biennial monitoring in the historic entrance area, no systematic effort to assess contemporary bat use had taken place here since the 1930s. Initial counts in 2015 showed relatively few bats were using the area, including mostly tri-colored (present year-round) and Indiana bats, with a few little and big brown bats, and a single northern long-eared bat. Disturbance and/or changes in microclimate associated with entrance/passage modifications are responsible for much of the habitat loss observed in Mammoth Cave (Thomas and Toomey 2017).

Bats have continued to occupy less-disturbed caves within the park, often in large numbers. Historic reports on bat distribution in the park date back to observations from the mid-19th century (Silliman 1850). Numerous species were reported from Colossal Cave, Dixon Cave, and Long Cave including the big brown bat, tri-colored bat, little brown bat, Indiana bat, northern long-eared bat, and the least brown bat (now known as the eastern small-footed bat, M. leibii) through the 1960s. Bailey et al. (1933) found the little brown bat and Indiana bat by the thousands in Colossal Cave, Dixon Cave, and Long Cave. The tri-colored bat demonstrated the most widespread distribution, with observations reported in Colossal Cave, Crystal Cave, Dixon Cave, Long Cave, and Mammoth Cave.

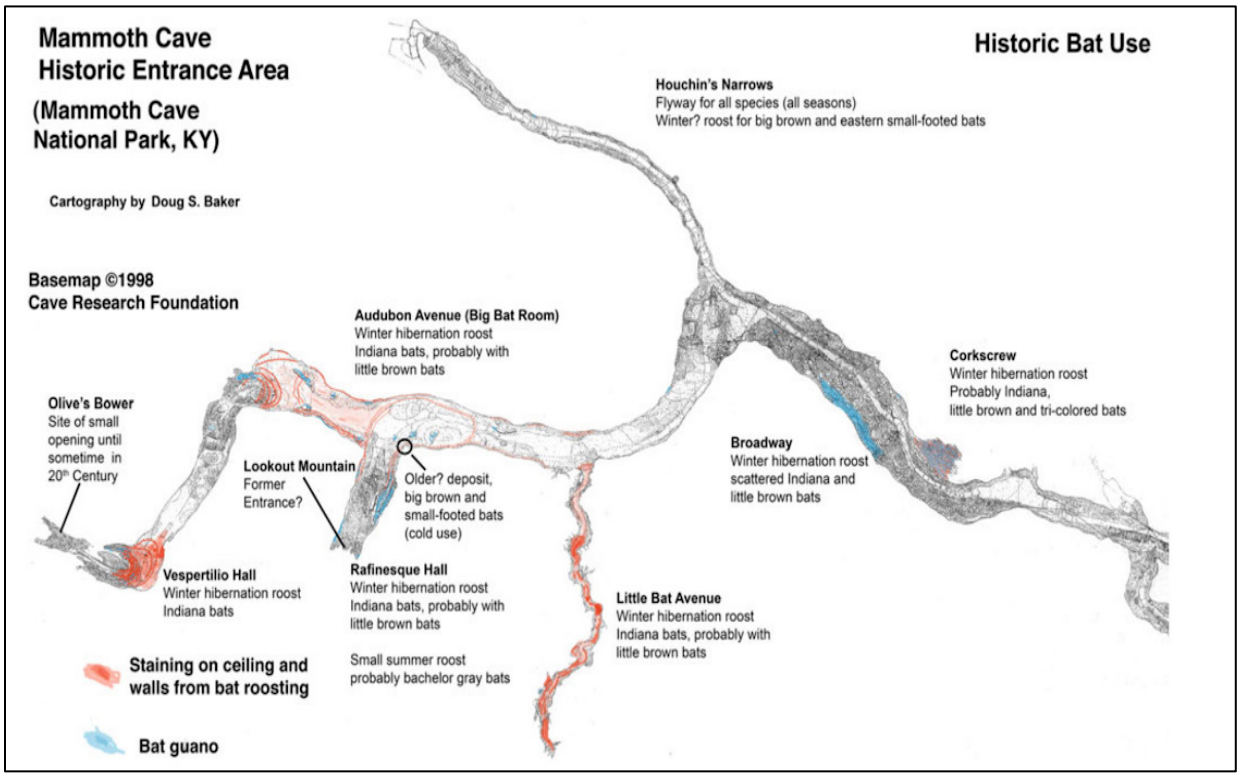


Figure 4.99. Map of the Historic Entrance area of Mammoth Cave and areas of historic bat use. (Thomas and Toomey 2017).

Bailey et al. (1933) reported the least brown bat (eastern small-footed bat) was observed in three locations on the park including near the Historic Entrance to Mammoth Cave, Crystal Cave, and Colossal Cave. The big brown bat, although common in abundance, was documented primarily from areas along the Green River, and a few were reported from Colossal Cave. The red bat, northern long-eared bat, and evening bat (less common) were reported from only two locations in the park. The gray bat was found in a single location at Dixon Cave by Giovannoli in 1929 and exhibited the most restricted distribution on the park at the time of the study. Not found, but within the known geographic distribution range, during Bailey et al.'s (1933) survey were the hoary and silver-haired bats. Jegla and Hall (1962) found that the free-tailed bat had been present near the Violet City Entrance to Mammoth Cave in prehistoric times. Barbour (1963) made collections of several species in attempt to augment poorly-known distributions of multiple bats species in Kentucky. Freeman et

al. (1973) observed several Myotis species between the entrance canyon and beginning of the trunk passage in Lee Cave. The authors were shocked that so few bats were found hibernating in this relatively undisturbed cave, and the bats that were present were restricted to the area near the entrance. The authors proposed this distribution pattern likely reflects preference for hibernation areas were suitable microclimate conditions are present. In the winter of 1983, Clawson surveyed Dixon Cave and found that approximately 30,000 Indiana bats scattered in small (10–200) to medium (200–1,000) sized clusters. Clawson also noted that about 125 gray bats were also present here (1983).

Recent Distribution Records

Many of the recent distribution records are based on a thorough inventory of bat activity on the park during 2004–2005 by Foster et al. (2007). This inventory is supplemented and updated by records from various scientists who have conducted bat research in the park in recent decades. In some instances, the species distribution has been impacted by WNS—first documented in MACA in 2013. In some cases, certain WNS susceptible species may have vanished from certain caves. However, park staff believes that these sites remain potentially suitable habitat for the species that have been (at least temporarily) extirpated (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Indiana bat

The Indiana bat is distributed throughout much of the eastern United States and is located across Kentucky, with winter distribution restricted to karst and cave regions (KDFWR 2014g). Indiana bats are usually found roosting beneath exfoliating bark of live or dead trees. The first evidence of reproductive success for this species at MACA occurred in 1995 when females and juveniles were captured among cave and upland habitats. Foster et al. (2007) tracked the species to 17 roost trees, of 11 species in 2004–2005. The majority of the roost trees were snags (82.4%), while only a few roosts (17.1%) were found in live trees. Two primary roosts for Indiana bats were identified in the park including a chestnut oak on the upland margins of Sal Hollow which was split into two trunks, one living and one dead. Many bats were found under the peeling bark of the dead trunk. The other primary roost was in a shellbark hickory (*Carya laciniosa*) located in close proximity to the previously mentioned chestnut oak. Thomas and Toomey (2017) report modest numbers (3–279) of Indiana bats hibernating in Colossal Cave, Lee Cave, Wilson Cave, Bat Cave, and the Historic Entrance to Mammoth Cave but in Dixon and Long Cave in numbers approaching 1,000 individuals. Steven Thomas notes Indiana bat numbers in Wilson Cave are similar to Lee Cave counts and numbers for Colossal Cave are similar to Long Cave. The most substantial hibernaculum for Indiana bats on the park is in Dixon Cave (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). Overall, recent winter counts (2015 and 2017) show decreased in abundance of this bat in all sites (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Gray bat

Gray bats range throughout karst areas of the southeastern United States with the core range covering the cave regions of Kentucky, Missouri, Tennessee, Alabama, and Arkansas. The species occurs

throughout Kentucky with maternity colonies concentrated in the Pennyroyal region and major hibernacula can be found in Edmonson County, in the Mammoth Cave area (KDFWR 2014e). They are known to form large maternal or bachelor colonies in caves, mines, storm drains, and beneath bridges. The species has not been documented to have maternal or bachelor roosts in trees. There are no records of summer maternal colonies of gray bats in the park, but males and non-reproductive females are known to roost in small colonies in Bat Cave and Dixon Cave during the summer and the Green River provides high quality foraging habitat for the species (Foster et al. 2007). Foster et al. (2007) captured this species from six sites on the park from June 2004 to July 2005. Nearly 75% of these captures occurred at Long Cave. Juvenile gray bats were also caught at Houchins Ferry. No gray bats were tracked using radio telemetry during this inventory. A fairly large (500–1000+) summer bachelor colony of gray bats is present in Long Cave (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). Thomas and Toomey (2017) report that two caves located near the park, James Cave and Coach Cave, serve as winter roosts for large numbers (approximately 400,000) of endangered gray bats, during the summer these caves house several thousand male and non-reproductive female gray bats. A few gray bats were observed hibernating in Lee Cave during winter surveys in 2011. Over 100,000 gray bats may now hibernate in Long Cave based on unofficial counts from winter 2017 (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication).

Northern long-eared bat

The northern long-eared bat is found throughout most of North America and is present year-round in Kentucky where it exhibits statewide distribution (KDFWR 2014i). This species is known to roost in live or dead trees during the summer, either alone or within maternity colonies (Caceres and Barclay 2000, Reid 2006). During the winter, this species hibernates singly in rock cracks and crevices of cave walls (Davis 1974). Foster et al. recorded numerous long-eared bats during their 2004–2005 inventory at multiple locations including Cedar Hill Church Road, Maple Springs Pond, Buffalo Trail Pond, and Triangle Pond (Foster et al. 2007). Summer distribution of the species (pre-WNS) was fairly well known on the park (the species was captured by netting in numerous locations) (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). Thalken (2017) provided a good idea of the habitat conditions at sites chosen as summer roosts for this species. However, solid information on hibernation sites (pre- and post-WNS) are lacking and additional study is recommended to better assess the status of hibernating long-eared bats at MACA. The paucity of recent summer capture records (2017 and 2018), in spite of netting, suggest a catastrophic decline of this species on park and the potential that it may become extirpated from the park due to WNS (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Tri-colored bat

The tri-colored bat is widespread across the eastern United States and Canada and commonly occurs in Kentucky throughout the year (KDFWR 2014n). Foster et al. recorded 100 individuals during 2004–2005 inventory, mostly from Long Cave (Foster et al. 2007). The Historic Entrance to Mammoth Cave continues to be a year-round roosting site for tri-colored bats and numbers ranging

from 3–494 were found hibernating in Dixon Cave since the mid-1980s (Thomas and Toomey 2017). Observations from cavers and data from the park's Lesser Cave Inventory indicated that this species was very widespread (present in hundreds of caves on the park in (at least) small numbers) at MACA prior to the arrival of WNS. Post-WNS, this species remains distributed throughout various caves on the park, but is observed less often (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Big brown bat

The big brown bat occurs across most of North America and is a year-round resident of Kentucky (KDFWR 2014a). Distribution data for big brown bats at MACA is moderately good (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). Foster et al. (2007) documented this species from several locations on the park including the Floyd Collins house. Thomas and Toomey (2017) report that a few big brown bats can be found in the Historic Entrance to Mammoth Cave and in Dixon Cave during the winter. Pre-WNS capture data offers a good idea of summer distribution of big brown bats at MACA. In addition, at least four structure roosts are present on the park where the species is found during the summer. During the winter, big brown bats occur in small numbers within most known colonial hibernacula on the park (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). In mist netting in 2017 big brown bats were, by far, the most frequently captured bats on park away from cave entrances (Thomas 2018).

Little brown bat

Little brown bats occur throughout most of North America and can be found throughout Kentucky where it may be locally distributed in heavily forested areas during the summer and restricted to cave areas during the winter (KDFWR 2014h). The habitat types present at MACA including dense upland forests in some regions and an abundance of caves provide preferred habitat for this species in all seasons. The little brown bat has been observed among several caves in the park. Foster et al. (2007) tracked little brown bats to Colossal Cave using radio transmitters. The majority of little brown bats observed by Foster et al. (2007) were captured from cave entrances. In 2011 the first known winter bat count at Lee Cave recorded 164 hibernating little brown bats (Thomas and Toomey 2017). The largest numbers of hibernating little brown bats since the 1970s have been found at (in descending order) Colossal Cave (max = 1,219 in 2001), Bat Cave, Long Cave, Wilson Cave, Lee Cave, and Dixon Cave (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). Overall, recent winter counts (2015 and 2017) show decreases in abundance of this bat in all sites. In fact, it is possible that in some cases, the little brown bat may not currently occur at some sites that it had been found at historically (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication; Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication).

Eastern small-footed bat

The eastern small-footed bat (also referred to as the eastern small-footed Myotis) is locally distributed across the southeastern United States. Within Kentucky the species is most frequently

found in association with expansive cliff lines found in the eastern part of the state in the Cumberland Plateau and Cumberland Mountains and also in the Mammoth Cave Plateau (KDFWR 2014b). The eastern small-footed bat is known to hibernate in caves, abandoned mines, rock quarries, rock shelters, and in crevices along cliff lines. Summer roost habitat is mostly ambiguous, but maternal roosts have been observed beneath bridges and in the crevices of rock outcrops. Reproductive females of the species have been found in MACA in recent decades. Foster et al. (2007) documented the eastern small-footed bat from a handful of locations including the entrances to Dixon Cave and Long Cave as well as the Floyd Collins house. As with the gray bat, the eastern small-footed bat was not radio-tagged or tracked during the inventory conducted by Foster et al. (2007). However, reproductively active females were captured and radio-tagged at the Crystal Cave Ticket Office during a 2017 bat inventory (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). The species has been regularly captured during summer/fall mist netting at the Historic Entrance to Mammoth Cave over the past decade, and a few have been observed in the Historic Entrance during recent biennial winter bat monitoring (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication).

Rafinesque's big-eared bat

This species is broadly distributed throughout the southeastern United States, and in Kentucky can be found predominantly along the western edge of the Cumberland Plateau and the Mammoth Cave region. The big-eared bat is a year-round resident of the state and likely moves only short distances between summer roost and winter hibernation sites (KDFWR 2014j). The species has been documented from a wide range of habitats. Hibernacula are typically located in caves, rock shelters, and bunkers. Summer roosts for the species can be found among sandstone rock shelters along bluffs, small caves, abandoned buildings, hollow trees, beneath bridges, and in cisterns. Foster et al. (2007) documented big-eared bats from several roost locations in MACA including cave entrances and several buildings that contained maternity colonies. The use of buildings during the maternity period for big-eared bats has been well documented (e.g., Marks and Marks 2006). Foster et al. (2007) found that nearly half (47.0%) of the Rafinesque's big-eared bats captured in the study were taken from three buildings on the park that contained maternity colonies. Foster et al. (2007) also noted that the species exhibited high fidelity to roosts. During this inventory, big-eared bats were captured at several locations that did not serve as summer roosts including Hickory Flat Cave, Snapping Turtle Pond, Buttonbrush Pond, Ray Davis Road, Buffalo Trail Road, and Wildcat Hollow Sink. During the winter, big-eared bats were recaptured in Hickory Flat Cave and Wildcat Hollow Sink while they hibernated. Johnson (2012) noted that MACA provides an ideal environment to study the hibernating behaviors of this species as it hibernates within caves here as opposed to other locations where species is more commonly observed hibernating in hollow trees and manmade structures. Thomas and Toomey (2017) note that Hickory Flat Cave is the largest natural Rafinesque's big-eared bat hibernaculum known. The authors also note that this species hibernates in smaller numbers within four other caves in the park. This species is reasonably well-represented in MACA as the park contains at least nine caves, and at least three structures, and until recently a large hollow tree that house summer nursery colonies of big-eared bats ranging in size from roughly 25–200 individuals. In addition, at least one other structure and five other caves may contain nursery colonies. More than eight caves on the park house summer bachelor (i.e., male and non-reproductive female) colonies of

big-eared bats in small numbers ranging from approximately two to 25 individuals (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication).

Evening bat

The evening bat is distributed locally across the eastern United States, with widespread distribution occurring in the southeast. The species is fairly common in the western third of Kentucky. This species was previously believed to be observed only as summer resident, but recent evidence suggests that it may overwinter (KDFWR 2014d). The evening bat was captured from and tracked to several locations on the park during inventory in 2004 and 2005 by Foster et al. (2007) (Table 4.44). All captures occurred in 2004, as no individuals of the species were captured in 2005. Captures occurred at Maple Springs Pond, Temple Hill Pond, and Mammoth Cave Ridge Pond D. Individuals captured were radio-tagged and tracked to four roost locations at MACA (Figure 4.100) including a small flowering dogwood and a large white oak tree near Maple Springs Pond, a white oak snag near Temple Hill Pond, a large post oak tree near a well-traveled park road. Each of the trees used as roost sites by the species were located in mature, upland deciduous forest which differs from other studies that have tracked this species to roost exclusively in bottomland forests (Whitaker and Gummer 2000, Kurta 2005). Although evening bats here were not found to utilize bottomland forest habitat on the park during radiotagging in 2004–2005, more recent mist netting regularly captures them in this habitat (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication; Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). An increase in evening bats has been observed in post-WNS netting (Thalken 2017, Thomas 2018). This observation is notable as the species was formerly among the less frequently captured bats at MACA, but following the detection of WNS it has become one of the most frequently captured bat species at MACA, especially at sites that are not associated with caves.

Table 4.44. Records of capture and roost tree locations for evening bats tracked via radio telemetry at MACA (Foster et al. 2007).

Band/ Bat No.	Capture Site	Date	Sex	Age	Repro. Status	Weight (g)	Forearm (mm)	Trees Used
A01680	Maple Springs Pond	30-Jun	F	A	L	10	38	1–04; 5–04
A01683	Maple Springs Pond	30-Jun	F	A	L	10	39	None found
A05660	Temple Hill Pond	1-Jul	F	A	L	–	–	501
3–2004	MC Ridge Pond D	8-Jul	F	A	PL	10	39	545

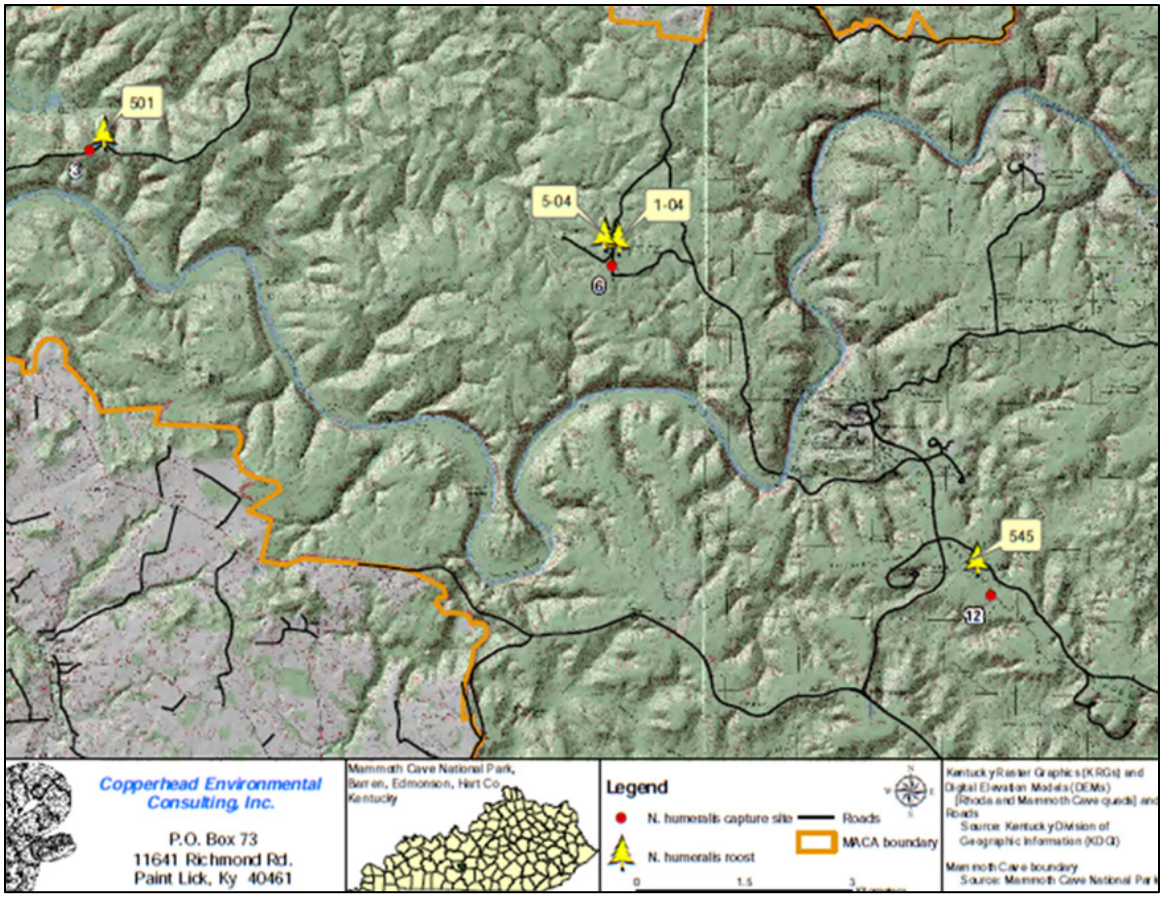


Figure 4.100. Capture sites and roost trees for three evening bats tracked at MACA in 2004 (Foster et al. 2007).

Southeastern bat

The southeastern bat is locally distributed across the southeastern United States and in Kentucky, the species can only regularly be found in the western half of the state (KDFWR 2014m). During the winter, the southeastern bat predominantly dwells in caves, although small groups have been found in manmade structures like bridges, culverts, and cisterns. The species is also known to use hollow trees during summer roosting. The southeastern bat was last seen on the park in the 1980s, no specimens have been observed or captured in recent decades, despite significant effort. Foster et al. (2007) were unsuccessful in capturing the species from sampling in cave entrances, several ponds, and one stream although the southeastern bat is known to forage near the water surface of ponds and streams (BCI 2001), and roost in caves, hollow trees, buildings (Marks and Marks 2006). Jansky et al. (2016) noted that southeastern bats were once present in Bat Cave in substantial colonies during the Holocene, but that the species is no longer present at the location.

Seminole bat

The Seminole bat (*Lasiurus seminolus*) is a tree-roosting bat broadly distributed throughout most of the southeastern United States (Lacki et al. 2014) with distribution extending to south-central Kentucky (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal

communication). The species is thought to be infrequent in Kentucky during summer and early fall, but potentially breeds in the Land Between the Lakes National Recreation Area in western Kentucky (KDFWR 2014k). The first Seminole bat record in Kentucky was documented in 1998 by John MacGregor outside the entrance to Coach Cave in Edmonson County. Two other records of Seminole bats were reported by Lacki et al. (2014) including a 2007 record in Edmonson County near the Historic Entrance to Mammoth Cave and a 2013 Barren County record from the Wondering Woods area. Another Seminole bat was captured near Echo River Spring in 2015 (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). The Seminole bat was verified as reproducing in Mammoth Cave area in 2017 when four juveniles were captured during the 2017 inventory (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). Fewer than two dozen records of this species are known from Kentucky; however, this number does not include at least five that have been captured on the park in 2017–2018. A few individuals of this species have been captured on the park during summer monitoring in each of many recent years (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication.

Eastern red bat

The eastern red bat is widely distributed across North America and is common throughout Kentucky where it is most often encountered during the summer. The species has also been observed as transient migrants, and some even overwinter in Kentucky (KDFWR 2014c). Eastern red bats are not frequently observed at cave entrance habitats, or are represented in minimal numbers where present in this habitat. For instance, Foster et al. (2007) report only two records during their 2004–2005 surveys on the park. Lacki et al. (2015) captured only three eastern red bats while surveying at Colossal Cave from 2011 to 2014. An exception is the fact that they will frequently swarm with other species at fall swarming cave entrances such as the Historic Entrance and Dixon Cave. They have been seen in those swarming sites and have been caught in early fall mist netting in these areas, and are fairly frequent overall (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). They are one of the most frequently captures bat in mist netting on park away from cave entrances (Thomas 2018).

Hoary bat

The hoary bat is the most widespread bat of American bats and scattered records exist for the species in Kentucky. It is usually observed in the summer, but the species is not known to overwinter in the state (KDFWR 2014f). These bats are rarely recorded on the park; however, summer and early fall mist netting provides a few records that indicate the species is present on the park (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication). Foster et al., 2007 captured three hoary bats from near Long Cave, Sloans Crossing Pond, and Wondering Woods Pond. Only a single specimen was captured during the 2017 inventory (Thomas 2018). It is not clear whether the rarity in capture records for this species represents the fact that they are difficult to capture or whether they are actually rare on the park (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Silver-haired bat

The silver-haired bat can be found throughout much of North America and has been recorded from various locations in Kentucky, mostly a spring and fall transient with a few summer and winter records (KDFWR 2014l). As noted for the hoary bat, there are only a few records of captures or sighting of silver-haired bats on the park in the last 20 years. Most of these have occurred in early fall mist netting efforts (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication Only five silver-haired bats were captured during 2004–2005 inventory (Foster et al. 2007). Single specimens were observed during biennial winter monitoring at Long Cave in 2007 and again in 2011, and in January 2010 at Wondering Woods bat house (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). This species is the only park species that has not been demonstrated to reproduce in the park area. The lack of sufficient captures represents a data gap that prevents detailed assessment of distribution or more general condition of this species in the park.

4.9.6. Changing Dynamics of Habitats and Roosts

Spanjer and Fenton (2005) assessed the effects of cave gates on bat behavior during pre-hibernation swarming. Bat echolocation, communicative calls, and flight speed did not differ consistently as a function of cave gate presence or absence. Likewise, flight behavior did not differ based on spacing of vertical gate supports, number of entrances, or gate position (entrance or passage) although bats generally circled more and passed directly through less frequently within passages (Spanjer and Fenton 2005). To better understand and manage reproductive bat populations, determine the locations of critically important roosts sites, and elucidate needs of specific maternity colonies, six bat species were assessed in the summer of 2004 and 2005 (including federally endangered Indiana and gray bats, as well as several regionally rare species including Rafinesque's big-eared, southeastern, eastern small-footed, and evening bats (Foster et al. 2007)). Numerous surface and subsurface locations were evaluated for bat use and activity during this study including various ponds, trails, roads, and park buildings as well as Dixon, Cathedral, Evening, Hickory Flat, Temple Hill, Misty Hole, Luna, Long, and Colossal caves. A total of 12 bat species were captured in this process, with capture rates being highest near cave entrances. Nine species were captured among the previously noted cave entrances. The evening, silver-haired, and hoary bat were not captured at entrances and only two eastern red bats were captured near cave entrances. However, substantial proportions of little brown bats (87.7% of all captures for the species), Indiana bats (80.0%), eastern small-footed (80.0%), tri-colored (70.0%), and gray bats (64.9%) were caught in and around cave entrances. No southeastern bats were successfully captured during these surveys, and subsequent surveys have met similar difficulty in capturing this species, indicating that it may no longer be present in the park or if present, demonstrates restricted distributions and low abundances. The same assessment tracked three of the targeted species (Rafinesque's big-eared, Indiana, and evening bats) using radio telemetry. Fourteen Rafinesque's big-eared bats (3 males, 11 females) were fitted with transmitters and 11 were successfully relocated and tracked to three unoccupied park buildings and three caves sites which served as maternity roosts. A total of 12 Indiana bats (8 males, 4 females) were fitted with radio transmitters, and 10 of these were successfully tracked to 17 roost trees of various species. Fourteen of the trees used by the tracked Indiana bats were snags, and the remaining three were live trees. In all cases, Indiana bats were found roosting under loose tree bark. Lastly, four

female evening bats were fitted with transmitters and three of these were successfully tracked to four roost trees representing three tree species. Two roosts were located beneath tree bark and the other two were in tree cavities (Foster et al. 2007). Among these results was the first documented use of roost trees by reproductive female evening bats in Kentucky.

Most Rafinesque's big-eared bats on the park roost in either caves or structures, but some roost in trees as well. Johnson (2012) found that most Rafinesque's big-eared bats in MACA that roost in trees tend to use large diameter trees. The author proposed that such trees allowed for larger colony sizes and may also provide more favorable microclimates. Foraging efforts for these bats appear to be concentrated in and adjacent to wetland and upland deciduous forests in response to localized abundance of preferred moth prey among these habitats. This highlights the importance of bottomland hardwood forests for foraging and roosting among big-eared bats (Johnson 2012). Griffitts (2016) assessed the value of prescribed burns to foraging Myotis bats at MACA in the wake of WNS on the park. Burning impacts forest vegetation, which in turn influences insect abundance and distribution, and this affects bat foraging on insect prey. The results of this study indicated that bat activity was generally altered across MACA in association with WNS and prescribed burning, with burned areas experiencing higher levels of bat activity following arrival of WNS on the park (Griffitts 2016). Species impacted by WNS have declined across the landscape, whereas bat activity increased among species less vulnerable to WNS. A statistically significant relationship between WNS and prescribed fire was observed for Myotis bats during this investigation. A shift was observed in Myotis activity during the study period. Prior to WNS, bat activity was greatest among unburned portions of the landscape. However, burned areas were found to experience higher levels of bat activity following the arrival of WNS on the park, suggesting the need for forest managers to consider prescribed fire and landscape features in managing bat populations affected by WNS (Griffitts 2016). A study of the response to WNS among Myotis bats performed by acoustic survey revealed that since the detection of the disease in the park, activity of Indiana bats, northern long-eared bats, and the Myotis phonic group have significantly declined across the forest landscape at MACA (Griffitts et al. 2016).

Jansky et al. (2016) studied fossil deposits in Bat Cave and demonstrated that geomorphic analysis of bat dentaries could be a useful tool for researchers and conservationists in distinguishing bat fossils to the species level, particularly among species that have been notoriously difficult to identify from dentaries in the past (i.e., southeastern bat, little brown bat, and Indiana bat). Bat Cave has long served as a home to several bat species, but the relative proportions of the species present here have changed with time. Bat Cave once housed substantial colonies of southeastern and Indiana bats. Indiana bats continue to use the cave in greatly reduced numbers, but southeastern bats have abandoned the site. An important application of this work relates to the federally endangered Indiana bat. When a species can reliably be identified from fossil specimens elsewhere one can infer the species was present at the site in the past and comparisons may be made relative to the current condition (Jansky et al. 2016). Others have noted that if a species is no longer present at a site due to recent alteration or disturbance of the roost, measures may be taken to restore the site. This action was applied at the Historic Entrance to Mammoth Cave for Indiana bats (Toomey et al. 2002). This may be an important step towards protecting and preserving cave habitat for the Indiana bat,

particularly since prior to WNS only 23 hibernacula house approximately 82% of all Indiana bats (USFWS 2007).

Thalken and Lacki (2017) assessed behaviors and roost selection among northern long-eared bats surviving to spring emergence and summer maternity in areas impacted by WNS. Adult male, non-reproductive female, and pregnant and lactating female bats were evaluated. The results of this study are summarized in Tables 4.45 and 4.46. Adult females selected summer roosts in trees within six areas. Within each of the six areas, several trees were used as roosts, and these trees were all within a 1 km proximity. Suitability of roosts for facilitating daytime sleep appears to be the driving factor in determining roost site selection among this species. No overlap in use of roosting areas was observed between non-reproductive females in the spring and pregnant/lactating females in the summer.

Table 4.45. Mean (± standard error, SE) habitat characteristics among tree roosts of reproductive (n = 30 roosts), non-reproductive (n = 39 roosts) female northern long-eared bats at MACA 2015–2016. Within rows, means without common letters are different (P<0.05) (from Thalken and Lacki 2017).

	Pregnant or lactating		Non-reproductive	
Characteristic	**x̄**	**SE**	**x̄**	**SE**
Diameter (cm)	31.2	4.3	32.3	3.4
Decay class (1–9)	3.23	0.3	2.46	0.3
Tree height (m)	15.6	2.1	19.1	1.5
Roost height (m)	7.43	1.0^{B}	10.03	$1.0^{A,B}$
Bark remaining (%)	71.6	6.4	78.3	5.1
Canopy cover (%)	66.7	4.7^{B}	79.4	2.8^{A}
Snag density (number/ha)	6.03	1.0	4.33	0.6
Tree density (number/ha)	38.9	$2.4^{A,B}$	35.1	1.6^{B}
Elevation (m)	240	3.0^{A}	211	5.4^{B}
Slope (%)	8.46	0.8^{B}	13.8	4.8^{B}
Aspect (°)	186	15.7	178	17.2
x̄ diameter (cm)	11.2	$0.2^{A,B}$	12	0.3^{A}
Basal area (m^2/ha)	5.89	1.4^{C}	14.2	1.9^{B}

Table 4.46. Mean (± standard error, SE) habitat characteristics among tree roosts of male (n = 14 roosts) northern long-eared bats at MACA 2015–2016. Within rows, means without common letters are different (P<0.05) (from Thalken and Lacki 2017).

Characteristic	$\bar{x}$	SE
Diameter (cm)	32.9	5.9
Decay class (1–9)	2.14	0.4
Tree height (m)	22.1	2.8
Roost height (m)	12.2	1.9^{A}
Bark remaining (%)	88.9	4.4
Canopy cover (%)	75.4	$8.1^{A.B}$
Snag density (number/ha)	6.5	1.2
Tree density (number/ha)	46.5	5.1^{A}
Elevation (m)	235	6.9^{A}
Slope (%)	14.6	2.3^{A}
Aspect (°)	186	20.6
$\bar{x}$ diameter (cm)	10.9	0.6^{B}
Basal area (m^2/ha)	26	2.3^{A}

Seasonal variation in roost selection between reproductive and non-reproductive females suggests these groups roost under different habitat conditions. Male bats were more broadly distributed over the landscape and demonstrated some roost area use overlap with non-reproductive females, but not reproductive females. Male bats were found to roost in stands with steepest slopes, highest tree densities, greatest basal area, and higher elevations than reproductive females. Pregnant and lactating female bats selected tree roosts with the least amount of canopy cover and lowest basal area volumes relative to non-reproductive females and males. The authors propose that by selecting trees that reduce clutter and tree density surrounding roosting sites, adult females could be opting for habitats with more open-air space for newly volant young, enabling juvenile bats to practice aerial maneuvers and prey capture. Steve Thomas noted that thermoregulation may also play a role in determining selection of more open roost habitats among reproductive females as these roosts should get more solar exposure, creating a warmer microclimate for raising young (Steven Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). Non-reproductive females selected roosts in forested stands with the highest amounts of canopy cover, greater basal areas than reproductive females, lowest tree densities, and lower elevations than reproductive females. Thalken and colleagues suggest that selection of roosts in more mature forests with higher degree of canopy cover, situated in more sheltered ravine bottoms reflect forest conditions promoting cooler microclimates inside roost trees which are expected to facilitate use of daytime sleep in tree roosting bats particularly among non-reproductive females when food supplies are scarce or weather conditions are inclement. This “torpor model” demonstrates that all bats evaluated were more likely to roost in tress with larger diameter trunks than in randomly available snags, which is consistent with evidence of increased thermal stability in the main stem of trees with increasing stem diameter. The benefit of this selection criteria to the bats is that it provides a more predictable micro-climate

environment throughout the day, which could facilitate lower body temperatures, decreased metabolic rates, and increased energy savings. The authors recommend that park land managers consider the seasonal and landscape-level variation in roosting habitat needs for northern long-eared bats (Thalken and Lacki 2017).

Reproductive Success

Bats have naturally low reproductive rates, and when combined with high mortality observed among populations affected by WNS, these factors decrease the likelihood that populations will recover quickly from the drastic declines in diversity and distribution (Thomas and Toomey 2017). Females of eight rare or federally listed bat species are known to form maternity colonies at MACA or adjacent areas. Federally endangered gray and Indiana bats and threatened northern long-eared bats are included among these, as are regionally rare species such as Rafinesque's big-eared, southeastern, eastern small-footed, little brown, and evening bats. During the summer of 2004 and 2005 reproductively active females and/or juvenile bats were captured for 11 bat species present in various habitats within MACA, which suggests that these species are reproductively active within or nearby the park. A twelfth species, the Seminole bat, was verified as reproducing in the area in 2017 when four juveniles were captured during the 2017 inventory (Steven Thomas, Monitoring Program Leader, CUPN, August 2018, personal communication). Detailed information regarding habitat type associated with maternity roosts and exit counts at probable roosting locations were recorded as well (Foster et al. 2007). Thalken and Lacki (2017) report pregnant or lactating female northern long-eared bats present in 30 tree roosts. Rafinesque's big-eared bats are reasonably well-represented in MACA as the park contains at least nine caves, three structures, and until recently a large hollow tree that house summer nursery colonies of big-eared bats ranging in size from roughly 25–200 individuals (Thomas and Toomey 2017). In addition, at least one other structure and five other caves may also contain nursery colonies (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Threatened and Endangered Bat Species

Table 4.47 lists bats in MACA with federal protection status.

Table 4.47. Bat species with federal status present in MACA (modified from NPS 2017c).

Scientific Name	Common Name	Federal Status
Myotis grisescens	Gray bat	Endangered
Myotis septentrionalis	Northern long-eared bat	Threatened
Myotis sodalist	Indiana bat	Endangered
Perimyotis subflavus	Tri-colored bat	Under Review
Myotis lucifugus	Little brown bat	Under Review

4.9.7. Condition and Trend

The overall condition of bat populations at MACA is deteriorating and warrants significant concern. As of 2016, seven of the eight cave-dwelling bat species present in MACA have exhibited symptoms of WNS. The fungus that causes the disease has also been found on the eighth cave-dwelling species

known to MACA (Rafinesque's big-eared bat), though the disease has not been found to occur in this species (Thomas 2016). Prior to the outbreak of WNS in MACA, the number and variety of bat species that use various caves within the park had vastly declined from historic and prehistoric reference conditions. Winter counts at three important bat caves in MACA (Colossal, Dixon, and Long caves) from 1987 through 2013 show a steady downward trend in the number of Indiana bats present in Dixon Cave (Colossal and Long caves were fairly stable) (Thomas 2015). This decrease was prior to the detection of WNS at MACA (Thomas 2015). Significant (>50%) declines have been observed among four bat species in the park since the arrival of WNS (Thalken and Lacki 2017, Thomas and Toomey 2017). Myotis bats appear to be particularly vulnerable to the disease (Griffitts et al. 2016). Substantial declines in the number of federally endangered Indiana bats, federally threatened northern long-eared bats, tri-colored bats, little brown bats, and to a much lesser extent big brown bats have been observed in recent years (Thomas 2016. Thomas and Toomey 2017). Biennial counts at colonial Myotis hibernation sites in 2015 showed over 80% declines in little brown bats, declines near 80% for Indiana bats and nearly 70% declines among tri-colored bats. Mist netting efforts on various recent projects show that capture of northern long-eared bats is low, suggesting populations have been drastically reduced in the summer landscape of the park (Toomey 2015, Thalken and Lacki 2017). More species are expected to become federally protected as they fall victim to the devastating effects of WNS. The decline of several Myotis species may impact other bat species that are less affected by WNS by altering niche partitioning of bat species within a forest community (Jachowski et al. 2014, Thalken et al. 2018). As such, other species may expand habitat use to include gaps left by WNS impacted Myotis species and reduced levels of competition may increase resource availability to other bat species. Thalken and others (2018) suggest that this may be happening with evening, big brown, and red bats at MACA. The impact of WNS continues and the overall loss in terms of numbers and diversity is not yet known. As there is no known cure for the disease, the only course of action land managers can take is to attempt to mitigate further exposure, control access to sensitive areas, and educate park visitors of the critical ecosystem services provided by bats and the potential loss of such services that may occur by spreading WNS to unaffected areas. Bats are critical components of surface and subsurface ecosystems in that they help control insect population on the surface, while importing the valuable organic matter needed to sustain cave food-webs. Several bat species are listed as federally endangered or threatened and the devastating effects of WNS threatens most bats in the park. Continued monitoring and control are needed to mitigate potential for further loss of species diversity among MACA bats, and to ensure the critical ecosystem services provided by these creatures continue (Thomas 2015).

4.9.8. Level of Confidence and Data Gaps

The level of confidence in this assessment is high as it is supported by an extensive body of research that spans from the mid-1800s to present. Even inferences of pre-historic bat diversity, distribution, and colony size can be made from the ample evidence left in the form of ceiling stains, guano, and bone deposits. The arrival of WNS in the United States, and later in MACA itself has driven a need for continuous monitoring of these imperiled biological resources in attempt to protect bats and conserve the critical ecosystem services they provide. Although WNS has proven to be very aggressive in its effects on bat population numbers, diversity, and distribution, a benefit has been that more is currently known about bats in the park than ever before because of increased research and

awareness. The work that has been done on bats over the past several decades shows a consistent declining trend among multiple species, and this is cause for concern (Table 4.48).

Although long-term data are available, systematic approaches to long-term monitoring have only begun since the early 2000s. Since WNS threatens the survival of most cave-dwelling bats in the park, it is critical to continue monitoring bat use and population characteristics to learn how the park lands and caves can best be managed to protect bats. The prevalence of WNS among some species, and the apparent resistance to the disease by others is a topic that deserves continued attention.

4.9.9. Condition Summary

Table 4.48. Graphical summary of status and trends for bats, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Bats	• Species diversity and richness • Impacts of WNS • Species distribution • Changing dynamics of habitats and roosts • Reproductive success • T&E species		Bats represent one of the most imperiled resource groups found on the park. Current bat diversity at MACA is fairly consistent with historical reports (13 out of 14 expected species in 2004–2005 (Foster et al. 2007). WNS along with human use and modifications to cave bat habitat have resulted in significant declines in numbers of several bat species (Indiana, northern long-eared, tri-colored, and little brown) over recent decades. However, some species (e.g., gray bat, Rafinesque's big-eared bat, evening bat, and eastern red bat), are increasing in abundance (Thomas and Toomey 2017). Most bat observations occur near cave entrances, followed by upland ponds, and dry road corridors (Foster et al. 2007). The majority of hibernation activity and use in the park is concentrated within Dixon, Long, Colossal, and Hickory Flat caves. Numerous other caves in and around MACA serve as important roosting, hibernating, or swarming locations. Changes in habitat use dynamics have been assessed with respect to cave habitat modifications (Spanger and Fenton 2005) prescribed burns, prey availability, and WNS (Dodd et al. 2012, 2013, 2015; Griffitts 2016; Fulton 2017). The impact of WNS appears to eclipse other factors that contribute to changes in habitat use among bats at MACA. Microclimate appears to be the primary control on roost selection among bat species that utilize caves, trees, or structures for roosting at MACA (Johnson 2012, Thalken and Lacki 2017; Steve Thomas, Program Monitoring Leader, CUPN, August 2018, personal communication). Twelve bat species are considered reproductively active from observations of pregnant/lactating females or juvenile bats. Seven of these are federally listed or regionally rare species (Foster et al. 2007, Thalken and Lacki 2017). MACA hosts two endangered bat species (Indiana bat and gray bat), one threatened species (northern long-eared bat) and numerous other species that are of management concern (big-eared bats, tri-colored bats, and eastern small-footed bats).It is expected that the number of threatened and endangered bat species will increase at MACA and elsewhere as the WNS outbreak continues.

4.9.10. Sources of Expertise

Rick Olson (Park Ecologist, MACA Division of S&RM), Rick Toomey (Cave Resource Management Specialist and Research Coordinator MACA Division of S&RM) and Steven Thomas (Monitoring Program Leader, CUPN) provided expertise for this section.

4.10. Birds

As a relatively large block of contiguous or mature and maturing forest, MACA serves as a significant conservation area within the Central Hardwoods Bird Conservation Region (Central hardwoods BCR) (CHBCR) for forest interior birds (Figure 4.101).



Figure 4.101. The Central Hardwoods Bird Conservation Region (Central Hardwoods Joint Venture 2013).

Bird populations are highly visible to the public and are practical status indicators for an ecosystem (Morrison 1986, Hutto 1998). We conclude with high confidence that birds in the park are in good condition and while there are significant yearly data fluctuations and that trends can be identified for given species (e.g., Kistler 2013), and bird diversity as discussed below is changing as forest succession evolves, overall the quality of the resource is stable.

Like other ecological systems that have evolved with the changing land management following establishment of the park, bird species change through time. Bird communities often correlate with the abundance and distribution of habitats (Blakesley et al. 2010). MACA has several unique habitat types, and the systematic efforts and success of reforestation of MACA are reflected in both the habitat and species distribution changes. There has been a decline in diversity with land use change, as the park has become a large contiguous block of maturing forest, and there has particularly been a decline in early successional species. Formerly larger grassland areas within the park boundaries, including the Barrens area, Chaumont, and the old Job Corps, are no longer large enough or need

more active management to support breeding populations of grassland species (Bill Moore, Supervisory Ecologist/Data Manager, CUPN, May 2018, personal communication). Many species noted in the proposed area of the park by Hibbard (1935a, 1935b) and later by Wilson (1968a, 1968b) are no longer present within park boundaries (Monroe 2005). The park has however gained one new breeding species. A bald eagle nest was discovered along the Green River in 2011—the first known to exist in the park's history (Figure 4.102).



Figure 4.102. Bald eagles have made a comeback in south central Kentucky and now at least two pairs are nesting in the park along the Green River (NPS photo by Brice Leech).

Over the longer term, there is evidence to suggest that the effects of climate change, particularly in a "high emissions" scenario within which little to no intervention with respect to greenhouse gas emissions are realized, there will be avian species turnover by 2050 (Wu et al. 2018). With some uncertainty models suggest that based on effects of climate change within the park species colonization may exceed extirpation, with a resulting increase in the number of species present. However, there are numerous other factors that influence the spatial and temporal distribution of species, and it is the overall sum of, and interrelationships between, these that determines how these conditions ultimately play out.

4.10.1. Description

As forest succession has taken place at MACA since the park was established, the distribution of species has changed. An inventory of wildlife, including birds, was also required. Claude Hibbard, who was the pre-park resident wildlife technician, conducted the wildlife surveys including birds, as well as mammals, reptiles, and amphibians (Hibbard 1935a, 1935b, 1935c, 1936). Understanding the habitats that Hibbard observed while conducting surveys is informative. The majority of the incipient park's landscape at that time was still open farm fields with many small roads connecting family home sites to their neighbors. Indeed, some landowners had not completely moved out of the area. Some 80 years later, MACA is dominated by mature or maturing forest.

The following indicators are considered for birds in this analysis:

- Species diversity
- Productivity and survivorship

4.10.2. Data and Methods

Birds in and around MACA have been inventoried and studied since before the establishment of MACA in 1941. The first relevant species list was published for a 16 km radius about the town of Bowling Green, about 32 km to the southwest of the current park boundary (Wilson 1922) and contained 164 species, based on observations from 1912–1921. This was followed by observations specifically for the Mammoth Cave area in the summer and fall of 1929 by Bailey et al. (1933) that had more detailed notes for each species. The work, part of a broader inventory of animal species in the area, got several favorable reviews (Bailey et al. 1933, Howell 1934) although Mengel (1965, p. 143) noted that while "a number of useful records resulted, her report was popular in nature and is disappointing from a technical standpoint." It is interesting to note conservation concerns of the day that Bailey et al. (1933, p. 465–466) described, including an observation that:

> Many of the birds recorded in Wild Life in Kentucky are conspicuously absent from sections adjoining the Mammoth Cave country. Notable in this class are the hawks, a large number of which are listed by Funkhouser. As Giovannoli stated, when, after two months' intensive work in the region he could report seeing only three hawks, each on one occasion, "the farmers have evidently waged a very successful war on all hawks in this section." This ignorance of the value of our birds of prey is especially unfortunate in a country where all possible help is needed to protect the scant crops from the ravages of rodents and insects.

As planning for the establishment of MACA was underway, a bird, mammal, reptile and amphibian survey was conducted in 1934 and 1935 (Hibbard 1935a, 1935b, 1935c, 1936). Among the most important contributors of the study of ornithology in the Mammoth Cave area was Gordon Wilson, Department Head of WKU's English department and an amateur, albeit very highly accomplished, ornithologist (Figure 4.103). Following the 1922 publication of the species list for Bowling Green, he spent decades observing and studying the birds of MACA published several editions of species lists for the park. (Wilson 1946; 1953, 1968a, 1968b). Wilson was also one of the cofounders of the

Kentucky Ornithological Society (KOS) and organized the first Christmas Bird Count in Bowling Green in December 1918 (KOS 2018).

More recent data regarding birds in MACA have been generated from five monitoring programs established to survey birds in or around MACA, which were summarized by Leech (2016a, 2016b). These surveys are: 1) the Breeding Bird survey (BBS), 2) Christmas Bird Counts (CBC), 3) the Monitoring Avian Productivity and Survivorship (MAPS) program (Leech 2013), 4) Night-jar surveys, and 5) various individual, one-time surveys. Results for the BBS, MAPS, Night-jar surveys, and other individual survey results were provided by Brice Leech, MACA Biological Resource Management Specialist. Christmas Bird Count data were provided by Dr. Blaine Ferrell, Emeritus Professor of Ornithology, Western Kentucky University.

The Breeding Bird Survey (Figure 4.104), which provides long-term population numbers, population trends and species diversity along more than 4,000 study routes in the US and Canada. The Mammoth Cave Route was established on the south side of the Green River in MACA in 1995 and continued through 2014 (Steve Kistler, President, Kentucky Ornithological Society, November 2017, personal communication). The same route is traveled every year during the same period, between late May and late June when breeding songbirds are singing (Kistler 2013). The Mammoth Cave Route has 50 three-minute stops, beginning 30 minutes before local sunrise. Another route, Mammoth Cave North, was established in 1995, though for logistical reasons only 33 stops were usually made. A third, the Demunbruns route (USGS 2018a), has been run, with a few gaps of up to a few years, from 1966 through to the present, most recently by Blaine Ferrell. Data are sent to, and compiled by, ornithologists at the Patuxent Wildlife Research Center in Maryland where they are made available online (USGS 2018a). Monroe (2005, p. 2) estimated

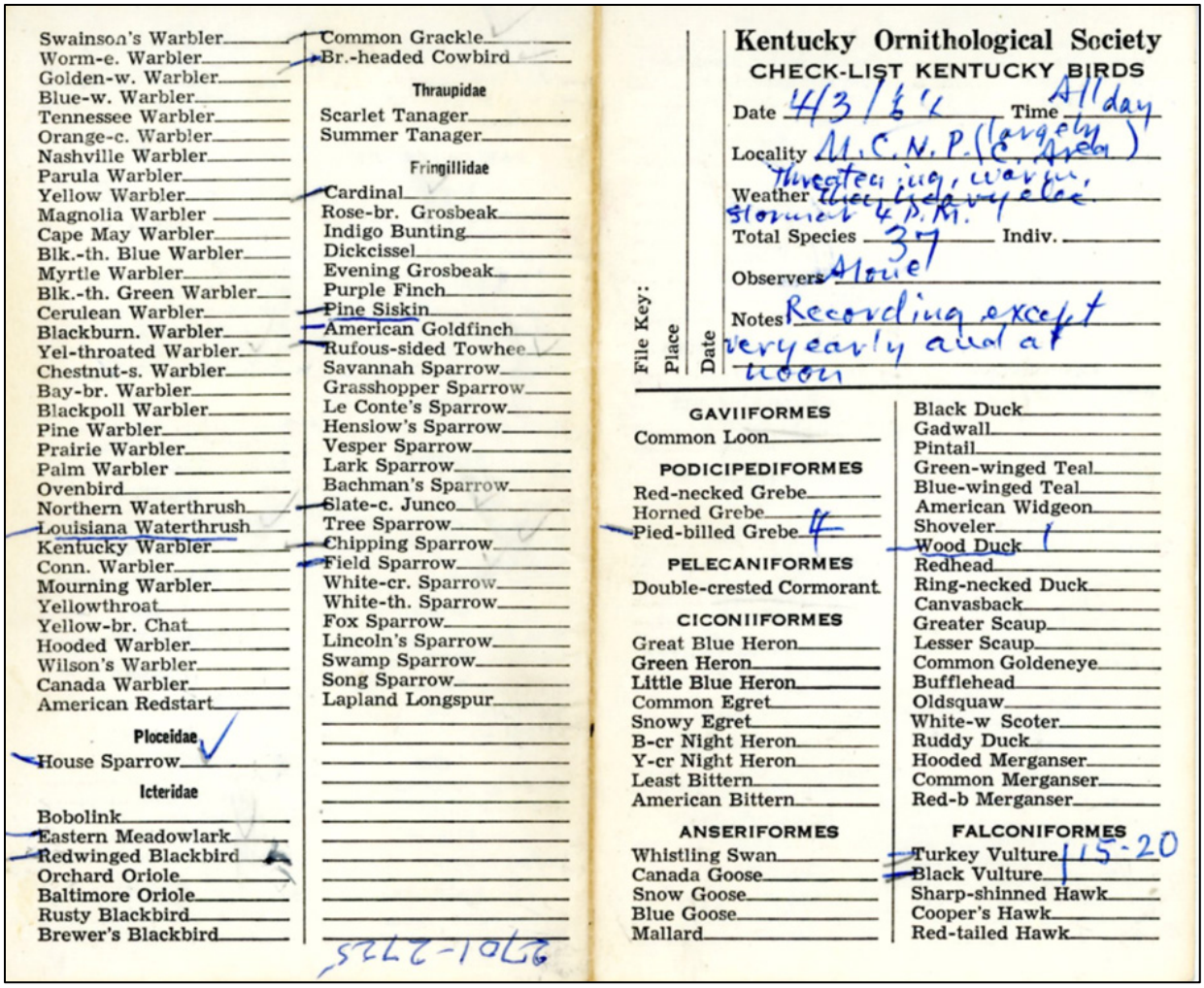


Figure 4.103. 1964 field notes of the ornithologist Gordon Wilson of Western Kentucky University, who made many contributions to the understanding of birds at MACA (Courtesy of Library Special Collections, WKU 2016).



Figure 4.104. Reforestation of the park has modified the species distribution for a number of taxa. The Eastern Meadowlark (*Sturnella magna*) prefers open fields and although it was noted by both Hibbard (1935a) and Monroe (2005) it is likely that they were once much plentiful in the park than today (photo by Blaine Ferrell).

breeding bird numbers by surveying 47 plots placed across the park in a grid. Each point was surveyed during morning hours (before 10 a.m.) during low wind (<10 mph) and non-rainy conditions (such that sound was not hampered). All birds seen and heard for 10 minutes were recorded. Each bird was listed by distance (under 25 m, under 50 m, under 100 m, over 100 m, and flyover) and time of detection (within 3 minutes, 3–5 minutes, and 5–10 minutes).

The Monitoring Avian Productivity and Survivorship Program (MAPS) was motivated by observed declines of songbird populations across North America. Dr. David DeSante founded the Institute for Bird Populations (IBP) in 1989 and initiated the Monitoring Avian Productivity and Survivorship (MAPS) program as a continent-wide collaborative attempt to understand why the declines were occurring. These stations are a component of KDFWR's efforts to monitor species of significant conservation need (Vorisek 2007). This effort coordinates different agencies, groups, and individuals in assisting in the conservation of birds and their habitats through demographic monitoring. Since 1989, more than 1200 MAPS stations encompassing almost every US state and Canadian province have collected more than 2 million capture records. In 2004, a MACA MAPS station was established

in the floodplain of the Green River (Moore 2009, Leech 2013). The majority of captures are migratory birds that breed within the park's boundaries, while some of the captures are year-round residents of the park. This survey is conducted during breeding season and focuses on capturing and banding songbirds (passerines or perching birds). On eight sampling days during the summer, 10 mist nets are set up at sunrise and checked every 45 minutes for six hours. The captured birds are identified, age and sex are determined, and the birds are measured and weighed.

Kentucky's Nightjar surveys (Center for Conservation Biology 2018) are coordinated by the Kentucky Department of Fish and Wildlife Resources and The Center for Conservation Biology at the College of William and Mary and are designed in conjunction with the National Nightjar Survey Network. The objectives of this project are to compare abundance and trends of nightjar species in Kentucky, compare abundance and trends with other locations in the United States, and understand the effects of forest management on Kentucky nightjars.

Kentucky hosts three nightjar species: the eastern whip-poor-will (*Caprimulgus vociferous*), the common nighthawk (*Chordeiles minor*), and the chuck-will's-widow (*Antrostomus carolinensis*). While there is a general sense that eastern whip-poor-wills and chuck-will's-widows are declining, limited information for these species is available. Data on how abundance varies across the state, and how habitat management actions may benefit these species, is essential for conservation planning. Nightjar surveys are standardized population counts conducted at roadside points, at night. All species that were heard or seen were recorded. Surveys must only be conducted when the moon is above the horizon and not obscured by clouds. Nightjars call less frequently when the moon is still below the horizon or hidden by dense cloud cover. Wind conditions must be no more than moderate. Since nightjar surveys began in 2016, trends from this resource cannot yet be determined.

4.10.3. Reference Conditions/Values

We consider for the resource to be considered in a good condition the birds should have healthy and breeding populations, comparable to populations representative of those that would naturally occur across the park within suitable habitat. In the case of birds, as well, since they are highly mobile changes in species composition are and natural function of the changing conditions as forest succession continues. We could consider that a baseline moving forward for the avian component in MACA could be the Monroe (2005) avian inventory of the park. This study represents the most thorough recent inventory that has occurred in the park and will serve as a benchmark for future comparison in future condition assessments.

We can qualitatively evaluate the impacts of forest succession on avian community structure by comparing the early inventories (described in the data section below) with later work, especially that of Wilson (1968a, 1968b) and Monroe (2005), who compared his inventory with Wilson's. Using point count methods (Hamel et al. 1996), Monroe recorded a total of 147 species, but suggested that 15 of the species that he did not find but which had been listed earlier by Wilson (1968a, 1986b) could still be feasible park residents, at least part time, based on the distribution of habitats by the time of his work. He also concluded, based on the same reasoning that another 42 species of waterfowl and birds that prefer open habitat were no longer likely to be found at MACA. Monroe's (2005) data highlight MACAs importance in providing habitat for species of conservation concern,

including Chuck-will's widows, whip-poor-wills, wood thrushes (*Hylocichla mustelina*), Acadian flycatchers (*Empidonax virescens*), Kentucky warblers (*Geothlypis formosa*), worm-eating warblers (*Helmitheros vermivorum*), cerulean warblers (*Setophaga cerulean*), Louisiana waterthrushes (Parkesia motacilla), prairie warblers (*S. discolor*), prothonotary warblers (*Protonotaria citrea*), and one blue-winged warbler (*Vermivora cyanoptera*). Each of these species appeared to be thriving or stable, except for blue-winged warbler. Traveling between points during the survey, the observers also noted a sharp-shinned hawk (*Accipiter striatus*) and a blue-headed vireo (*Vireo solitaries*).

4.10.4. Condition and Trend

Species Diversity

Species diversity is an indicator of overall habitat availability for birds. Changes in species diversity over time can be used to evaluate the influence of changing landscapes on biodiversity. The NPS Certified Bird Species List contains 210 species, 127 (60%) of which are passerine species (Figure 4.105). This list, however, does not allow for a specific analysis of annual species diversity, as no data are collected yearly, and the list only documents the presence (or historic presence) of the identified species. The NPS Certified Bird Species List is based on the Hibbard (1935a) bird survey, which identified 160 birds, the 1968 survey conducted by Gordon Wilson, and the most recent survey by Mark Monroe in 2005. Thirty-eight species were identified as not currently in the park but were confirmed based on historic regional records. Eight were considered as probably present, four were unconfirmed and one species is under review. Of the 161 species confirmed as present, 110 species (68%) were identified as passerines. Seventy-five species were documented as breeding within MACA. Passeriformes make up more than half of all living species of birds (Ericson et al. 2003).

Hibbard (1935a) noted more prairie and woodland edge species compared to the more recent surveys. We can quantify the impacts of forest succession on avian community structure by comparing the early inventories (described in the data section below) with later work, especially that of Wilson (1968a, 1968b) and Monroe (2005), who compared his inventory with Wilson's.

Monroe (2005, p. 2) wrote that in his breeding bird survey

Woodland species were the most numerous and widespread species found suggesting that the park supports a healthy forest ecosystem. Some small openings do exist in various areas of the park allowing edge species, including Brown-headed Cowbirds, to maintain fair populations. A total of 1,322 individuals of 74 species were recorded on point counts during the survey. Plots averaged 17.3 species with a range of 13 to 28 species (Table 4 [in Monroe 2005]). The largest numbers of individuals detected were of Red-eyed Vireos (127), Ovenbirds (102), and Scarlet Tanagers (88). The most frequently seen species were the same three, each present at 41 of 47 points.



Figure 4.105. Scarlet tanagers (*Piranga olivacea*) are well suited for life at MACA, as they prefer relatively large patches of deciduous forest (photo by Blaine Ferrell).

Christmas Bird Count (1948–2016)

The CBC survey area, for many decades, has encompassed MACA. However, the earliest counts extended beyond the park boundary. Counts such as the CBC (or other index counts, e.g., breeding bird surveys) are neither censuses nor density estimates (Link and Sauer 1998). Results of the CBC should be interpreted with a degree of caution.

During the 68 years of CBC efforts, 98 different species have been observed with 52 different passerines (53%). The highest number of species observed in a given year was 57 (1961; 17 observers), while the lowest number of species observed was 30 (1952, 5 observers). The average number of passerine species observed during the CBC was 27.5, and the average number of observers per year was 9.5.

Raptors

Raptors are top-level predators and are excellent bioindicators of the health of their associated ecosystems (Morrison 1986, Hutto 1998). In the 1940s, raptor populations across North America experienced a sharp population decline as the use of organochlorine pesticides increased (e.g., dichlorodiphenyltrichloroethane – DDT).

Bioaccumulation of these chemicals (particularly DDE, a persistent metabolite of DDT) inhibited calcium metabolism in many raptor species (Fischer et al. 2000). As a result, affected birds laid eggs that were too thin for successful incubation; eggs that did not break during incubation often contained dead embryos, and mortality rates for hatchlings were high (Fischer et al. 2000). DDT was banned in the United States in 1972 and reproductive success rates subsequently increased following this ban (Fischer et al. 2000). Species especially affected by the use of organochlorines, such as the peregrine falcon (*Falco peregrinus*), experienced a dramatic population recovery following the ban. Some affected raptor species recovered to levels that allowed for their removal from the Endangered Species List.

The many diverse habitats of MACA (e.g., Barrens (grasslands)), hardwood forests, wetlands and riparian areas) can support a variety of different raptor species. Observed raptor species in MACA include the red-tailed hawk (*Buteo jamaicensis*) and the great horned owl (*Bubo virginianus*) (Kistler 2020). The NPS Certified Bird Species List for MACA identifies 19 raptor species in the park, with two of those species either a historical occurrence or considered unconfirmed.

One of the more charismatic raptor species recently in MACA is the bald eagle (Figures 4.102, 4.106). Eagles had not been recorded as a nesting species in MACA prior to 2011 when a pair constructed a nest on the Green River, and now there are at least two.

Monroe (2005) identified 15 raptor species during his MACA inventory. According to Monroe, the number of raptor species was low and is likely due to the heavy forest cover at MACA as several species of raptors depend on grasslands for food and habitat.



Figure 4.106. Bald eagles are more frequently seen in MACA along the Green and Nolin Rivers and their tributaries. This one was photographed at Barren River Lake a few kilometers south of the park (photo by Blaine Ferrell).

From 1965–2016, 19 raptor species have been observed during the CBC. The number of raptor species observed on the CBC is higher than the total number of raptor species that have been confirmed in MACA, this may be due to the larger survey area of the CBC and potentially due to the longer period of survey data. An average of 11.7 raptor species observed during the CBC.

Turkeys

The wild turkey (Figure 4.107) exists in a wide variety of habitats across its native range (historically in 39 states in the Unites States), and the bird was almost driven to extinction shortly after North America was colonized by Europeans (Dickson 1992). By 1920, wild turkey populations had been extirpated in 18 of the 39 states within the species' native range, though there was still a small population in Kentucky (Dickson 1992). Wild turkeys were historically present in the MACA area, however Hibberd noted them as extirpated in his survey. Towards re-establishing the MACA population, the NPS reintroduced between 8 and 20 turkeys to the park in 1982 and 1983 (Brice Leech, Resource Management Specialist, August 2018, personal communication). Populations numbers across the country have increased substantially. At MACA, wild turkeys are frequently observed.

Currently, no monitoring of wild turkey density exists in MACA. Monroe (2005) confirmed breeding evidence of the species in the park as has also been confirmed by the CBC surveys. Until a more in-depth and species-specific survey occurs in the park, the current condition of turkey density in the park cannot be determined although it is probably high. Wild turkeys were among the 98 species reported during the CBC between 1948 and 2016. While density estimates were not reported during this effort, abundance estimates were calculated. The first CBC turkey observation occurred in 1959 (7 individuals). The next observation occurred in 1967 (1 individual). Since both these observations predated the reintroduction effort, these individuals clearly crossed into MACA. The next turkey observation occurred in 1985. Between 1985 and 2016, a total of 330 turkeys have been observed during 22 of the 31 years. The peak wild turkey abundance during the CBC efforts was observed in 2005 when 49 wild turkeys were identified. The average wild turkey observations since 1985 is 11.7 turkeys per year.



Figure 4.107. Although Hibbard (1935a) listed wild turkeys as extirpated as a result of his survey, they are now frequently seen by visitors to the park, often in substantial flocks (photo by Blaine Ferrell).

Productivity and survivorship

The Monitoring Avian Productivity and Survivorship Program (MAPS) is a continent-wide collaborative attempt to understand trends of avian success through time. The majority of captures are migratory birds that breed within the park's boundaries, while some of the captures are year-round residents of the park. During the 12 years of banding, fluctuations in capture numbers have been observed. Low numbers were notable in 2010, 2011 and 2015. A heavy rain event in 2010 has been hypothesized as the cause for the low numbers in 2010 and 2011. Numbers increased in 2012 indicating a delayed recovery. In 2015, heavy snowstorms, which occurred close together, are believed to be responsible for the decreased numbers. The actual underlying factors are not completely understood in either of these severe weather episodes.

Moore (2009) analyzed the first four years (2004–2007) of data from the Mammoth Cave MAPS station, with a total of 432 captures and 324 birds newly banded. He noted that the results showed positive news for MACA, as two high priority species for the Central Hardwoods BCR (Figure 4.101), the worm-eating warbler and the Kentucky warbler, were found in relatively large numbers, and for both species reproductive indices exceeded long term averages for both the Central Hardwoods BCR and the continental scale.

4.10.5. Threats and Stressors

MACA staff must balance the preservation of the historical and cultural landscape with creating and maintaining the natural habitat of the native species in the park. Grassland dependent species abundances have shifted since the establishment of MACA. Investigation into this avian community and how it is affected by changing habitat is warranted.

One of the major threats facing land bird populations across all habitat types is land cover change (Morrison 1986). Land cover changes to breeding habitat as well as non-native plant species may alter habitats which can compromise reproductive success or survival rates of species adapted to that habitat. Non-native avian species, such as the European starling (*Sturnus vulgaris*) can expand and supplant native birds. Grassland dependent species in MACA, such as the eastern meadowlark (*Sturnella magna*) require specific vegetative communities for successful nesting to occur. As discussed elsewhere in this chapter, at MACA the single largest stressor is forest succession, which may favor some species while forcing others to relocate, as was made clear by comparison of the Wilson (1968a, 1968b) and Monroe (2005) inventories. There is evidence also that climate change is likely to impact park diversity (Wu et al. 2018). Land use outside of the park can also impact conditions for birds that rely on, for example, contiguous forest corridors.

Migratory bird species also face deteriorating habitat conditions along their migratory routes and wintering grounds. Most of the birds that breed in the United States winter in the Neotropics (MacArthur 1959); deforestation rates in these wintering grounds have occurred at an annual rate up to 3.5% (Lanly 1982). While forest and habitat degradation does occur in the United States, it does not approach the level of degradation seen in the tropics. Furthermore, Robbins et al. (1989) supported the suggestion that deforestation in the tropics has a more direct impact on Neotropical migrant populations than deforestation and habitat loss in the US.

Avian brood parasite species (e.g., brown-headed cowbird (*Molothrus ater*) represent a threat to several avian species in MACA. Brood parasites are species that lay their eggs in the nests of other breeding species, which then in turn incubate and care for the young. Cowbirds can directly contribute to the reduced nesting success of host species, as they will often puncture or remove host species eggs (Freidmann 1963). Brown-headed cowbirds often hatch earlier than host species eggs, and grow larger and faster than the host species, which often results in the death of the host chicks due to starvation, neglect, overcrowding, or direct mortality by trampling or removal from the nest (Freidmann 1963, Payne 1977). Many breeding species are targeted by brood parasites.

Climate change, both regionally and globally, is one of the major forces affecting bird communities. Changes in the temperature and precipitation norms in the park could have both direct and indirect effects on the breeding bird community of MACA. Direct impacts may come from plant impacts, while indirect impacts resulting from shifts in temperature and precipitation could include effects on the frequency, extent, and severity of insect outbreaks, which can affect tree mortality and overall habitat structure and species composition for many years. There is evidence to suggest that the effects of climate change, particularly in a “high emissions” scenario within which little to no intervention with respect to greenhouse gas emissions are realized, there will be avian species turnover by 2050 (Wu et al. 2018). With some uncertainty, models suggest that based on effects of

climate change within the park species colonization may exceed extirpation, and this may result in an increase in the number of species present. However, there are numerous other factors that influence the spatial and temporal distribution of species, and it is the overall sum of, and interrelationships between, these that determines how these conditions ultimately play out.

Several bird species depend on temperature ranges or weather cycles to cue their breeding. As global temperatures change, some bird species have adjusted by moving their home range north (Hitch and Leberg 2007). Other species have adjusted their migratory period and have begun returning to their breeding grounds earlier, which could lead to lower reproductive success (Jones and Cresswell 2010).

4.10.6. Level of Confidence and Data Gaps

There is a long and rich history of data collection for birds in the park due to intense interest among ornithologists for nearly a century, and this is a well-studied park (Table 4.49). One potentially fruitful study would be the analysis of the last decade of MAPS data to compare with the positive results of the last analysis of Moore (2009) (Kate Slankard, Nongame Avian Biologist, KDFWR, November 2017, personal communication).

4.10.7. Condition Summary

Table 4.49. Graphical summary of status and trends for birds.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Avians	diversity		There is a long and rich history of data collection for birds and MACA and they are well studied. Species diversity is changing primarily due to forest succession, but bird resources are in good condition, the park serves a s a refuge for numerous species of conservation interest.
	productivity and survivorship		The MAPS program, the Breeding Bird Surveys, and inventory data suggest that the resource is in good condition.

4.10.8. Sources of Expertise

Brice Leech (Resource Management Specialist MACA Division of S&RM), Bill Moore (Supervisory Ecologist/Data Manager, CUPN), Blaine Ferrell (Dean Emeritus, Ogeden College of Science and Engineering, Western Kentucky University), and Steve Kistler (President, Kentucky Ornithology Society) provided expertise for this section.

4.11. Herpetofauna

Herpetofauna appear to be in fair, but deteriorating condition with need for moderate concern based on declines in the number of salamander, lizard, and snake species detected. Little can be said regarding statistical trends in diversity or distribution among these groups as monitoring efforts have not been equal across years and sampling techniques are not randomized. Therefore, statistical trend analysis of these populations cannot be assessed accurately. In general, frogs, toads, newts, and salamanders seem to be doing better than lizards and snakes. Frogs and toads appear to be doing better than salamanders and newts. All species of frogs and toads known to historically exist in the park have been found by survey within the past three years apart from the upland chorus frog which has not been observed in MACA since 2006. The salamanders are not doing as well and have experienced some declines. In the past 15 years 14 of 16 (87.5%) expected salamander species were found. Five salamander species reported in the park have not been found within the past decade (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b, 2017). Lizard populations in MACA have remained relatively stable through time. Six of 7 (85.7%) lizard species known to MACA were found in recent surveys. Slender glass lizards and coal skinks were uncommonly observed and have very likely declined since initial surveys in the 1930s. The six-lined racerunner has been extirpated from MACA in association with a lack of open habitat preferred by this species. Snakes appear to have experienced the greatest declines. Recent surveys reported 16 of 22 species previously known to MACA (MacGregor 2017).

The herpetofauna of MACA includes the amphibian and reptile populations present in the park. These organisms are ectotherms with characteristically efficient metabolisms (Pough 1980). Amphibians and reptiles often comprise a high percentage of the vertebrate biomass within ecosystems, although many are reclusive and rarely observed (Burton and Likens 1975, Congdon and Gibbons 1989, Petranka and Murray 2001). These organisms also serve as important predators and prey (Gibbons and Dorcas 2004, Taylor et al. 1988) making them important trophic links. Thus, biodiversity and condition of herpetofauna populations reflect ecological well-being and serve as measures for evaluating anthropogenic impact on the environments that serve as habitat for amphibians and reptiles (Vitt et al. 1990, Knutson et al. 1999, Gibbons et al. 2000).

Approximately half of more than 450 amphibian and reptiles present in the United States can be found in the southeast (Conant and Collins 1998). The documented record of herpetofauna within MACA is based on studies conducted in the park since the 1930s and includes 14 anurans (frogs and toads), 16 salamanders, 22 snakes, 7 lizards, and 9 turtles (Bailey et al. 1933; Hibbard 1936; Brandon 1965; Hale 1984; MacGregor 2007, 2017). However, the framework document for the herpetofauna section of this natural resource condition assessment (NRCA) recommends a limited assessment focusing on the frogs and toads, salamanders and newts, lizards, and snakes of MACA. This decision was made for several reasons. Turtles are not included in this assessment because turtle populations seem to be doing quite well in MACA relative to conditions reported since the 1930s (MacGregor 2007, 2017). Frogs and toads were included in the assessment due to 1) their status as an indicator species for habitat degradation, and 2) large-scale dieoffs of egg masses among some species observed in the park. Salamanders were included in the assessment because 1) many that inhabit the aquatic terrestrial interface serve as biological indicators of environmental conditions, (Roy 2002,

Beebee and Griffiths 2005), 2) mortality among salamanders and salamander egg masses may be linked to emerging amphibian diseases, (MacGregor 2016a, 2017), and 3) because some salamanders appear to be facing declines in the park (MacGregor 2007, 2016a, 2017). Lizards and snakes are included in the assessment because 1) many species in these taxa are negatively impacted by habitat loss associated with reforestation of the park such that they may face extirpation, (MacGregor 2007, 2016a, 2017), and 2) diseases and skin infections such as snake fungal disease (SFD) threaten existing populations (MacGregor 2017). This is not a complete representation of all populations that could be referenced to evaluate the status of the herpetofauna within the park but rather an examination of select groups that exhibit high priority for concern in association with habitat loss and degradation, emerging diseases, small and/or isolated populations, or status as environmental indicators. With regard to habitat loss, MACA park ecologist Bill Moore notes that the loss of fire from the ecosystem and potentially dense populations of deer are likely having deleterious effects resulting or potentially resulting in degraded forest conditions and therefore loss of habitat among MACA herpetofauna (Bill Moore, Supervisory Ecologist/Data Manager, CUPN, May 2018, personal communication).

Several amphibian and reptile species in Kentucky are declining or of uncertain conservation status (KDFWR 2013). The declines observed among reptiles and amphibians in MACA are associated with the loss of early successional habitats and more open forest conditions and emerging diseases (MacGregor 2017). Management of these lands as a national park and international biosphere preserve has caused available habitats to shift from a mixture of private agricultural and forested land, to a heavily forested bioreserve (MacGregor 2007). This transition has undoubtedly impacted numerous reptiles and amphibians (MacGregor 2007). Several salamander species are experiencing declines and at least one salamander has been extirpated from MACA (MacGregor 2016a). The condition of the reptiles seems to be deteriorating, declines were observed among several snakes and at least one lizard species. Several snakes and lizards documented from the park in early surveys appear to have been extirpated, likely from habitat loss as more open environments have become scarce. Following years of survey efforts MacGregor (2016a) concluded at least six reptiles documented during the 1930s appear to be extirpated from the park, along with the eastern tiger salamander. He attributed this loss in biodiversity to "… habitat loss as grasslands, pastures, and open woodlands have largely disappeared during 75 years of fire suppression and uncontrolled reforestation" (MacGregor 2016a). Some species can be expected to return with restoration of adequate habitat (MacGregor 2007, 2017). Changes in aquatic habitat associated with land use and declining water quality have motivated efforts to enhance monitoring of these taxa.

A better understanding of the current condition of reptile and amphibian fauna in the park is needed for several reasons. Both groups are globally at-risk. The International Union for the Conservation of Nature (IUCN) Global Amphibian Assessment indicates that up to a third of amphibian species on earth have undergone severe declines or extinction (Stuart et al. 2004) and "nontropical montane, stream-associated species are at particular risk" (Beebee and Griffiths 2005). Furthermore, amphibians are indicators of water quality as they inhabit aquatic environments and adjacent terrestrial buffer zones and are often adversely affected by contaminants such as agrochemicals that absorb through the skin. Observed declines in amphibian populations may reflect water quality

conditions within the drainage vicinity (Roy 2002). Furthermore, since several amphibian species in Kentucky are declining or of uncertain conservation status the availability of current data and comprehensive monitoring programs are essential to tracking to condition of these organisms (MacGregor 2013a). The very recent and thorough accounts provided by MacGregor (2007, 2010, 2011, 2012, 2013b, 2014, 2016b, 2017) can provide useful information in efforts to understand changes in park reptiles and amphibians in association with changes to habitat and the emergence of diseases that threaten these groups. It is important to monitor changes in occurrence and distribution of these taxa to preserve biodiversity and inform how park management practices may impact the imperiled reptiles and amphibians. The NPS plays a critical role in protecting the herpetofauna resources of the park by implementing proper use and preservation of national park land and water resources. The NPS needs current data to continue to protect and conserve the herpetofauna within MACA and develop water and land use regulations within the park to maintain suitable habitats in the park.

Herpetofauna were evaluated using the following resource indicators:

- 4.11.1. Amphibians: Frogs and Toads
- 4.11.2. Amphibians: Salamanders and Newts
- 4.11.3 Reptiles: Lizards
- 4.11.4. Reptiles: Snakes

4.11.1. Amphibians: Frogs and Toads

Description

Frogs and toads (anurans) are by far the largest group of living amphibians, and exhibit worldwide distribution except for polar and extreme desert environments and some isolated islands. Anurans have evolved a body form and size that enables them to survive in most any terrestrial environment where fresh water is present for part of the year (Webb et al. 1981). Within MACA, 14 species of frogs and toads are recorded (Hibbard 1936, Hale 1984). In general, the frogs and toads present in the park appear are concentrated around suitable habitat in moist wooded areas, vernal ponds, low-laying marshy areas, seeps, streams, ephemeral pools, and some springs in the park. All of the anuran species found here are considered pond-breeding species. Several species present in the park including the American toad (*Bufo americanus*), Fowler's toad (*B. fowleri*), American bullfrog (*Rana catesbeiana*), green frog (*R. clamitans*), and pickerel frog (*R. palustris*) often make use of stagnant or sluggish backwater areas of rivers, streams, and man-made lakes (MacGregor 2007). Most of the species appear to be doing quite well and are in no immediate danger of extirpation (MacGregor 2007). No federally-listed frogs or toads occur on the park.

Data and Methods

The measures of community structure used to evaluate the status of reference indicators for frogs and toads within the framework of this report include diversity, distribution, and species changes. These ecological parameters can be represented quantitatively which is important in evaluating how resource conditions change over time and space. The assessment of the condition of anurans of MACA is supported by field surveys dating from the 1930s to 2016. Reference conditions are

relative to historical reports and museum records of frogs and toads present within MACA. These records are the best existing reference conditions but are not representative of undisturbed or even minimally-disturbed conditions. In the initial faunal survey of the Mammoth Cave region, Bailey et al. (1933) reported eight frog species. Hibbard (1936) provided an early taxonomic survey of this area and reported 13 anuran species. One frog was found along surface tributaries of the park, however small agricultural ponds provided the highest diversity with nine species of frogs either recorded in ponds or adjacent woodlands. Hale (1984) later added the upland chorus frog (*Pseudacris feriarum*) to the list of park fauna. Scott (1994, 1997) set up the protocols for a long-term monitoring program to obtain data for number and percent survival of egg masses deposited by two salamander species and the wood frog (*Rana sylvatica*) in vernal ponds, caves and streams in MACA. Petranka and others (2004) evaluated habitat shifting among wood frogs and spotted salamanders at four national parks, including MACA, but did not conduct a comprehensive survey. A survey of park amphibians and reptiles from 2003–2006 reported 14 anuran species (MacGregor 2007). Monitoring of park herpetofauna from 2010–2016 detected 13 species of frogs and toads. The upland chorus frog was not observed during this monitoring period (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b). Reference conditions used by MacGregor for the long-term ecological monitoring of amphibians in the park are based on current species distribution maps for counties in Kentucky along with a review of field guides of the amphibians of the Eastern US (Conant and Collins 1998, Petranka 1998). In addition to geographic ranges, MacGregor (2007, 2010, 2011, 2012, 2013b, 2014, 2016b) also evaluated the habitat requirements of amphibian species with the habitats available to these organisms in the park. Sampling was conducted by search efforts of experienced herpetologists among habitats likely to support amphibian populations. Visual and active searches of natural cover (raking through leaf litter, overturning logs, peeling loose bark, and close examination of other refugia) were applied. Ponds and vernal ponds were visited to search for amphibian eggs, larvae, and/or adults. Evidence of natural or disease-related mortality was documented during visits. Some amphibians were also documented by driving roads at night, conducting chorus surveys at ponds for frogs, and dipnetting in ponds and streams for amphibian larvae (MacGregor 2016a). CUPN maintains a list of species present in the park and offers the most recent inventory of the anuran species in MACA (NPS 2017c). However, the species list does not contain information regarding sampling locations, or the number of observations among collection sites. Hence, these data are not useful for making inferences about distribution, density, or other measures involving a spatial component. It is important to consider that detection probabilities vary greatly across species, and fluctuate seasonally and in response to environmental conditions. The numbers reported from MacGregor's monitoring are to be considered as simple observations and are not necessarily representative of current conditions. Caution should be used in assessing patterns in ecological parameters used to assess amphibian populations in MACA.

Reference Conditions/Values

Diversity

In general, frogs and toads appear to be in good standing at MACA. A total of 14 anuran species were recorded by MacGregor (2007), this value matches the number of frogs and toads expected on the park based on geographic range and historical records (100%). In 2016, MacGregor reported 12

of 14 anurans (93%) expected (the upland chorus frog was not observed) (MacGregor 2017). During the 2003–2006 survey, the green frog was the most commonly observed anuran species (280 observations) and is considered to be doing quite well on the park (Bill Moore, Supervisory Ecologist/Data Manager, CUPN, May 2018, personal communication). The Fowler's toad (155), American bullfrog (117), American toad (89), Cope's gray treefrog (*Hyla chrysoscelis*) (74), spring peeper (*Pseudacris crucifer*) (73), southern leopard frog (*R. spehnocephalus*) (60), cricket frog (*Acris crepitans*) (52), wood frog (42), mountain chorus frog (*P. brachyphona*) (35), and pickerel frog (29) were also observed in fair numbers. By comparison, the eastern narrowmouth toad (11), eastern spadefoot (*Scaphiopus holbrookii*) (11), and upland chorus frog (5) were much less commonly observed during survey periods (MacGregor 2007). During the 2010–2016 surveys, seven species were observed in high numbers based on observations by MacGregor (2010, 2011, 2012, 2013b, 2014, 2016b). The wood frog was detected in the greatest numbers (906 observations reported), followed by Cope's gray treefrog (314), green frog (214), Fowler's toad (164), cricket frog (135), spring peeper (124), and American bullfrog (118). Six other species were observed in modest numbers including the American toad (39), eastern spadefoot toad (24), mountain chorus frog (20), southern leopard frog (20), pickerel frog (8), and eastern narrowmouth toad (4). There have been no observations of the upland chorus frog since 2006. During surveys from 2003–2006 (MacGregor 2007) and continued surveys from 2010–2016 (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b), wood frogs comprised the majority of observations (948), followed by the green frog (494), Cope's gray treefrog (388), Fowler's toad (319), and American bullfrog (235). These five species comprise 76 percent of anuran observances over the past 15 years but may reflect temporal differences, climate conditions, habitat preference among monitoring locations, etc. and are probably do not accurately represent the true diversity among anurans at MACA. Most (9 of 14 expected species) were observed in at least moderate numbers (MacGregor 2017). The anuran population appears be doing quite well (Table 4.50), but MacGregor (2007) indicated the eastern spadefoot toad may be in decline on the park since he was unable to confirm that spadefoot breeding efforts were successful during 2003–2006 monitoring and only a few have been recorded in the time since.

Table 4.50. Anuran observations among non-random sampling locations in MACA during 2003–2006 survey (MacGregor 2007) and subsequent monitoring 2010–2016 (2010, 2011, 2012, 2013b, 2014, 2016b).

	Year										
Species	**2003**	**2004**	**2005**	**2006**	**2010**	**2011**	**2012**	**2013**	**2014**	**2016**	**Total # individuals**
Cricket frog	16	25	7	4	101	14	4	10	1	5	187
American toad	21	41	20	7	1	18	0	3	3	14	128
Fowler's toad	9	32	98	16	1	149	2	4	6	2	319
Eastern narrowmouth toad	1	6	1	3	0	0	0	2	0	2	15
Cope's gray treefrog	17	44	9	4	11	14	1	19	2	267	388
Mountain chorus frog	3	25	4	3	0	15	0	0	0	5	55
Spring peeper	14	51	5	3	9	33	0	47	24	11	197
Upland chorus frog	0	4	0	1	0	0	0	0	0	0	5
American bullfrog	27	81	3	6	51	18	4	13	26	6	235
Green frog	18	213	39	10	24	42	15	42	22	69	494
Pickerel frog	3	26	0	0	1	1	0	0	6	0	37
Southern leopard frog	10	39	6	5	2	6	1	4	4	3	80
Wood frog	26	11	5	0	1	43	348	15	470	29	948
Eastern spadefoot toad	3	7	0	1	3	6	1	8	0	6	35
Total # individuals	168	605	197	63	205	359	376	167	564	419	3,123
Total # species	13	14	11	12	11	12	8	11	10	12	14

Distribution

Anurans are broadly distributed where suitably moist habitats exist in the park. Exceptions include the eastern narrowmouth toad and upland chorus frog which exhibit highly restricted distributions. All observations of eastern narrowmouth toads occurred at a single breeding pond while upland chorus frogs were found at just three locations. Some generalizations can be made regarding breeding sites preferred by certain anuran species. Cricket frogs, American bullfrogs, and pickerel frogs tend to use large permanent ponds as breeding sites on the park. American toads, Cope's gray treefrogs, mountain chorus frogs, southern leopard frogs, and wood frogs utilize shallow ephemeral pools for breeding. Eastern narrowmouth and upland chorus frogs prefer to breed in shallow grassy pools, and meadows that are temporarily saturated. Small wooded ponds within the park are often used by Cope's gray treefrogs, spring peepers, green frogs, southern leopard frogs, wood frogs, and eastern spadefoot toads (MacGregor 2007). Habitat shifting, particularly among breeding ponds and pools, has been shown to occur in response to beaver activity that either created new ponds or allowed fish to invade habitats where eggs were deposited (Petranka et al. 2004).

Species Changes

The current species composition among the frogs and toads in the park compares very well with historical accounts. Early surveys report the presence of 13 species (Hibbard 1936), but surveys over the past several decades consistently report 14 species of anurans (Hale 1984, MacGregor 2007). The upland chorus frog was not reported by Hibbard (1936), but was later heard by Hale (1984) albeit only from a single location with no successful specimen collections. The upland chorus frog has only rarely been found on the park in recent decades. Likewise, the wood frog is now common in the park, but Hibbard (1936) discovered just one specimen and considered it to be rare.

Condition and Trend

Frogs and toads in the park appear to be in good condition with populations essentially unchanging relative to historic records. Anuran species are increasing in abundance and appear to be experiencing greater success than salamanders. Three anurans (eastern spadefoot toad, eastern narrowmouth toad, and upland chorus frog) may be declining but data are not definitive. Both the eastern narrowmouth toad and upland chorus frog are considered rare in the park (NPS 2017c).

The greatest threats posed to amphibian communities in the park are emerging amphibian diseases and habitat loss or degradation. MacGregor believes that the observed major die-offs of frog and salamander larvae in ponds on the park are related to several recently discovered diseases (MacGregor 2016a). Mass dieoffs of amphibian larva have been observed in the park. Ranaviruses have been shown to cause high levels of mortality in tiger salamanders, but populations typically recover (Jancovich et al. 1997, 2001). Certain fungal infections can result in high levels of egg mortality in amphibians (Kiesecker and Blaustein 1995). The chytrid fungus *Batrachochytrium dendrobatidis* is associated with mass population declines in North and South America, Europe, Australia, and New Zealand (Berger et al. 1998). MacGregor (2016a) notes that the only way to identify these agents would be to collect and test samples taken during a die-off in progress. Additionally, numerous forms of habitat loss and degradation present challenges to amphibian success in the park and elsewhere. Amphibians are highly vulnerable to aquatic toxicity since they

inhabit the land-water interface, and can easily absorb pollutants through the skin. Run-off from agrochemicals such as fertilizers, pesticides, and herbicides pose elevated threats to amphibians (Roy 2002). Fortunately, the amphibians dwelling in most habitats of MACA are protected from exposure to agricultural runoff by the land management practices in place within the park. Exceptions include amphibians inhabiting surface streams in the park that may encounter pollutants sourced from agricultural activity upstream from the park. Increased sedimentation has been shown to significantly impact density of amphibians in streams (Welsh and Ollivier 1998). Road traffic in the park may act as a threat to amphibians, particularly during migrations to breeding sites (Findlay and Bourdages 2000, Hels and Buchwald 2001). Recent citizen science programs in the park have showed increased salinity and decreased wood frog egg mass numbers in some of the vernal pools along the bike trail relative to egg mass numbers in these same ponds approximately 18 years prior. Notable changes that have occurred in the area include construction of the bike trail and allowing road brine applications to park roads during winter storm events. This suggests that runoff from park roads and trails can also impact amphibian populations (Shannon Trimboli, Citizen Science Coordinator, MACA Division of Interpretation and Visitor Services/Western Kentucky University Ogden College, October 2018, personal communication).

Level of Confidence and Data Gaps

The level of confidence regarding the condition of frogs and toads in the park is high (Table 4.51). Although historical accounts of amphibian fauna at MACA are limited, the records that do exist (i.e., Bailey et al. 1933, Hibbard 1936, Hale 1984) account for the number of anuran species expected to be present according to geographic distribution maps. Long-term monitoring of amphibians in the park by MacGregor (2007, 2010, 2011, 2012, 2013b, 2014, 2016b) provides some basis for a current condition assessment over to the past decade, but is not appropriate for use in trend analysis. Although several emerging diseases have been implicated in massive die-offs observed particularly among amphibian larvae, only *Batrachochytrium dendrobatidis* has been confirmed at MACA. MacGregor (2016a) notes that this is due to the difficulty of catching and sampling during a die-off in progress so that samples could be analyzed for viruses, chytrids and other fungal pathogens. Data of this nature could offer an explanation to as to why a few frog and salamander species are experiencing declines in the park. The lack of such information represents a data gap that must be addressed to improve our knowledge of primary threats to the frogs and toads of MACA.

Condition Summary

Table 4.51. Graphical summary of status and trends for frogs and toads, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Herpetofauna	Frogs and Toads		Overall, the frogs and toads of MACA appear to be in good condition, with populations essentially stable through time. All species of frogs and toads known to historically exist in the park have been found be survey within the past three years apart from the upland chorus frog which has not been observed in MACA since 2006 (MacGregor 2007). Some anuran species are increasing in number. Diversity is high in terms of richness, but less so in terms of evenness. A few species tend to dominate community structure. Distribution is concentrated to areas where suitable habitat exists including vernal ponds, wetlands, and riparian environments. The level of confidence in this assessment is high as it relies heavily on recent, long-term monitoring efforts within the park that exhibit similar trends (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b).

Sources of Expertise

John MacGregor (Herpetologist, KDFWR) and Bill Moore (Supervisory Ecologist/Data Manager, CUPN) provided expertise for this section.

4.11.2. Amphibians: Salamanders and Newts

Description

Sixteen species of salamanders are known to the park from historical reports since the 1930s. These organisms tend to dwell in areas with access to water as reproductive cycles rely on water for egg-laying and larval development. Six of the species found in MACA are considered pond-breeders (the four-toed [*Hemidactylium scutatum*], Jefferson [*Ambystoma jeffersonianum*], marbled [*Ambystoma opacum*], spotted [*Ambystoma maculatum*], and tiger [*Ambystoma tigrinum*] salamanders as well as the red-spotted newt [*Notophthalmus viridescens*]). Of these, five salamanders are wholly terrestrial in the adult stage, while mature red-spotted newts split time between aquatic and adjacent woodland habitats. Another six of the salamander species known from the park (the cave [*Eurycea lucifuga*], longtail [*Eurycea longicauda*], midland mud [*Pseudotriton montanus*], northern dusky [*Desmognathus fuscus*], northern red [*Pseudotriton ruber*], and southern two-lined [*Eurycea cirrigera*] salamanders) breed in slow-flowing regions of lotic systems including springs, seepages and headwaters. The eastern hellbender (*Cryptobranchus alleganiensis)* and common mudpuppy (*Necturus maculosus*) are exclusively aquatic organisms that dwell and reproduce within rivers and large order streams. Finally, the northern slimy (*Plethodon glutinosis*) and northern zigzag

(*Plethodon dorsalis)* are entirely terrestrial, depositing eggs in moist areas on land with larval development occurring prior to emergence from the egg (MacGregor 2007). No state or federally threatened or endangered salamanders or newt species were found on the park (NPS 2017c). However, two salamanders (northern dusky and four-toed salamanders) and the eastern hellbender are state SGCN (KDFWR 2013). The eastern hellbender, a rare giant aquatic salamander formerly common in the Green River, has not been reported since the late 1980s and is under review for federal listing (NPS 2017c).

Data and Methods

The measures of community structure used to evaluate the status of reference indicators of the salamander community of MACA as described in the framework of this report include diversity, distribution, and species changes. These ecological parameters can be represented quantitatively which is important in evaluating how resource conditions change over time and space. Reference conditions are relative to historical reports and museum records of amphibians present within MACA.

Historical records by Bailey et al. (1933) and Hibbard (1936) offer limited inventories of the park amphibians. Bailey et al. (1933) reported nine salamander species in the park. Hibbard (1936) provided an early taxonomic survey of the area proposed for the park and reported 14 salamander species. The four-toed salamander was added to the list of park fauna by Brandon (1965), only the second record of this species in Kentucky at the time. Hale (1984) reported 13 salamander species and added the midland mud salamander to the park species list, making a total of 16 salamanders species known to MACA. These studies provide historical reference conditions to evaluate changes in structure among the park's salamanders as indicated by surveys conducted over the past few decades Among more contemporary work, Scott (1994, 1997) began a long-term monitoring program (1994–1997) focused on amphibians of vernal ponds, caves, and streams in MACA and documented a total of 11 salamander species. KDFWR herpetologist John MacGregor completed a long-term (2003–2006) study of herpetofauna in MACA with the goal of establishing comprehensive, up-to-date distribution data for park herpetofauna to monitor species occurrences and populations, and gather baseline information regarding habitat use and condition. MacGregor (2007) compiled a list of amphibians and reptiles expected to occur on the park from reviews of his own county distribution maps for Kentucky along with field guides of the reptiles and amphibians of the Eastern US (Ernst et al. 1994, Conant and Collins 1998, Pentranka 1998). In addition to geographic ranges, MacGregor (2007) also compared the habitat requirements of reptile and amphibian species with the habitats available to these organisms in the park. During the initial phase of the inventory (2003–2006) MacGregor observed 13 of 16 expected salamander species in the park (MacGregor 2007). MacGregor continued monitoring efforts among herpetofauna within MACA and several unpublished datasets offer additional insights about the condition of these populations from 2010–2016 (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b). During this period 9 of 16 expected salamanders were documented among monitoring sites in MACA.

The conservation status of herpetofauna populations is often a challenge to assess due to the reclusive and fossorial nature of many reptiles and amphibians. During recent monitoring (MacGregor 2007,

2010, 2011, 2012, 2013b, 2014, 2016b) sampling was conducted by experienced herpetologists among habitats likely to support amphibian populations. Ponds and vernal ponds were visited to search for amphibian eggs, larvae, and/or adults. Visual and active searches of natural cover (raking through leaf litter, overturning logs, peeling loose bark, and close examination of other refugia) were applied. Some amphibians were also documented by driving roads at night and dipnetting in ponds and streams for amphibian larvae. Evidence of natural or disease-related mortality was documented during visits (MacGregor 2007, 2017). It is important to consider that detection probabilities vary greatly across species, and fluctuate seasonally and in response to environmental conditions. And caution must be used in assessing patterns in ecological parameters used to assess salamander populations in MACA.

Reference Conditions/Values

Diversity

Despite moderate fluctuations in diversity in recent decades, 14 of 16 salamander species previously known to the park have been discovered in MACA within the past 15 years. However, a declining trend in richness has occurred since 2010 and species evenness has been dominated by a few species in recent years. This suggests that although species richness is moderate, diversity is decreased because of the high relative abundance of a select few species (Table 4.52).

Monitoring conducted in the park from 1994–1997 documented 11 of 16 salamander species expected (69%) (Scott 1997). Relative to previous reports, fewer salamander species were present during this period. Among pond surveys in 1997, spotted and Jefferson salamander egg masses were most abundant, followed by marbled salamanders and red-spotted newts (Scott 1997). During the same study, Scott surveyed six cave entrances on the park from 1995–1997 and found that cave salamander abundance was decreasing. Totals for 1995, 1996, and 1997 were 205, 180, and 158 individuals, respectively. Three genera and four species were observed in stream stretches in MACA from monitoring conducted by Scott in 1994, 1996, and 1997. These include the red, southern two-lined, long-tailed, and northern dusky salamanders. Overall, numbers increased among stream salamanders from 1994 to 1997. Of the 374 salamanders surveyed from streams in the park, the red salamander dominated in terms of relative abundance, constituting about 83% of all salamander observations in stream habitat. The southern two-lined salamander was present in the second greatest abundance among stream environments (4%), followed by long-tailed salamanders (<1%). The remaining stream salamanders (about 12%) could only be identified as members of the genus *Eurycea* (Scott 1997). Species evenness was low during this period due to the high relative abundance of a select number of species in the community.

Relative to Scott's findings during the 1990s, a slight increase in the number of species detected was observed during MacGregor's 2003–2006 survey. However, comparisons between these two datasets should be considered tenuous since Scott's work focused on pond breeding salamander species and the cave salamander and did not survey all available habitats. Due to this difference among habitats sampled, it follows that Scott's surveys would be expected to produce fewer species detections that MacGregor (2007). During MacGregor's 2003–2006 study, 13 of 16 (81%) expected salamander species were accounted for (MacGregor, 2007). Relative to historical conditions reported by Bailey

et al. (1933) and Hibbard (1936), species richness among salamanders declined slightly over this time but remained high. The red-spotted newt was the most abundant of 13 salamander species with 78 individuals reported during the 2003–2006 field survey. The marbled (67), spotted (48), and northern red (36) salamanders were also in high relative abundance. Together, these four species represented about 63 % percent of all salamander observations. The Jefferson (25), four-toed (24), longtail (20), cave (20), northern zigzag *(*19), and two-lined (16) salamanders were present in moderate abundance, representing approximately 34 % of all salamanders observed during this survey. The slimy (8), midland mud (1), and northern dusky (1) salamanders were present in low numbers and account for about three percent of all salamander observations during this period (MacGregor 2007). Not documented during this period were the eastern tiger salamander, eastern hellbender, and common mudpuppy (MacGregor 2007).

Following completion of an inventory in 2007 (MacGregor 2007) began selective monitoring in 2010 and continues to the present (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b). To date, data from these surveys has yielded 9 of 16 (56%) expected salamander species.

Table 4.52. Salamander abundance among non-random sampling locations in MACA during 2003–2006 survey (MacGregor 2007) and subsequent monitoring 2010–2016 (2010, 2011, 2012, 2013b, 2014, 2016b).

	Year										#
Species	**2003**	**2004**	**2005**	**2006**	**2010**	**2011**	**2012**	**2013**	**2014**	**2016**	**individuals**
Tiger salamander	0	0	0	0	0	0	0	0	0	0	0
Spotted salamander	0	33	11	4	4	50	74	6	124	2	308
Marbled salamander	12	42	10	3	13	14	51	30	1	2	178
Northern dusky salamander	0	1	0	0	0	3	0	0	0	0	4
Two-lined salamander	0	4	12	0	0	0	0	0	0	0	16
Longtail salamander	2	12	6	0	0	0	0	0	0	0	20
Cave salamander	3	9	8	0	0	2	0	0	0	1	23
Four-toed salamander	0	9	15	0	5	0	1	3	0	2	35
Red-spotted newt	3	14	60	1	0	0	0	0	0	0	78
Northern zigzag salamander	7	9	0	3	0	3	0	6	0	4	32
Slimy salamander	0	2	4	1	0	1	0	2	0	6	17
Midland mud salamander	0	0	0	1	0	0	0	0	0	0	1
Northern red salamander	1	17	17	1	0	0	0	1	0	2	39
Jefferson salamander	2	8	13	2	6	12	129	6	8	1	187
Eastern hellbender	0	0	0	0	0	0	0	0	0	0	0
Common mudpuppy	0	0	0	0	0	0	0	0	0	0	0
# species	7	12	10	8	4	7	4	7	3	8	–

As of 2016 only eight of 16 salamander species were found in MACA (the eastern tiger, northern dusky, southern two-lined, longtail, and midland mud salamanders, eastern hellbender, common mudpuppy, and red-spotted newt were not observed during 2016 sampling) (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b, 2017). In terms of relative abundance, spotted salamanders were best represented during recent surveys (260 observations), followed by Jefferson (162), and marbled (111) salamanders. Together, these three species account for nearly 93 % of the total richness among salamander observations. The northern zigzag (13), four-toed (11), northern slimy (9), northern red (3), northern dusky (3), and cave (3) salamanders were present in low abundance and accounted for the remaining seven percent of salamanders reported during this period. The eastern tiger salamander has not been observed in MACA since the early 1980s and should probably be considered extirpated (John MacGregor, Herpetologist, KDFWR, December 2017, personal communication). Documentation of 14 out of 16 salamander species previously discovered in MACA over the past 15 years suggests than species richness remains fairly high. However, the high relative abundance of a few species suggests that evenness in the MACA salamander community may be lower now than in recent decades. Species evenness appears to be dominated by spotted, Jefferson, and marbled salamanders, as these are more abundant in MACA than other salamander species (93% of salamander observations during 2010–2016 monitoring). This suggests that although species richness is moderately high, diversity is decreased because of the high relative abundance of a select few species (Table 4.52). However, it is important to consider that the probability of detection varies greatly among species, and also fluctuates according to seasonal and environmental conditions, as well as specific habitats surveyed. Therefore, measures of species diversity inferred from the data may not accurately portray the condition of salamander diversity.

Distribution

Most of the salamanders recorded by Hibbard (1936) and Hale (1984) were common to abundant among a variety of habitats and remain so today, with the exception of a few. Scott (1997) reported spotted, Jefferson, and marbled salamanders to be common at breeding ponds. Scott often found zigzag and slimy salamanders at several cave entrances on the park in 1995 and 1996, but neither species was observed at any monitoring site in 1997. Remarks on current distribution are based on the recent and long-term (2003–2006 and 2010–2016) surveys by MacGregor (2007, 2010, 2011, 2012, 2013b, 2014, 2016b). Northern dusky salamanders, which were once commonly found in the springs and headwater streams of the park are now restricted to only two isolated populations although no obvious signs of physical change have been observed in these habitats. Adding to uncertainty is that other semiaquatic salamanders that exhibit similar habitat requirements are doing quite well (MacGregor 2017). It has been proposed that perhaps water quality issues have contributed to the declines and restricted distribution of the northern dusky salamander in MACA (MacGregor 2007). The eastern tiger salamander may be gone from MACA, the most recent discovery of this species dates from Hale (1984). Tiger salamander distribution follows preference for open habitats and deep semi-permanent breeding ponds. As open habitats have become less and less available, the tiger salamander seems to have disappeared from the park. The northern slimy salamander was described by MacGregor (2007) as “much less common in good forest habitat at MACA” than at nearby survey locations. The slender morphology of southern two-lined salamander larva renders them poorly-suited for burrowing in the substrates of small intermittent surface streams that often go

dry during the summer and fall and thus these organisms are expected to be found in perennially moist locations where substrate is soft. The large aquatic salamanders of the park have not been reported in recent decades (MacGregor 2007). Neither MacGregor (2007, 2017) nor Hale (1984) were successful in determining a reliable means of searching for the eastern hellbender or common mudpuppy in the deep-water habitats they occupy. However, Hibbard (1936) reported both hellbenders and mudpuppies to be abundant in the Green and frequently caught by fishermen on trot lines. Hellbenders and mudpuppies may remain locally-distributed in free-flowing reaches of the Green River (MacGregor 2007) but have simply eluded survey.

Species Changes

The salamander fauna of the park is fairly consistent with historical accounts, with most species being common or even abundant. Historical accounts of the salamanders in the park report 16 species. Hibbard (1936) observed 14 species during the initial survey. The four-toed salamander (Brandon 1965) and mud salamander (Hale 1984) were later discovered on the park. The survey conducted between 2003–2006 reported presence of 13 salamander species, all previously known to MACA. A few salamander species found in MACA are now present in small or isolated populations relative to historic accounts. MacGregor believes the eastern tiger salamander to be extirpated from the park although Hibbard (1936) reported these to be quite common around ponds during breeding season. The eastern tiger salamander is known to prefer breeding ponds located in open habitats, which are disappearing from the park under current land management practices as wooded areas return (MacGregor 2007). The northern dusky salamander has experienced declines that are difficult to explain over recent decades though declines of this species have been reported from other National parks (Bank et al. 2006). This species was abundant in the springs and streams of the park as recently as the 1960s, but were found in only two locations by Hale (1984) and are now found in only one location on the park (MacGregor 2007). Northern slimy salamander populations have also deteriorated in recent decades although both Bailey et al. (1933) and Hibbard (1936) found this species during initial surveys. Hibbard noted that this species was abundant in a range of habitats including cave entrances and wooded ridgetops. Declines and potential extirpation of dusky salamanders from areas where they were once considered common have been reported by Bank et al. (2006) and Means and Travis (2007). Although the Eastern hellbender and common mudpuppy are both native, and thought to be present in the park, these species have not been confirmed in field surveys conducted in recent decades. This observance likely results from the lack of a reliable method for sampling for these exclusively aquatic species within the Green River (MacGregor 2007). Emergent infectious diseases such as chytridomycosis are linked to global declines among amphibians. Preliminary findings from a 2016–2017 study led by KDFWR Wildlife Veterinarian Iga Stasiak reveal that a high percentage of red-spotted newts sampled from two ponds in MACA tested positive for *Batrachochytrium dendrobatis*, but no cases of the newly discovered salamander chytrid fungus, *B. salamandivorans* were found (Iga Stasiack, Wildlife Veteranarian, KDFWR, June 2018, personal communication).

Condition and Trend

The current salamander fauna of the park is essentially consistent with historical accounts, with most species being common. The eastern tiger salamander is now gone from the park. Extirpation of this

species is most likely a consequence of habitat loss and degradation. The open habitats preferred by the tiger salamander are gradually being replaced by forested environments in the park and semi-permanent breeding ponds have shallow, more temporary features or have vanished altogether. The northern dusky salamander has experienced steady declines in the past several decades. This trend does not appear to be associated with any observable change in the physical condition of habitats. Declines have also been observed among northern slimy salamanders, but it is unclear as to whether this apparent decline is the result of a specific stressor (MacGregor 2007). Widespread declines have been observed among many populations of woodland salamanders (genus *Plethodon*) throughout the eastern US from the 1970s through the 1990s, including numerous northern slimy salamander populations (Highton 2005).

Level of Confidence and Data Gaps

The level of confidence regarding the condition of the salamanders stated herein is moderate. This qualitative assessment is based on species presence, abundance, and general distribution patterns inferred from recent and long-term field surveys aimed at establishing baseline conditions of the park's herpetofauna (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b)(Table 4.53). Although historical accounts of amphibians in MACA are somewhat limited in number and in scope, the records that do exist (i.e., Bailey et al. 1933, Hibbard 1933, Hale 1984) account for all species expected to be present according to geographic distribution maps. The recently-completed, long-term (2003–2006 and 2010–2016) monitoring of herpetofauna in the park by MacGregor provides a sound basis for a current condition assessment over the past decade. Additional study may be required to better assess the effects of emerging diseases on amphibians. Several new diseases are thought to be related to high mortality among amphibian larvae, but limited evidence for this exists in the park at present. MacGregor (2017) notes that this is due to the difficulty of catching a die-off in progress so that samples could be collected and analyzed for viruses, chytrids and other fungal pathogens that may cause disease. Condition Summary

Condition Summary

Table 4.53. Graphical summary of status and trends for salamanders among the herpetofauna communities, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Herpetofauna	Salamanders		The salamanders of MACA appear to be in fair, but deteriorating condition with need for moderate concern. Several salamander species have experienced declines. The eastern hellbender has not been observed in the park since 1989 (MacGregor 2017) and before that had not been reported since the mid-1930s (Hibbard 1936). The other exclusively aquatic salamander known to MACA, the mudpuppy, has not been found since the 1930s (Bailey et al. 1933, Hibbard 1936). Five of 16 salamander species historically known to MACA (eastern tiger salamander, two-lined salamander, longtail salamander, midland mud salamander, and red-spotted newt) have not been found within the past 10 years (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b). Declines in northern dusky and northern slimy salamanders have also been observed (MacGregor 2007). The eastern tiger salamander is believed to be extirpated from the park as suitable open habit has vanished (John MacGregor, Herpetologist, KDFWR, December 2017, personal communication). Emerging infectious diseases are linked to declines in amphibian populations globally, and preliminary results of recent studies in MACA suggest that a high percentage of red-spotted newts test from pond and wetland areas were positive for *Batrachochytrium dendrobatis*, the amphibian chytrid fungus responsible for the disease chytridomycosis. The level of confidence in this qualitative assessment is moderate as it relies on recent, long-term monitoring efforts within the park (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b). However, because sampling techniques focused on non-random locations expected to support salamander habitat, statistical trend analysis is not possible for measures of diversity and distribution.

Sources of Expertise

John MacGregor (Herpetologist, KDFWR) and Bill Moore (Supervisory Ecologist/Data Manager, CUPN) provided expertise for this section.

4.11.3. Reptiles: Lizards

Description

Nine species of lizards are known from Kentucky, all are native (KDFWR 2013). Seven species have been observed in MACA in the past, all reported in an early survey by Hibbard (1936). The lizards that occur here are carnivorous, feeding on insects and other invertebrates. Typically, lizards prefer dry, open habitats (KDFWR 2013) with the ground skink (*Scincella lateralis*) being the only species that prefers forested habitats (MacGregor 2007). Other lizards, such as five-lined skinks (*Eumeces fasciatus*), coal skinks (*Eumeces anthracinus*), broadhead skinks (*Eumeces laticeps*), and fence lizards (*Sceloporus undulatus*) will occasionally inhabit damp woodlands (MacGregor 2007). Four species are designated under KDFWR Comprehensive Wildlife Conservation Strategy (CWCS) including the coal skink, eastern five-lined skink (*Eumeces inexpectatus*), six-lined racerunner (*Aspidoscelis seclineata*), and eastern slender glass lizard (*Ophisaurus attenuatus*) (KDFWR 2013). Of these, the coal skink and glass lizard have been observed in the park in the past 20 years, although numbers are generally low for the glass lizard and the occurrence of the coal skink comes from a single record in 2006 (MacGregor 2007). The six-lined racerunner has not been present in MACA in recent decades, but was abundant during early surveys by Hibbard (1936). The other CWCS lizard species, the eastern five-lined skink, has never been observed in the park, but has been reported on adjacent properties and was likely present during Hibbard's surveys. Park management to restore open habitats and breeding/egg-laying sites may enable comebacks among species that have been impacted by the reforestation of the park land (MacGregor 2007, 2017).

Data and Methods

The measures of community structure used to evaluate the status of reference indicators of the lizard community of MACA as described in the framework of this report include diversity, distribution, and species changes. These ecological parameters can be represented quantitatively which is important in evaluating how resource conditions change over time and space. Reference conditions are relative to historical reports and museum records of amphibians present within MACA. These records are the best obtainable reference conditions but are not representative of undisturbed or even minimally-disturbed conditions.

Historical reports include Bailey et al. (1933) and Hibbard (1936). Bailey et al. (1933) reported four lizard species in MACA. Hibbard (1936) provided an early taxonomic survey of the area proposed for the park and reported seven lizard species. More recently, KDFWR herpetologist John MacGregor completed a long-term (2003–2006) inventory (MacGregor 2007) and has continued monitoring from 2010–2016 (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b) of herpetofauna in MACA. The reference conditions used by MacGregor (2007) are based on current species distribution maps for counties in Kentucky along with a review of field guides of the reptiles of the eastern US (Ernst et al. 1994, Conant and Collins 1998, Petranka 1998). In addition to geographic ranges, MacGregor (2007) also compared the habitat requirements of reptile species with the habitats available to these organisms in the park. This information was considered in the compilation of a list of reptiles that could be expected to be found in MACA. MacGregor's 2003–2006 survey included a variety of monitoring locations across a range of habitats, but the primary field method used was frequent checks of coverboards placed in non-random locations (MacGregor 2007). Sampling was

conducted by search efforts of experienced herpetologists among habitats likely to support reptile populations. Visual and active searches of natural cover (raking through leaf litter, overturning logs, peeling loose bark, and close examination of other refugia) were applied. Most lizards were observed at coverboards (sheets of tin and/or plywood) placed on non-random plots (i.e., where suitable habitat existed) and frequently checked (MacGregor 2007). Subsequent monitoring has operated with the goal of establishing comprehensive, up-to-date distribution data for park herpetofauna to monitor species occurrences and populations, and gather baseline information regarding habitat use and condition. Focus was given to restoration and management of SGCN under Kentucky's Wildlife Action Plan (WAP; MacGregor 2013a). Again, the primary field method used in 2010–2016 monitoring by MacGregor included frequent checks of coverboards and tin sites as well as visual encounter surveys conducted along park roads and near natural features (e.g., rock outcrops) (MacGregor 2017). Collectively, these monitoring events have documented 6 of 7 expected lizard species in the park between 2003 and 2016. The nature of the sampling technique employed creates some inherent bias within results of the monitoring. For example, among both lizards and snakes, the most abundant species were also the species most commonly associated with coverboards. Therefore, relative abundance of these species may appear artificially inflated in comparison to other species that may be equally well-represented elsewhere in MACA but do not prefer the habitats offered by the coverboards. Such considerations play a larger role in the monitoring of snake communities, but may be of less importance when sampling lizard communities. Interpretation of reptile distribution is also impacted by this bias as coverboards were placed in locations that were expected to support lizard and snake populations, and therefore capture only limited information about the spatial distribution of these organisms throughout the range of habitats found in MACA.

Reference Conditions/Values

Diversity

The lizard species of MACA are doing quite well. Seven kinds of lizards were documented in the park by Hibbard (1936), six of which were encountered on the park during the 2003–2006 survey conducted by MacGregor (2007). The ground skink was the most commonly observed lizard during this survey (147 observations). Five-lined skinks (36) and fence lizards (23) were found in moderate numbers. These three species are considered common at MACA and collectively represent about 91 % of the lizard observances during the study period. Slender glass lizards were present in minimal numbers (15) and are not common in the park. Little can be said of the abundance of broadhead skinks and coal skinks in the park, as MacGregor (2007) noted great difficulty in surveying for these species with only four broadhead skinks and a single coal skink found during the field survey. The three less common species represent only about nine percent of the all lizards observed during this survey. MacGregor later reported five lizard species during surveys from 2010–2016 (the coal skink was not observed over the course of this monitoring). Again, ground skinks were most abundant (113), followed by fence lizards (27) and these are considered common in the park, accounting for 86 % of all lizards reported during this survey. Common five-lined skinks (11), broadhead skinks (8), and slender glass lizards (2) were present in relatively low abundance, representing approximately 14 % of the lizard observances at the time (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b). The coal skink is extremely rare to observe in MACA, and the single individual found in 2006 represents

the only recent park record for this species (MacGregor 2007). The six-lined racerunner reported by Hibbard (1936) was not observed during recent surveys and "… has likely been extirpated from the park as forest has replaced open sunny habitat preferred by this lizard." (MacGregor 2007). An additional species, the southeastern five-lined skink is believed to have been present but not observed during Hibbard's assessment. This species has not been found in the park during recent field surveys but has been found on property adjacent to MACA. MacGregor says both the six-lined racerunner and southeastern five-lined skink should return to MACA as open habitats preferred by these creatures are restored (MacGregor 2007). The combined results of MacGregor's 2003–2006 and 2010–2016 lizard surveys are presented in Table 4.54.

Table 4.54. Lizard abundance among non-random sampling locations in MACA during 2003–2006 survey (MacGregor 2007) and subsequent monitoring 2010–2016 (2010, 2011, 2012, 2013b, 2014, 2016b).

	Year										
Species	**2003**	**2004**	**2005**	**2006**	**2010**	**2011**	**2012**	**2013**	**2014**	**2016**	**# individuals**
Broadhead skink	0	3	0	1	0	1	0	2	3	1	11
Fence lizard	1	13	6	3	1	2	4	2	3	15	50
Five-lined skink	4	24	2	6	0	0	1	2	3	5	47
Ground skink	8	47	60	32	8	8	8	36	21	32	260
Slender glass lizard	0	8	4	3	0	0	0	1	1	0	17
Coal skink	0	0	0	1	0	0	0	0	0	0	1
# species	3	5	4	6	2	3	3	5	5	4	–

Distribution

Lizards generally prefer dry, open areas and forest edges, although some species, such as the common five-lined skink, occur in damp woodlands as well (KDFWR 2013). Most lizard observations occurred among tin or plywood coverboards placed in open grasslands, forest openings, and along forest margins. During the 2003–2006 survey period ground skinks were most widely distributed (13 sites), followed by fence lizards (12), and five-lined skinks (11) (MacGregor 2007). These are also the most abundant lizard species represented among the monitoring locations in MACA. The slender glass lizard and broadhead skink demonstrated more restricted distributions with observations at just five and four monitoring locations, respectively. A single coal skink was observed at Cedar Sink coverboards in 2006 by park employee Bill Moore and may be present elsewhere in the park but is notoriously difficult to survey (MacGregor 2007). The ground skink is the only lizard historically reported from the park that prefers largely forested habitat. The six-lined racerunner appears to be extirpated from the park due to the loss of open, sunny habitat (MacGregor 2007). Continued monitoring by MacGregor from 2010–2016 reflects similar trends in distribution among sites surveyed. Ground skinks exhibited broad distribution and were found at 9 monitoring locations. Broadhead skinks and five-lined skinks were each found at 6 sites. The fence lizard (4 sites) and slender glass lizards (2 sites) exhibit restricted distribution. The Great Onyx area was the most specious monitoring location during this time and represented the largest number of individual

observances. Five of 6 expected species were observed in this vicinity and 55 individuals were found here. The Wandering Woods vicinity was also notable in terms of richness and diversity (4 species and 50 individuals observed) (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b).

Species Changes

Some lizard species that have historically been considered common, abundant, and/or widely distributed on the park have experienced changes in these community measures. The six-lined racerunner is no longer present on the park although Bailey et al. (1933) and Hibbard (1936) observed the species. Bailey et al. (1933) noted that although it was less common and generally distributed relative to other lizards, the six-lined racerunner was fairly common in the Eaton Valley area. Hibbard (1936) found the six-lined racerunner to be abundant along paths and cleared areas in the park. MacGregor (2007) proposed the extirpation of this species probably results from the loss of open, sunny habitat preferred by the species (MacGregor 2007). The slender glass lizard and coal skink are now much less widespread in the park than Hibbard (1936) observed during early surveys. The slender glass lizard is present in fewer numbers and more restricted populations than previously documented from the park. Hibbard (1936) reported the glass lizard to be common among wooded ridgetops, but only two specimens have been recorded in the past 10 years (MacGregor 2013b, 2014). MacGregor found a lone male glass lizard near the tin site at Floyd Collins house (McGregor 2013b) and a shed skin was documented at a tin monitoring site located near Great Onyx meadow. As with the six-lined racerunner, the glass lizard exhibits preference for open conditions (MacGregor 2007). The coal skink, although present, is notoriously difficult to find and this may explain the reduction in numbers and distribution range observed on the park during recent survey attempts. In contrast, the ground skink is now far more common compared to Hibbard's survey, which only accounted for one specimen during 15 months of work and considered the organism to be rare in the park area (MacGregor 2007). The increase in the distribution and abundance of this species is correlated to the organism's preference for primarily forested habitat. As the only species present on the park that displays this characteristic, it seems the ground skink has benefited from the reforestation of the park.

Condition and Trend

The condition of the lizard population at MACA appears to be essentially stable. MacGregor's monitoring from 2003–2006 and 2010–2016 have accounted for 6 of 7 (86%) lizard species expected in the park. However, the six-lined racerunner has not been observed in recent decades and the coal skink was last observed in MACA in 2006 and as such species richness is decreased. Species evenness was dominated by species that thrive in the forested habitat (i.e., ground skink). Species that require open, sun-lit areas (slender glass lizard and six-lined racerunner) or marginal areas of forest (broadhead skinks, coal skinks, five-lined skinks, and fence lizards) were present in lower numbers and exhibited more restricted distribution among monitoring locations. Lizards that are experiencing declines appear to do so in association with loss of open habitats as areas that were previously open have gradually been replaced by dense forest.

Level of Confidence and Data Gaps

The level of confidence regarding the condition of the lizards of MACA is moderate. This qualitative assessment is based on species presence, abundance, and general distribution patterns inferred from recent, long-term, and comprehensive field surveys aimed at establishing baseline conditions of the park's herpetofauna (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b)(Table 4.55). Such studies provide a sound basis for a qualitative current condition assessment relative to the past decade and beyond. However, because the sampling techniques do not represent an equal effort over the years, and monitoring locations are not random, the data from recent studies does not allow for statistical trend analysis or direct comparison.

Condition Summary

Table 4.55. Graphical summary of status and trends for lizards among the herpetofauna communities, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Herpetofauna	Lizards		Lizard populations in MACA are stable. Six of seven species known to the park have been found in recent surveys). However, the six-lined racerunner is presumed extirpated from MACA. Consequently, species richness is decreased with an uneven distribution of individuals among the species present. The ground skink is the most common species observed in monitoring over the past decade. The coal skink and slender glass lizard were observed in very low numbers. The condition of lizards with respect to diversity is declining slightly based on recent, long-term monitoring. Slender glass lizards and coal skinks were uncommonly observed and have likely declined since initial surveys in the 1930s. Both species exhibit highly restricted distributions in MACA. In contrast, ground skinks are now far more common than during Hibbard's survey (1936). The ground skink is now the most widely distributed lizard species on the park. The six-lined racerunner has been extirpated from MACA in association with a lack of open habitat (MacGregor 2007). The condition of lizard distribution is declining based on recent monitoring. The level of confidence in this assessment is moderate as it relies on recent, long-term monitoring efforts within the park that exhibit similar trends (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b). However, the nature of the sampling technique employed does not allow for statistical trend analysis or comparison of survey results.

Sources of Expertise

John MacGregor (Herpetologist, KDFWR) and Bill Moore (Supervisory Ecologist/Data Manager, CUPN) provided expertise for this section.

4.11.4. Reptiles: Snakes

Description

Thirty-three species of snakes have been documented in Kentucky (KDFWR 2013). Twenty-two species have been observed in MACA in the past (MacGregor 2007), 20 of which were known from Hibbard (1936), while the smooth earth snake (*Virginia valeriae*) and queen snake (*Regina septemvittata*) were later added to the list of park fauna by MacGregor and team. Snakes can be found in a variety of habitats, but all require some degree of openness to enable basking as an external means of regulating body temperature. These carnivores feed on insects, small rodents, frogs and toads, birds, and other snakes. In fact, snakes provide valuable ecosystem services and are beneficial to humans as they consume many pests (Moore and Slone 2007). Five of the snake species found in the park were selected for CWCS including the corn snake (*Elaphe guttata*), northern pine snake (*Pituophis melanoleucus*), scarlet kingsnake (*Lampropeltis elapsoides*), scarlet snake (*Cemophora coccinea*), and southeastern crowned snake (*Tantilla coronata*) (KDFWR 2013). Only four of the snake species present in Kentucky are venomous (eastern copperhead [*Agkistrodon contortrix*], western cottonmouth [*Agkistrodon picivorus*], timber rattlesnake [*Crotalus horridus*], and western pigmy rattlesnake [*Sistrurus streckeri*]) (Moore and Slone 2007). The copperhead and timber rattlesnake are the only venomous snakes documented in MACA.

Threats to the snakes of MACA and elsewhere include habitat loss and change as well as disease. The northern pine snake is believed to be extirpated from the park as large patches of open grassy forest and open field areas this organism requires have gradually been replaced by close-canopied forest. Several other snake species (southeastern crowned snake, scarlet snake, and scarlet kingsnake) have not been identified in recent long-term surveys and may also be gone from the park due to loss of more open habitat. However, these small primarily nocturnal snakes are a challenge to find during field surveys. These organisms also prefer open woodland habitats and may still occur in and around the park but have simply evaded detection in surveys (MacGregor 2007). With restoration of open habitat may recover and extirpated species may return.

Data and Methods

The measures of community structure used to evaluate the status of reference indicators of the snake community of MACA as described in the framework of this report include diversity, distribution, and species changes. These ecological parameters can be represented quantitatively which is important in evaluating how resource conditions change over time and space. Reference conditions are relative to historical reports and museum records of snakes present within MACA. These records are the best obtainable reference conditions but are not representative of undisturbed or even minimally-disturbed conditions.

Historical accounts of snakes in the park are somewhat limited. During early surveys, Bailey et al. (1933) reported 12 snake species in MACA while Hibbard (1936) reported 20 snake species. More

recently KDFWR herpetologist John MacGregor completed a long-term (2003–2006) study (MacGregor 2007) and has continued monitoring from 2010–2016 (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b) of herpetofauna in MACA. The reference conditions used by MacGregor (2007) are based on current known species distribution maps for counties in Kentucky along with a review of field guides of the reptiles of the Eastern US (Ernst et al. 1994, Conant and Collins 1998, Petranka 1998). In addition to geographic ranges, MacGregor (2007) also compared the habitat requirements of reptiles with the habitats available to these organisms in the park. This information was considered in the compilation of a list of snake species that could be expected to be found in MACA. MacGregor's 2003–2006 survey included a variety of monitoring locations across a range of habitats, but the primary field method used was frequent checks of coverboards placed in non-random locations (MacGregor 2007). Sampling was conducted by search efforts of experienced herpetologists among habitats likely to support reptile populations. Most snakes were observed at coverboards (sheets of tin and/or paneling). Visual and active searches of natural cover (raking through leaf litter, overturning logs, peeling loose bark, and close examination of other refugia) were applied. Snakes were also documented by driving roads at night. Evidence of natural or disease-related mortality was documented during visits (MacGregor 2007). Subsequent monitoring has operated with the goal of establishing comprehensive, up-to-date distribution data for park herpetofauna to monitor species occurrences and populations, and gather baseline information regarding habitat use and condition. Focus was given to restoration and management of SGCN under Kentucky's Wildlife Action Plan (WAP) (MacGregor 2013a). Again, the primary field method used in 2010–2016 monitoring by MacGregor included frequent checks of coverboards and tin sites as well as visual encounter surveys conducted along park roads and near natural features (e.g., rock outcrops) (MacGregor 2017). Collectively, these monitoring events have documented 18 of 22 snakes expected in the park between 2003 and 2016.

The nature of the sampling technique employed creates some inherent bias within results of the monitoring. For example, among both lizards and snakes, the most abundant species were also the species most commonly associated with coverboards. Therefore, relative abundance of these species may appear artificially inflated in comparison to other species that may be equally well-represented elsewhere in MACA but do not prefer the habitats offered by the coverboards (e.g., rough green snake). Interpretation of reptile distribution is also impacted by this bias as coverboards were placed in locations that were expected to support reptile populations, and therefore capture only limited information about the spatial distribution of these organisms throughout the range of habitats found in MACA.

Reference Conditions/Values

Diversity

Twenty-two species of snakes have previously been reported from MACA; 20 of which were originally found by Hibbard (1936). Later, the smooth earth snake was documented in the park by MacGregor and others (2007). MacGregor and park herpetologist Bill Moore added the queen snake to the list of park fauna in 2005, representing a new record for MACA and Edmonson County (MacGregor 2007). During the 2003–2006 survey, a total of 18 snake species were identified in the park, with all but the queen snake previously observed in MACA. The ringneck snake (*Diadophis*

punctatus) was by far the most common species (429 observations), followed by the black racer (*Coluber constrictor)* (250), eastern garter snake (*Thamnophis sirtalis*) (239), and eastern copperhead (235). Collectively these individuals account for 75% of the snake community reported from MACA during the 2003–2006 survey. The remaining 14 species were less common but still moderately abundant including the timber rattlesnake (93), corn snake (55), eastern kingsnake (*Lampropeltis getula*) (40), worm snake (*Carphophis amoenus*) (36), smooth earth snake (34), brown snake (*Storeria dekayi*) (23), prairie kingsnake (*Lampropeltis calligaster*) (22), northern water snake (*Nerodia sipedon*) (21), milk snake (*Lampropeltis triangulum*) (21), eastern hognose (19) (*Heterodon platirhinos*), black rat snake (*Pantherophis obsoletus*) (13), and northern red-bellied snake (*Storeria occipitomaculata*) (13). A single individual was observed for both the rough green snake (*Opheodrys aestivus*) and queen snake and these species are considered rare in the park (MacGregor 2007). Monitoring conducted by MacGregor during 2010–2016 also reports 18 of 22 snake species known to MACA. It should be noted that these surveys were less intensive than the 2003–2006 study efforts and were focused mainly on tin or coverboard monitoring sites placed in open areas. The species present and relative abundance reported for these locations are likely biased toward the species that prefer these types of habitats and likely under-represent species that prefer forested habitats and aquatic habitats. For example, the northern water snake and queen snake were observed in low numbers during this monitoring period and this likely reflects the sampling methodology employed. Species most commonly observed among tin and board cover plots during 2010–2016 monitoring include ringneck snakes (723 observations), black racers (370), and copperheads (301) (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b). Eastern garter snakes (73), timber rattlesnakes (65), milk snakes (28), eastern hognose snakes (27), brown snakes (25), prairie kingsnakes (24), and northern red-bellied snakes (20) were moderately abundant, composing approximately 16 % of the detections within the snake community. The black rat snake (14), eastern black kingsnake (10), smooth earth snake (10), rough green snake (1) and queen snake were present in low abundance, representing about 2 % of all snakes reported during this time (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b). Although not documented during recent field surveys the scarlet snake, scarlet kingsnake, and crowned snake may still exist in small, isolated populations in and around MACA as these species are difficult to find in the field (MacGregor 2007). The combined results of MacGregor's 2003–2006 and 2010–2016 snake surveys are presented in Table 4.56.

Distribution

Snakes occupy highly variable habitats, but virtually all require open areas (KDFWR 2013). Distribution data presented herein are based on the most recent published multi-year inventory (2003–2006) (MacGregor 2007) and follow-up long-term surveys (2010–2016) by MacGregor (2010, 2011, 2012, 2013b, 2014, 2016b). Some of the most common snakes (ring-necked snake, black racer, and copperhead) also exhibited the most widespread distribution in MACA. Ringneck snakes, black racers, and copperheads were each observed among 22 locations during surveys conducted from 2003–2006 (MacGregor 2007). Also, widely distributed in the park were worm snakes (found at 19 locations), eastern garter snakes (15 locations), timber rattlesnakes (14 locations), and smooth earth snake (12 locations). Species that exhibit more restricted distributions include brown snakes, northern water snakes, and black rat snakes (all documented at 9 locations), corn snakes (7 locations), northern red-bellied snakes (6 locations) and prairie kingsnakes and milk snakes (each

reported in 5 locations). Both black kingsnakes and eastern hognose snakes were documented in fair numbers but are restricted to only a few locations on the park. The restricted distribution of these species is likely the result of habitat preference for open areas and without efforts to restore prairies, grasslands, and open canopy forest habitats, these organisms will likely be extirpated from MACA (MacGregor 2007). Additionally, while the rough green snake and queen snake are only known from single individuals observed from two sites within the park, these organisms are likely more common than records indicate. It is difficult to assess the distribution of the scarlet snake and scarlet kingsnake, which may still be present in isolated populations in the park although none have been reported recently. Although the pine snake is believed to be extirpated from MACA (John MacGregor, Herpetologist, KDFWR, December 2017, personal communication), a single specimen was found just north of the park boundaries in 2006 (MacGregor 2007).

Since most observations were associated with coverboards, MacGregor presented a sub-set of monitoring results that includes only records from the 10 coverboard sites used during his 2003–2006 survey (MacGregor 2007). A total of 15 snake species were observed among the 10 sites. The northern water snake, queen snake, and rough green snake were not found among these locations. It worth noting that these three species would not be expected among the tin sites due to specific habitat requirements. The northern water snake and queen snake are restricted to areas in and around water (primarily the Green River) and the rough green snake is a characteristically arboreal species (Plummer 1997). This reinforces the potential bias and need for caution in interpreting results of reptile monitoring in MACA. Black racers and ringneck snakes were each found at 9 of the 10 sites, eastern garter snakes and earth snakes were each present at 8 sites, and copperheads and worm snakes were each observed at 7 monitoring locations. The Wandering Woods vicinity had the greatest number of cover objects and yielded the greatest number of snake species (14). The worm snake was not found in this area and all other snakes found at this site were anticipated species except for the corn snake (MacGregor 2007).

Most snakes during 2010–2016 monitoring were likewise observed under artificial coverboards of tin or plywood placed in open areas of the park apart from a single queen snake (found in the Green River near Dennison Ferry) and northern water snake (found at Sloans Crossing Pond), and a pair of rough green snake (found south of Temple Hill trailhead on McCoy Hollow Trail). Black racers were most widely distributed among sites surveyed during this period (present at 12 sites) followed by copperheads (11 sites), and timber rattlesnakes (9 sites), while ringneck, eastern garter, and worm snakes were each present at 8 locations. A few snake species exhibited moderately restricted distributions including the brown snake (found at 6 sites), corn snake (5 sites), smooth earth snake (4 sites), and the eastern hognose, eastern milk snake, and black rat snake were each present at 3 sites. Several species displayed highly restricted distribution among sampling sites including the eastern kingsnake and prairie kingsnake (each present at 2 sites) and the northern water snake, queen snake, northern redbellied snake, and rough green snake (each reported from only a single location). A distribution pattern similar to the 2003–2006 survey was observed among coverboard sites, with the largest number of species found under cover set-ups in the Wandering Woods vicinity (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b).

Table 4.56. Snake abundance among non-random sampling locations in MACA during 2003–2006 survey (MacGregor 2007) and subsequent monitoring 2010–2016 (2010, 2011, 2012, 2013b, 2014, 2016b, 2017).

	Year										
Species	**2003**	**2004**	**2005**	**2006**	**2010**	**2011**	**2012**	**2013**	**2014**	**2016**	**# individuals**
Brown snake	1	16	2	4	5	2	2	3	1	12	48
Corn snake	2	32	9	12	3	6	8	12	7	5	96
Eastern black kingsnake	0	8	17	15	3	1	0	0	0	6	50
Eastern copperhead	4	38	58	135	5	38	36	78	67	84	543
Smooth earth snake	3	20	9	2	1	3	0	1	0	5	44
Eastern garter snake	2	69	78	90	4	16	9	20	6	18	312
Eastern hognose snake	0	7	6	6	1	5	7	8	1	5	46
Eastern black racer	11	105	71	63	22	103	42	82	56	76	631
Milk snake	1	14	0	6	1	8	0	3	7	9	49
Northern red-bellied snake	2	9	2	0	0	2	0	3	0	15	33
Northern ring-necked snake	20	135	166	108	39	88	51	211	120	231	1,169
Prairie kingsnake	0	14	4	4	1	2	2	12	5	2	46
Rat snake	2	5	3	3	0	5	1	6	1	1	27
Rough green snake	1	0	0	0	0	0	0	0	0	2	3
Timber rattlesnake	61	8	14	10	0	3	1	19	37	5	158
Worm snake	2	15	12	7	36	4	3	10	12	36	137
Northern water snake	1	14	0	6	0	1	1	1	0	0	24
Queen snake	0	1	0	0	0	0	1	0	0	0	2
# species	14	17	14	15	12	16	13	15	12	16	–

Species Changes

Within the past ten years 18 of 22 (82%) expected snake species have been observed in the park through monitoring efforts. Distribution and abundance of some species has changed relative to historical accounts. In some cases, there has been an increase in diversity. For example, the queen snake has been observed in segments of the Green River within the park in recent years, but was never reported present in the park prior to 2005 (MacGregor 2007). Likewise, the smooth earth snake was not known to occur in MACA before MacGregor and others identified several on the park during 2003–2006 surveys (MacGregor 2007). Other species may have declined in terms of diversity and/or distribution. Hibbard (1936) found the rough green snake to be common in wooded areas, but only three were reported from between 2003 and 2016 (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b). These species are likely more common in the park than monitoring records suggests. The northern pine snake, scarlet snake, scarlet kingsnake, and crowned snake have not been found in recent surveys. The pine snake has been extirpated from habitat change, but the others may continue to exist but have evaded survey. Apparent changes in diversity and distribution may reflect a preference for habitats not offered by monitoring sites and so it is difficult to produce a meaningful assessment of species changes among snakes. Snakes that are experiencing declines appear to do so in association with loss of more open habitat. It is thought that under proper management, these habitats can be restored and some species of snakes may return to MACA.

Condition and Trend

The potential for sampling bias among monitoring locations that are naturally preferred by some snake species makes it difficult to render meaningful assessments of the condition of the snake community at MACA. Overall, fewer species are now present in the park than were originally observed in the 1930s. Although one species (queen snake) previously unreported is now present at MACA, four snake species (northern pine snake, southeastern crowned snake, scarlet snake, and scarlet kingsnake) previously found in the park have not been observed in recent long-term surveys and are thought to be extirpated due to loss of open habitat. Other species appear to be present in lower numbers or more restricted distributions and these are at increased risk for extirpation. MacGregor notes that the black kingsnake and eastern hognose snake (both which show distinct preference for open habitat) are at risk of extirpation from MACA unless efforts are made to restore prairies, grasslands, and forest clearings (MacGregor 2007).

MacGregor (2007) proposed several stressors that may be responsible for observed declines among some snakes, primarily citing the loss of more open habitats. Specific factors include the growth of thick (closed-canopied) forest cover over 95% of MACA, reforestation of fields, glades, prairies, and sunny rocky habitats, loss of connectivity among existing patches of these habitats, and loss of fire in the ecosystem. Snake Fungal Disease (SFD), may be partially responsible for declines observed among some snakes. In 2016, a total of 269 snakes were visually examined for active and/or healing skin infections from SFD. Fifty-five snakes (20%) displayed active infections and 33 others (12%) appeared to be healing from prior infections. The occurrence of SFD appears to fluctuate seasonally, with the highest proportion of infected snakes was observed during the spring months and declined into the late summer months. Eleven of the 16 snake species known to MACA exhibited apparent

SFD conditions. The only snake species in which SFD was not detected included eastern garter snakes, brown snakes, rat snakes, red-bellied snakes, and rough green snakes (MacGregor 2017).

Level of Confidence and Data Gaps

The level of confidence regarding the condition of the snakes stated herein is moderate. This qualitative assessment given is based on species presence, abundance, and general distribution patterns inferred from recent, long-term, and comprehensive field surveys aimed at establishing baseline conditions of the park's herpetofauna (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b)(Table 4.57). The recently-completed inventory (MacGregor 2007) and continued monitoring (MacGregor 2010, 2011, 2012, 2013b, 2014, 2016b) provides a sound basis for a qualitative current condition assessment relative to the past decade. Continued monitoring for SFD among the snakes in MACA is recommended to allow for a better understanding of the declines observed among these organisms.

Condition Summary

Table 4.57. Graphical summary of status and trends for snakes, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Herpetofauna	Snakes		The snakes of MACA warrant the need for moderate concern. Relative to the diversity exhibited by other herpetofaunal groups on the park, snakes appear to be the most imperiled. Recent monitoring between 2003 and 2016 reveled 18 of 22 (82%) expected species were (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b). One species (northern pine snake) has been extirpated (MacGregor 2017), and three other species have not been observed in the park in the past 20 years (southeastern crowned snake, scarlet kingsnake, and scarlet snake). Several species that are present in small or isolated population in the park are at increased risk for extirpation (e.g., corn snake, eastern kingsnake, and eastern hognose snake) (MacGregor 2007). On a positive note, a new park record for the queen snake was added by John MacGregor and Bill Moore (NPS) in 2005. Threats and stressors to snake populations in MACA are primarily associated with loss of open habitats (MacGregor 2017). MacGregor notes that as dense forest replaces open habitats, many species are being pushed into smaller and more isolated patches. However, it is thought that these species will experience a comeback once habitats are restored (MacGregor 2007). Snake fungal disease (SFD) may also threaten snake communities in the park. MacGregor documented several instances of the skin infection during 2016 monitoring and found that 88 of 269 (32%) individuals examined were experiencing of recovering from SFD. The level of confidence in this assessment is moderate as it relies heavily on recent, long-term monitoring efforts within the park that exhibit similar trends (i.e., MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b). However, the nature of the sampling techniques employed renders the data unsuitable for statistical trend analysis.

Sources of Expertise

John MacGregor (Herpetologist, KDFWR) and Bill Moore (Supervisory Ecologist/Data Manager, CUPN) provided expertise for this section

4.12 Surface Aquatic Communities

Based on the assessment of the indicator species outlined in the framework document, the overall condition of the surface aquatic community merits the need for moderate concern. In terms of diversity, most communities evaluated exhibit high species richness, but low evenness. The condition of fish and mussel populations appears to be improving. More fish species are now present in the Green River in MACA than ever before (NPS 2017c), although there are some exotic species. Many non-game species exhibit high abundances, and the Green River within MACA has received an "excellent" fishery rating for smallmouth bass, and even contains some trophy-size individuals. Presence of several rare and endangered mussels in the habitats offered by the Green River and successful efforts to reintroduce the endangered pink mucket to long-term monitoring stations in the Green River within the park are positive signs for the condition of the mussel fauna of the park. Thorough treatment of the amphibian components of the park's surface aquatic communities is given in Section 4.11 Herpetofauna of this report. The level of confidence in this assessment is high as it relies on well-documented historical records, recent and long-term monitoring efforts of park fauna using intensive surveys and these show similar patterns among and between groups. A positive, dramatic change in conditions related to surface aquatic fauna occurred in November 2016 with the unplanned breaching, and subsequent removal, of Lock and Dam on the Green River just downstream from MACA, which has restored free flowing conditions to the Green and lower Nolin Rivers in the park.

Assessments of fish and mussels in the park are supported primarily by surveys conducted within the Green River (See Appendix F, Table F-1). Prior to the breaching of Lock and Dam #6 construction of the locks and dams on the Green River by the US Army Corps of Engineers (USACE) had altered the aquatic habitat from that of a cool free-flowing river to a slow-flow aquatic environment. In impounded regions, riffle and shoal areas with cobble and gravel substrates had been replaced by perennially inundated pools that exhibit fine-grained sediment substrates such as silt. Species composition within these impounded reaches can be highly impacted, particularly among organisms with sensitivity to flow, temperature, substrate, turbidity, and/or water quality. Species composition in the impounded areas has been shown to favor organisms well-adapted to a slower, warmer water system (USACE/TNC 2011a).

The Green River and lesser surface water bodies of the park support many diverse aquatic communities. The segment of the Green River that flows through the park supports three fish species under review for federal listing (Tippecanoe darter (*Etheostoma tippecanoe*), Popeye shiner (*Notropis ariommus*), and longhead darter (*Percina macrocephala*), one species (spotted darter (*Etheostoma maculatum*) listed as threatened by Kentucky Department of Fish and Wildlife Resources (KDFWR; KDFWR 2013), four fish identified as species of greatest conservation need (SGCN) by KDFWR (Kentucky darter (*Etheostoma rafinesquei*), spotted darter, stargazing minnow (*Phenacobius uranops*), and western sand darter (*Ammocrypta clara*; KDFWR 2013), three species endemic to Kentucky (teardrop (*Etheostoma barbouri*), orangefin (*Etheostoma bellum*), and Kentucky snubnose darter (*Etheostoma atripinne*)) (NPS 2017c), and is designated as critical habitat for at least one federally endangered fish species (diamond darter (*Crystallaria cincotta*)) (Thomas and Brandt 2016). The Green River also serves as a habitat for nine species of freshwater mussels

currently listed as federally endangered (spectaclecase (*Cumberlandia monodonta*), fanshell, northern riffleshell, snuffbox (*Epioblasma triquetra*), pink mucket (*Lampsilis abrupt*), scaleshell (*Leptodea leptodon*), ring pink, sheepnose (*Plethobasus cyphyus*) and rough pigtoe (*plurobema plenum*)), one federally threatened species (rabbitsfoot), five species under review for federal listing (longsolid (*Fusconaia subrotunda*), round hickorynut (*Obovaria subrotunda*), pyramid pigtoe, salamander mussel (*Simpsonaias ambigua*), and Kentucky creekshell (*Villosa ortmanni*)) (NPS 2017c), one mussel endemic to Kentucky (Kentucky creekshell) (McGregor et al. 2015), and 28 mussel species are identified as SGCN (KDFWR 2013). Some species mussel species that are present in the Green River are thought to be extirpated from the park, including the northern riffleshell and scaleshell (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication; Leroy Koch, Senior Biologist, USFWS, December 2017, personal communication). Amphibians that inhabit surface streams, ponds, springs, and ephemeral pools of the park offer insight as environmental indicators and are a subject of much interest regarding emerging diseases that may threaten these populations. Among the frogs and toads (anurans) no state or federally threatened or endangered species are present in MACA, but two frogs (the wood frog and the southern leopard frog) and the eastern spadefoot toad are considered state SGCN (KDFWR 2013). Likewise, no state or federally threatened or endangered salamanders or newt species were found on the park (NPS 2017c). However, three salamanders (northern dusky (*Desmognathus fuscus*), four-toed salamander (*Hemidactylium scutatum*)) and eastern hellbender (*Cryptobanchus alleganiensis*) are state SGCN (KDFWR 2013). The eastern hellbender, a rare giant aquatic salamander formerly common in the Green River, has not been reported since the late 1980s and is under review for federal listing (MacGregor 2017, NPS 2017c).

Within the framework of this assessment, fish, freshwater mussels, and amphibians are reviewed. This is in no way a complete representation of all populations that could be referenced to evaluate the status of the surface aquatic communities within the park but rather an examination of select groups that exhibit high priority for concern due to potential threats, small population size, status as environmental indicators, or potential loss of ecosystem services associated with declines in biodiversity among certain groups. Some of the most highly imperiled biota within the Green River and other surface aquatic environments exist in small, isolated populations such that these organisms risk extirpation from the park. The potential loss of biodiversity among these impaired populations highlights the importance of preserving suitable habitat in the park to ensure continued reproductive success. Additionally, the structural and functional traits of fish (Price 1978, Simon 1999, McCormick et al. 2001, Oberdoff et al. 2001, Young et al. 2014), benthic macroinvertebrates (Lenat 1988, Klemm et al. 2003, Korte et al. 2010, Young et al. 2014) and amphibians (Beebee and Griffiths 2005) are often referenced as indicators of water quality. Thus, an assessment of these indicators is appropriate for inclusion when evaluating the condition of the surface water resources within MACA. Minor discussion of the results of recent work in the park evaluating benthic macroinvertebrate (Schuster et al. 1996) and plankton (Laughlin 2003) communities have been included within the fish and freshwater mussel sections for the services these organisms provide to as biological indicators of water quality and key trophic links.

Surface aquatic communities were evaluated using the following resource indicators:

- 4.12.1 Fish
- 4.12.2 Freshwater Mussels
- 4.12.3 Amphibians

4.12.1. Fish

Description

The Green River includes some of the most diverse fish fauna in Kentucky and is nationally significant in terms of zoogeography and conservation. Prior to the last ice age, the Green River was a headwater tributary to the ancestral Ohio River, which was considerably smaller and more isolated than at present. This isolation has rendered the Green River able to support the most unusual fish fauna known in the lower Ohio-upper Mississippi basin (Cicerello and Hannan 1991, USACE/TNC 2011a). Two-thirds (151) of the 226 total species of fish in Kentucky are known from the Green River drainage (Burr and Warren 1986, Cicerello and Hannan 1991). Within the portion of the Green River that transverses MACA, three endemic species are present as well as several species designated as candidates for listing by the United States Fish and Wildlife Service (USFWS) as federally threatened or endangered. Free-flowing river reaches above Green River mile 199 contain diverse communities supporting populations of smallmouth bass (*Micropterus dolomieu*), darters, madtoms, sculpin, and other cool water species. In impounded regions of the Green River, warm water fish species (e.g., largemouth bass (*Micropterus salmoides)*, catfish, bluegill, carp, gar, shad, buffalo, redhorse, and drum) are more prevalent (USACE/TNC 2011a). The Green River within the park is designated as an unoccupied critical habitat unit for the federally endangered diamond darter (*Crystallaria cincotta*) (Thomas and Brandt 2016). Many important sportfish are also present in the park including largemouth, spotted (*Micropterus punctulatus*), and smallmouth bass; bluegill; white (*Pomoxis annularis*) and black crappie (*Pomoxis nigromaculatus*); channel catfish; longear (*Lepomis megalotis*), redear (*Lepomis microlophus*), and green (*Lepomis cyanellus*) sunfish; walleye (*Sander vitreum*); rock bass (*Ambloplites rupestris*); sauger; white bass (*Morone chrysops*); and striped bass (*Morone saxatilis*) (USACE/TNC 2011a). Pool 6 of the Green River has received an “excellent” population assessment among rock bass and smallmouth bass and trophy size (>51 cm) smallmouth bass are present here (Baker et al. 2016). However, note that Pool 6 no longer exists following the failure of Lock and Dam #6 in November 2016.

Fish are important bioindicators of stream health as fish species richness and population distributions reflect water quality (Price 1978, Simon 1999, McCormick et al. 2001, Oberdoff et al. 2001, Young et al. 2014). Additionally, fish are essential to the reproductive success of another bioindicator, freshwater mussels, by serving as a host to larval mussels. Habitat alteration (e.g., contamination, dam construction, channel engineering) is the primary threat to fish biodiversity in the park. Rick Olson notes that mercury contamination in Kentucky rivers is significant enough to merit an advisory to limit consumption (Rick Olson, Park Ecologist, MACA S&RM, February 2018, personal communication; KDFWR, 2014o). The National Park Service (NPS) plays a critical role in protecting the fish and wildlife resources of the Green River by implementing proper use and preservation of National Park land and water resources. The NPS needs current data to continue to

protect and conserve the fish fauna within MACA and develop water and land use regulations within the park to maintain suitable aquatic habitats of the Green River in the park.

Data and Methods

The measures of community structure used to evaluate the status of reference indicators for surface water communities within the framework of this report include diversity, distribution, and species changes. These ecological parameters can be represented quantitatively which is import in evaluating how resource conditions change over time and space. Multiple datasets were used in evaluating the condition of the fish assemblage at MACA. The current assessment relies on several field surveys that were made from 1933 to 2017. Reference conditions are relative to historical reports and museum records of fish fauna present in the Green River within MACA. These records are the best existing reference conditions but are not representative of undisturbed or even minimally-disturbed conditions. Few museum records and no reports regarding fish fauna in the park exist prior to impoundment of the Green River by Lock and Dam #6, which was constructed in the early 1906 and knowledge of physical and biological characteristics under unaltered stream conditions is lacking. As such, it is difficult to evaluate changes in fish species composition or distribution associated with the presence of Lock and Dam #6 relative to natural conditions. Several cooperative studies between the USACE and USFWS have evaluated the ecological impacts of Lock and Dam #6 on biologic assets of the Green River (Widlak 1999, USACE 2004, Andrews and Koch 2014) and serve as the best reference to evaluate probable conditions before the river was impounded.

Historical reports of the icthyofauna of MACA considered in this assessment include those of Bailey et al. (1933), Carter (1970), Laflin (1988), Cicerello and Hannan (1991), and Thomas and Brandt (2016). Bailey et al. (1933) provided an initial survey of biota in the cave region. In a limited survey of the Green River, 29 fish species were collected. Carter (1970) surveyed the Green River at Houchins Ferry and Dennison Ferry and a tributary, Buffalo Creek and found a total of 41 taxa. Cicerello and Hannan (1991) reported that Sickel and others discovered 30 species between two sites in impounded segments of the Green River downstream of Cave Island. Laflin (1988) sampled the entire length of the Green River within MACA from 1970–1987 and discovered 57 species in addition to those included from Carter (1970). Both Carter (1970) and Laflin (1988) used electrofishing techniques and were focused on large game fish. Perhaps the most comprehensive information available is derived from the field survey focused on nongame fish conducted in 1990 by Cicerello and Hannan (1991). This assessment relies on the information therein to a great extent. Fish were collected from 24 sites in the Green River in MACA during the spring and summer of 1990 using seines and gill nets. More recently, several studies have evaluated the status sportfish including smallmouth and rock bass (Baker et al. 2016) and nongame fish, particularly darters within the park (Thomas and Brandt 2016). Thomas and Brandt (2016) reported that 55 species were identified among five locations in the Green River within MACA. The recent failure and removal of LD6 has prompted ecological study of subsequent changes in community structure among the surface aquatic communities of the Green River within MACA. Compton and others (2017) have recently completed a survey of aquatic biota in the Green River. During the study, ichthyofauna was found to be diverse, with 58 native species reported. Fish richness and abundance were greatest within free-flowing sections of the river whereas benthic fish species were in low abundance in free-flowing habitat. This

observance suggests the current ichthyofauna of the Green River in the park still reflects historical impounded conditions (Compton et al. 2017).

Other benthic macroinvertebrates, such as aquatic insects, bear mentioning in this section as these are important trophic links in aquatic systems and are important to maintaining quality fish habitat. A brief mention of the previous work done to evaluate the condition of this community is appropriate as aquatic macroinvertebrates reflect stability and diversity of the larger aquatic food web, although these organisms are not specifically included in the framework for this assessment. Aquatic macroinvertebrates play a critical role in the balance and flow of nutrients in aquatic systems as a food source for fish and a vital link connecting aquatic plants, algae, and leaf litter to fish species. Furthermore, these serve as bioindicators of water quality. For example, members of the Ephemeroptera and Plecoptera orders indicate high quality, clean systems whereas Chironomids are typically associated with polluted, low quality systems. The relative abundance of these taxa can identify habitat impairment and changes in water quality among stream reaches. A detailed assessment of the condition of the benthic macroinvertebrates among free-flowing and impounded segments of the Green River within MACA was provided by Schuster et al. (1996). The study found that two distinct communities were represented among the free-flowing and impounded stretches. Rheophilic species were predominant in free-flowing reaches, whereas limnophilic species dominated the impounded stretch of the Green River within MACA. Distribution of macroinvertebrate functional feeding group gilds shifted between segments of the river that behave as a lotic system and those that display lentic characteristics. Scrapers and filter feeders were virtually eliminated from the impounded section but were well represented in free-flowing reaches. The patterns observed among functional feeding groups were reinforced by changes in water quality moving from lotic to lentic zones. Water quality ranged from “good” to “fair” to “poor” respectively, in the free-flowing, transitional, and impounded zones using the Ohio Invertebrate Community Index (ICI; OEPA 1987a, 1987b, 1989). Community composition shifted from diverse filter feeder and scraper communities in free-flowing reaches to communities dominated by collector-gatherers and low taxa diversity in impounded segments. These observations reflect changes in hydrological flow regime and subsequent alteration of substratum in the area of the Green River impounded by Lock and Dam #6. Schuster and colleagues proposed increased siltation among impounded reaches as the primary mechanism responsible for the differences observed among macroinvertebrate communities of the Green River in MACA. Siltation is also known to impact Unionid communities by altering substrate composition and affects spawning and foraging locations for many fish species. Cicerello and Hannan (1990, 1991) reported that both mussel and fish taxa were present in lower numbers in impounded sections of the Green River in MACA relative to free-flowing reaches.

Reference Conditions/Values

Diversity

The fish fauna of the park represents what is perhaps the most diverse assemblage in the National Parks System (Cicerello and Hannan 1991). Species richness remains high. Eighty-four species were known from MACA based on accepted literature and museum records (Cicerello and Hannan 1991). However, recent surveys conducted in the Green River following the removal of Lock and Dam #6 encountered three new species including the smallmouth redhorse (*Moxostoma breviceps*), highland

shiner (Notropis micropteryx), and hybrid striped bass (*Morone saxatilis* X *Morone chrysops*), bringing the total number of fish species present at MACA to 87 (Clare Bledsoe, Biologist, CUPN, August 2018, personal communication). Presently the NPS Species List for MACA reports 87 fish species as approved present in the Green River in the park, including 80 native species and three endemic species of darters (teardrop (*Etheostoma barbouri*), orangefin (*Etheostoma bellum*), and Kentucky snubnose (*Etheostoma rafinesquei*) (NPS 2017c).

Recent surveys suggest the number of fish species present in the park more closely resembles species counts in the mid-50s. Compton et al. (2017) reported the diversity of the fish fauna at MACA as high, with 58 fish species represented among the free-flowing and formerly impounded sections of the Green. The free-flowing sites on the Green River displayed the greatest richness and abundance of fish species whereas the single site on the Nolin River represented the least diverse and least abundant sampling site in association with impoundment of the lower Nolin from Green River Lock and Dam #5 (Compton et al. 2017). Although this most recent survey accounts for fewer fish species than the Cicerello and Hannan report from 1991 (58 compared to 84), it should be noted that the survey strategies employed by each study are not the same. Cicerello and Hannan (1991) surveyed 24 sites across five months, whereas Compton et al. (2017) surveyed just five sites over two days. It is also important to consider that Cicerello and Hannan (1991) only encountered 52 species during their extensive survey of 24 sites within the Green River at MACA. The remainder of the 84 species referenced in the 1991 report come from museum records and fish species listed as present in historical reports of MACA fish fauna. Similarly, Thomas and Brandt (2016) reported 55 fish species in the park, but sampling was restricted to free-flowing segments of the Green River that were likely to support target species for the study (darters and shiners). The survey by Thomas and Brandt (2016) may underrepresent fish taxa that inhabit deeper pools. The minor variation in species encountered among these contemporary studies is likely explained by variation in sampling efforts and strategies.

Species evenness is not well-distributed, as the relative abundance of some species is quite high (Cicerello and Hannan 1991, Thomas and Brandt 2016). Data from the 1990 survey shows the fish assemblage within MACA is dominated by shiners (mimic (*Notropis volucellus*), rosyface (*Notropis rubellus),* and ghost (*Notropis buchanani*); minnows (bluntnose (*Pimephales notatus*) and bullhead (*Pimephales vigilax*); darters (crystal (*Crystallaria asprella*), slenderhead (*Percina phoxocephala*) and channel (*Percina copelandi*); and largescale stonerollers (*Campostoma oligolepis*). Collectively, these nine species account for about 71 percent of the total observations within the Green River system in MACA. The remaining 43 species compose about 30 percent of total fish reported in the park (Figure 4.108). Species richness appears to be greater moving upstream in the Green River, among the areas less influenced by impoundment (Cicerello and Hannan 1991; Table 4.58). However, this dataset is somewhat noisy and clear signal trends are not easily distinguished, so the apparent increase in diversity moving upstream would require additional analysis on more recent sampling efforts to confirm. Thomas and Brandt (2016) found that species evenness was greater in the upper reaches of the Green River within MACA. Although no sampling was conducted in impounded regions during this survey, species were more evenly distributed moving upstream among the free-flowing sections. Thomas and Brandt (2016) reported that 60 percent of the 55 species collected during the survey were darters (18 species) or minnows (15 species). Four species captured

in recent sampling have state conservation status and three are considered “at risk” (Thomas and Brandt 2016; Table 4.59).

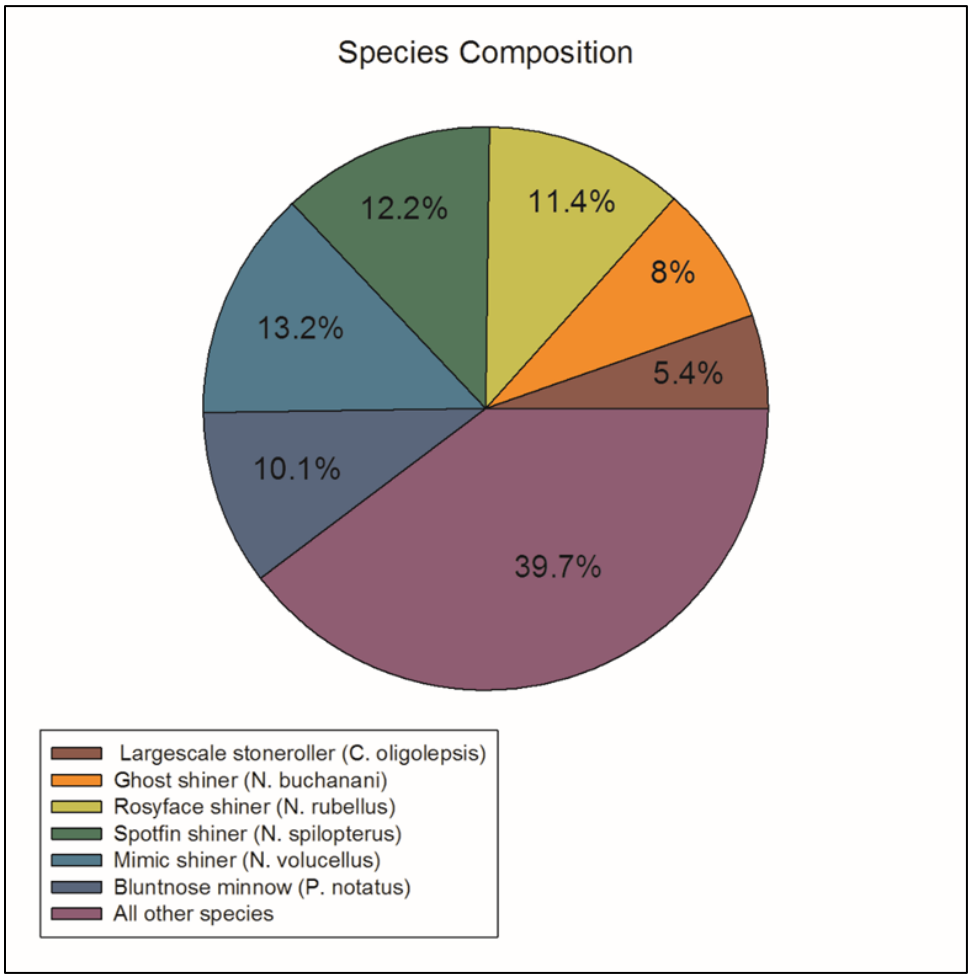


Figure 4.108. Relative abundance of fish species in MACA community in 1990 (Cicerello and Hannan 1991).

Warm water sportfish in the park appear to be in good standing, with recent population assessments of Pool 6 in the Green River yielding an “excellent” rating (Baker et al. 2016). This assessment may change following the failure and subsequent removal of Lock and Dam #6, and the associated draining of Pool 6 on the Green River (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, March 2018, personal communication).

Table 4.58. Species richness by site from Green River mile 207.8–183.6 in 1990 (Cicerello and Hannan 1991).

Site Number	Location	Total Individuals	Total Species
1	183.6 just upstream from Nolin River	3	3
2	188.6 Crump Island; 6.2 km ENE Brownsville	99	15
3	188.8 at Buffalo Creek	4	2
4	190.0 at upstream end Stice Island; 9.7 km NE Rhoda	342	26
5	192.1 at upstream end Boardcut Island; 6.5 km ENE Rhoda	164	19
6	192.5 E bank; 6 km ENE Rhoda	467	27
7	193.7 at upstream end Sand Cave Island; 10.6 km ESE Brownsville	143	15
8	195.9 just downstream from Running Branch; 15.1 km ENE Rhoda	11	7
9	197.8 at downstream end Cave Island	176	12
10	198.1 at upstream end Cave Island; 14 km E Brownsville	526	29
11	198.6 at downstream end Floating Mill Island; 14.2 km E Brownsville	291	29
12	199.4 at upstream end unnamed island; 14 km ENE Brownsville	69	11
13	199.9 near mouth Big Hollow; 14.5 km ENE Brownsville	393	26
14	200.4 adjacent Nappers Rollover; 9.5 km W Northtown	41	10
15	200.8 just upstream from Sank Hollow; 15 km ENE Brownsville	224	22
16	201.7; 3.8 km N Mammoth Cave; 7.9 km W Northtown	259	22
17	203.1 at upstream end unnamed island; 6.6 km W Northtown	160	20
18	203.5 at Houchins Hollow; 5.8 km W Northtown	109	22
19	204 at upstream end Three Sisters Island	119	21
20	205.2; 4.3 km WNW Northtown	131	13
21	206; 3.8 km NW Northtown	128	20
22	206.6 near Wilson Cave Hollow; 4 km NW Northtown	62	14
23	207.4 at upstream end unnamed island	94	18
24	207.8 upstream end MACA; 4.5 km NNW Northtown	204	27

Table 4.59. Species richness and abundance for sampling sites in MACA 2012–2014 (Thomas and Brandt 2016).

	Green River Mile Points				
Species	203.7–203.3	203.0–202.1	200.9–200.8	200.6–200.1	199.8–199.7
banded darter	14	95	–	–	2
bluegrass darter	–	5	–	–	–
orangefin darter	8	64	–	–	1
northern hog sucker	3	2	3	1	–
greenside darter	–	–	–	–	–
banded sculpin	3	6	–	–	–

Table 4.59 (continued). Species richness and abundance for sampling sites in MACA 2012–2014 (Thomas and Brandt 2016).

Species	Green River Mile Points				
	203.7–203.3	203.0–202.1	200.9–200.8	200.6–200.1	199.8–199.7
spotted darter	–	65	–	–	1
mimic shiner	14	2	–	197	1
gilt darter	9	35	–	1	5
Tippecanoe darter	2	15	–	–	5
streamline chub	1	4	–	3	1
smallmouth bass	–	–	–	1	–
channel darter	12	3	–	4	–
bigeye chub	–	22	15	26	–
brindled madtom	1	16	–	–	1
largescale stoneroller	–	–	35	–	–
rainbow darter	–	–	–	–	–
highland shiner	15	1	–	–	15
bluntnose minnow	–	–	–	1	–
channel catfish	–	4	–	–	–
silver shiner	2	1	–	–	–
longear sunfish	–	–	–	–	–
spotfin shiner	–	–	–	23	–
mountain madtom	–	–	–	–	–
western sand darter	12	–	11	7	1
fantail darter	–	–	–	–	–
rock bass	–	–	–	–	–
stripetail darter	–	–	–	–	–
golden redhorse	–	–	–	–	–
logperch	2	–	–	–	–
stargazing minnow	–	2	–	–	–
spotted bass	–	–	1	–	–
striped shiner	–	–	–	–	–
longhead darter	–	–	–	–	–
creek chub	–	–	1	–	–
black redhorse	–	–	–	–	–
elegant madtom	–	–	–	–	–
northern studfish	–	–	–	–	–
longnose gar	–	–	–	–	–
western mosquitofish	–	–	–	–	–
Ohio lamprey	–	–	–	–	–

Table 4.59 (continued). Species richness and abundance for sampling sites in MACA 2012–2014 (Thomas and Brandt 2016).

Species	Green River Mile Points				
	203.7–203.3	203.0–202.1	200.9–200.8	200.6–200.1	199.8–199.7
bullhead minnow	–	–	–	–	–
slenderhead darter	–	–	–	–	–
Kentucky darter	–	–	–	–	–
popeye shiner	–	–	–	4	–
Johnny darter	–	–	–	1	–
# species	14	17	6	12	9
# individuals	98	342	66	269	28

Distribution

The greatest concentration of fish species can be found among free-flowing riffle-run-pool reaches of the Green River. Lotic conditions provide ideal habitat for species that prefer highly-oxygenated waters such as darters and madtoms. Fish typically do not thrive in impounded streams, and these conditions were present in the park within the Nolin River and the lower stretch of the Green River until late 2016 (Cicerello and Hannan 1991). Intensive field surveys of 41 sites in the free-flowing sections of the Green River between 2012 and 2015 reported that 89 percent of species sampled were considered occasional (suitable habitat may or may not yield specimens through prolonged search) to generally distributed (suitable habitat expected to yield specimens with a thorough search) and that these were often abundant where appropriate habitat existed (Thomas and Brandt 2016). The remaining 11 percent displayed sporadic (likelihood of encountering specimen is unpredictable) distribution. Thomas and Brandt (2016) focused on species with state or federal conservation status including the diamond darter, popeye shiner (*Notropis ariommus*), stargazing minnow (*Penacobius uranops*), western sand darter (*Ammocrypta clara*), spotted darter (*Etheostoma maculatum*), Tippecanoe darter (*Etheostoma tippecanoe*) and longhead darter (*Percina macrocephala*). No diamond darters have been discovered in the park during the past 50 years and the species is thought to be extirpated. Woolman (1892) noted this fish was "not widely distributed, nor common anywhere." Less than five collection records exist for this fish, and it is probably historically uncommon in the Green River and the park (Thomas and Brandt 2016). Popeye shiners were found to be sporadically distributed and difficulty in surveying was noted due to preference for deep water habitats. Only four specimens were found at a single location, just downstream of Cave Island in the park. Stargazing minnows were described as occasional in distribution and locally common in the upper Green River. Just two individuals were observed at a single site in the park in a segment between Green River mile 200.9–200.8. The western sand darter exhibits occasional distribution patterns in the Green River, particularly in the segment downstream of Munfordville to Green River Ferry where sandy channel substrate is present. A total of thirty-three specimens were collected among four sites in MACA and are present from river mile 203.7–199.7 (Thomas and Brandt 2016). The spotted darter was reported to be fairly common and evenly distributed in the main stem of the Green River between Roachville Ford and the downstream-most shoal in MACA by Cicerello

(2003). Recent studies found 65 spotted darters in the segment of the Green between Horton Hollow and Big Hollow and a single specimen in the section between Echo River and the Green River Ferry (Thomas and Brandt 2016). The Tippecanoe darter was reported to be sporadic and relatively uncommon, found in low numbers at just three locations in the park (Thomas and Brandt 2016). Although Cicerello (2003) identified three populations of longhead darters in the Green River drainage, none have been discovered in the park as of 2015 (Thomas and Brandt 2016).

Following the failure and subsequent removal of Green River Lock and Dam #6 downstream of the park, Compton et al. (2017) surveyed fish fauna and found that several species reported from flowing reaches were not encountered in impounded segments. Overall, fish richness and abundance were much higher in the free-flowing sections owing to a more complex flow regime and greater variety of available habitats offered by flowing reaches. The authors note it is unclear whether fish previously used such habitats under low water conditions within the historical transitional zone, or whether the diversity of species observed here have colonized following the removal of Lock and Dam #6.

Species Changes

The composition of the fish assemblage at MACA has changed with time. Some species may be extirpated from the park while others have been introduced. Recent surveys for the diamond darter (*Crystallaria cincotta)* in the segment of the Green River designated as a critical habitat unit (CHU) failed to produce any records to suggest this organism still exists in the river (Thomas and Brandt 2016). Comparison of ichthyofaunal representation among these surveys is of interest as it informs which taxa are improving, remaining stable, or facing the greatest declines. Several species have not been found in surveys since the late 1980s including the American eel (*Anguilla rostrata*), white sucker (*Catostomus commersonii*), warmouth (*Lepomis gulosus*), rainbow trout, white crappie, highfin carpsucker (*Carpiodes velifer*), bigmouth buffalo (*Ictiobus cyprinellus*), spotted gar (*Lepisosteus oculatus*), and silver chub (*Macrhybopsis storeriana*). Thomas and Brandt (2016) note that the silver chub is likely extirpated from the CHU with the park. In contrast, a single blackstripe topminnow (*Fundulus notatus*) was recently reported in the Green River within MACA by Compton et al. (2017) but prior to this finding, the species had not been observed since the late 1970s (Cicerello and Hannan 1991).

Review of contemporary fish surveys in the park yields much variation in the number of species present. The NPSpecies List for MACA lists approved records for 79 fish species in the park (NPS 2017c) but this value may not be defensible as Compton et al. (2017) reported encountering just 58 species in a recent assessment, sampling fish in both the free-flowing and formerly impounded segments of the Green River at MACA. Prior to the survey by Compton et al., Thomas and Brandt (2016) reported 55 fish taxa, although this survey was specifically conducted in habitats that foster darter species and thus fish occupying deep, or less-free flowing reaches are likely under-represented by the survey. Cicerello and Hannan (1991) reported presence of 52 fish species during their extensive field survey of rare and nongame fish. Laflin (1988) reported 57 fish species. Cicerello and Hannan also reference a survey completed by Sickel and others in the late 1970s that encountered just 30 fish species in the park. Carter (1970) reported finding 41 species, and original surveys by

Bailey et al. (1933) reported the presence of 46 species. Overall, the number of fish species now reported as present in the park is higher than numbers reported by early surveys.

Variation in methodology and target species assessed may explain differences in number of species reported among various surveys. The apparent increase in the number of species present over time is most likely the result of improved survey methods among a variety of habitats rather than an actual increase in the number of species present in MACA. For instance, the sampling techniques used in Cicerello and Hannan (1991) were much more intensive than general survey conducted by Bailey et al. (1933). Thomas and Brandt (2016) focused sampling to stream habitats where target fish species were likely to exist. Compton et al. (2017) represents a recent and comprehensive survey among both the formerly impounded and free-flowing reaches of the Green River within the park and offers a better characterization of the current condition of ichthyofauna in MACA.

Several exotic fish species are present in MACA. Meiman (2006) broadly evaluated water resources in the park, noting that rainbow trout are present due to stocking in the tailwaters of Nolin Dam and within the Green River upstream of park boundaries. This species is native to the western United States but is often introduced as a sportfish in the east. Meiman also mentioned the common carp (*Cyprinus carpio*) (native to Eurasia) and its relative the goldfish (*Carassius auratus*) are present in the Green and Nolin rivers within the park. Mosquitofish (*Gambusia affinis*) have been found in the surface rivers of MACA, and experts believe the species is not native to the Green River basin and has possibly been introduced there or the range has extended to the Green River in association with habitat modifications that favor the fish (Meiman 2006). More recently highly invasive Asian carp have been found within, upstream and downstream of the park. Of the Asian carp, at least the bighead carp (*Hypophthalmichthys nobilis*) has been captured from the Green and Nolin Rivers in the park. They are beginning to be reported regularly. These new invasive fish present a significant threat to park aquatic habitats (Rick Toomey, Cave Resource Specialist and Research Coordinator, MACA Division of S&RM, October 2018, personal communication).

Condition and Trend

Overall, the fish assemblage appears to be doing well in the park. Despite the increase in the overall number of taxa, measures of evenness show that a select number of species dominate the population. Studies that have focused on free-flowing sections of the river (e.g., Cicerello and Hannan 1991, Thomas and Brandt 2016) show that darters and shiners are the most prevalent taxa collected. More general surveys indicate the structure of the faunal composition has shifted to favor species that do well in warm, slow-flowing water. Species with a preference for highly-oxygenated, free-flowing systems, such as darters, face greater challenges associated with changes in physical flow regime (Cicerello and Hannan 1991, Widlak 1999, Olson 2006, Andrews and Koch 2014, Thomas and Brandt 2016). This may improve as the segment of the Green River within MACA returns to a free-flowing habitat following the recent failure and subsequent removal of Lock and Dam #6 in April 2017 (The Nature Conservancy 2017) and planned removal of Lock and Dam #5 (Rick Toomey, Cave Resource Specialist and Research Coordinator, MACA Division of S&RM, October 2018, personal communication).

Records to support reference conditions for the fish in the park prior to the impoundment of the Green River are lacking. These baseline conditions are important for evaluating changes in diversity and distribution relative to unaltered stream environments. The US Fish and Wildlife Service completed a report on the ecological impacts of Lock and Dam #6 in MACA in 1999, with a recent update completed in 2014 (Widlak 1999, Andrews and Koch 2014). Key findings of these studies pertinent to fish in the park are that (1) free-flowing conditions the Green River supported many more fish species than currently observed, (2) the dam-related shift to slower, warmer water conditions has caused the composition of the fish population to favor "rough" species including carp, gar and shad, and (3) restoring free flow conditions would enable recolonization by fish such as darters that serve as hosts for and assist in the dispersal of larval mussels, providing a critical service to mussel populations. Other reference conditions include the historical studies and museum records reported from MACA. These observations from the impounded areas will provide critical data as the impacts of the now free flowing conditions in the lower half of the Green in and the Nolin in MACA impact ecological conditions.

Basic stressors to fish communities include habitat loss and degradation. Free-flowing riffle-run-pool habitat in the Green River is highly important and represents the array of microenvironments naturally present in large, rivers prior to alteration (e.g., impoundment). Many species, darters for instance, are adapted to cool, well-oxygenated, flowing waters. Such organisms typically are less successful among impounded streams including the lower segment of the Green River in the park (Widlak 1999, Olson 2006, Andrews and Koch 2014). Activities within the park that may contribute to habitat loss and degradation include winter road treatment, construction, and land use changes. In contrast, removal of Lock and Dam #6 is expected to have positive ecological impacts by reestablishing free flowing areas of pools and riffles. Protecting the unique, high-quality aquatic habitats in and upstream from the park is critical to maintaining the high diversity of aquatic biota, which is thought to be among the most diverse in the National Park system (Cicerello and Hannan 1991).

Level of Confidence and Data Gaps

The level of confidence regarding the condition of the fish fauna stated herein is high based on the availability of numerous surveys ranging from the late 1920s to recent years (Table 4.60). A caution to interpretation based on these data is that although multiple datasets exist, the most comprehensive field study of fish in MACA (Cicerello and Hannan 1991) is outdated by nearly 30 years. More recent surveys have focused the scope of their efforts on either sportfish (Baker et al. 2016) or species deemed to be at elevated risk due to habitat alteration, particularly darters (Thomas and Brandt 2016). This identifies a data gap that limits the ability to assess the true condition of fish fauna in the park. A better understanding of the threat posed to park surface aquatic resources by exotic and invasive fish species is also needed. Additional study in these areas will allow for a more accurate assessment of the present status of the fish communities in the surface rivers of MACA.

Condition Summary

Table 4.60. Graphical summary of status and trends for fish among the surface aquatic communities, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Surface aquatic communities	Fish		The ichthyofauna of MACA appear to be in good condition, although threats from invasive species, such as the Asian carp, present a threat to the native fish fauna. Eighty-seven fish species are reported as present in the park, but contemporary studies report values ranging from 52–58 fish species present at MACA (Cicerello and Hannan 1991, Thomas and Brandt 2016, Compton et al. 2017). Three new fish species were added to the park species list in 2017 including smallmouth redhorse (*Moxostoma breviceps*), highland shiner (*Notropis micropteryx*), and hybrid striped bass (*Morone saxatilis* X *Morone chrysops*). Recent surveys indicate that several state and federally listed species are present within the Green River at MACA (Thomas and Brandt 2016, Compton et al. 2017). The sportfish population in the park has recently been rated as “excellent”, suggesting adequate conditions for continued success among these species (Baker et al. 2016). Diversity is high in terms of richness but communities appear to be dominated by a few species present in large numbers. Distribution records demonstrate preference for cool, free-flowing, highly-oxygenated habitats among nongame species. In the past, researchers have noted a shift in diversity to favor species that prefer deeper, warm water systems in response to impoundment of the lower segment of the Green River by Lock and Dam #6 (Widlak 1999, Andrews and Koch 2014). However, the most recent comprehensive field surveys report that darters and shiners (which have a preference for lotic habitats) are in greatest abundance among sampling locations (Cicerello and Hannan 1991, Thomas and Brandt 2016, Compton et al. 2017). Note that Thomas and Brandt (2016) only sampled in the free-flowing zone rather than impounded areas, thus it is to be expected that species preferring lotic conditions (e.g., darters and shiners) would be found in greatest abundance here. These taxa are expected to increase in abundance following completion of the removal of remaining portions of Lock and Dam #6 on the Green River. The level confidence in this assessment is high as sources of data are multiple, recent, and show similar patterns.

Sources of Expertise

Rick Olson (Park Ecologist, MACA Division of S&RM), Rick Toomey (Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM), and Clare Bledsoe (Biologist, CUPN) provided expertise for this section.

4.12.2. Freshwater Mussels

Description

Freshwater mussels (unionids) are most diverse and abundant within North America where 297 species have been documented historically (Williams et al. 1993, Turgeon et al. 1998). However, an additional species was recently recognized, bringing the total for North American unionids to 298 species (Williams et al. 2017). Freshwater mussel fauna have suffered a disproportionately high rate of extinction in North America (Haag and Williams 2014). The Nature Conservancy cites that 55% of North American mussels are extinct or imperiled (Master et al. 1998). The Green River and its tributaries are credited for supporting one of the most diverse assemblages of mussel fauna in North America (Isom 1974). The Nolin River has not received the same degree of intensive survey as the Green River, as the entirety of the segment of the Nolin found in MACA was impounded by Lock and Dam #6 until recently, and has several km still impounded by Lock and Dam #5, creating habitat that has not been shown to support mussels (Meiman 2006). The only endemic Green River and Kentucky unionid, the Kentucky creekshell (*Villosa ortmanni*), was first identified from the reach now within the park (Ortmann 1926). Several threatened and endangered mussel species are found in the park and the conservation of such rare and imperiled taxa are of chief concern when it comes to preserving biodiversity. Within MACA there are numerous mussel species with state or federal conservation status designations (Table 4.61). Ten species of mussels found in the park are listed as federally threatened or endangered, with nine of these having been collected live from MACA in the past 15 years (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication).

Table 4.61. MACA mussel species with state or federal conservation status (NPS 2017c; Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication; Leroy Koch, Senior Biologist, USFWS, December 2017, personal communication; Compton et al. 2017). Federal conservation status letters are as follows: E=endangered, T=threatened, UR=under review, SC=species of concern; see (USFWS 2012) for descriptions. Kentucky status letters are the same except S= special concern and X= presumed extinct or extirpated in Kentucky; see (KDFWR 2014p) for descriptions.

Number	Common Name	Scientific Name	Federal Status	KY Status	Presence
1	Spectaclecase	*Margartifera monodonta*	E	E	Present
2	Fanshell	*Cyprogenia stegaria*	E	E	Present
3	Snuffbox	*Epioblasma triquetra*	E	E	Present
4	Pink mucket	*Lampslilis abrupta*	E	E	Present
5	Ring pink	*Obovaria retusa*	E	E	Present
6	Sheepnose	*Plethobasus cyphyus*	E	E	Present
7	Clubshell	*Pleurobema clava*	E	E	Present

Table 4.61 (continued). MACA mussel species with state or federal conservation status (NPS 2017c; Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication; Leroy Koch, Senior Biologist, USFWS, December 2017, personal communication; Compton et al. 2017). Federal conservation status letters are as follows: E=endangered, T=threatened, UR=under review, SC=species of concern; see (USFWS 2012) for descriptions. Kentucky status letters are the same except S= special concern and X= presumed extinct or extirpated in Kentucky; see (KDFWR 2014p) for descriptions.

Number	Common Name	Scientific Name	Federal Status	KY Status	Presence
8	Rough pigtoe	*Pleurobema plenum*	E	E	Present
9	Northern riffleshell	*Epioblasma rangiana*	E	E	Possibly Extirpated
10	Scaleshell	*Leptodea leptodon*	E	X	Extirpated
11	Catspaw	*Epioblasma obliquata*	E	E	Reintroduced
12	Rabbitsfoot	*Theliderma cylindrica*	T	T	Present
13	Kentucky creekshell	*Vilosa ortmanni*	UR	T	Present
14	Salamander mussel	*Simpsonaias ambigua*	UR	T	Present
15	Pyramid pigtoe	*Pleurobema rubrum*	UR	E	Present
16	Longsolid	*Fusconaia subrotunda*	UR	S	Present
17	Round hickorynut	*Obovaria subrotunda*	UR	–	Present
18	Elktoe	*Alasmidonta marginata*	SC	T	Present
19	Pocketbook	*Lampsilis ovata*	–	E	Present
20	Cracking pearly mussel	*Hemistena lata*	–	X	Extirpated

Freshwater mussels have been particularly hard hit by presence of dams in rivers, causing numerous species (e.g., *Epioblasma* species) to become extinct (Haag 2012). These and other aquatic organisms are experiencing substantial declines in numbers resulting from habitat destruction. Unionids are believed to provide critical ecosystem services including production of nutrients, processing of particulates, and sediment mixing (Strayer et al. 2004, Vaughn et al. 2004). Additionally, freshwater mussels make good indicator species of stream health (Williams et al. 1993) as they are filter feeders with limited mobility such that knowledge of freshwater mussel distributions and abundances can be used to make certain inferences about water quality in a particular area (Bauer and Wachtler 2001). Knowledge of mussel diversity and distribution applies directly to the park's water resource management efforts in addition to addressing concerns regarding a potential loss of biodiversity and subsequent loss of ecosystem services provided by the mussels. The NPS plays a critical role in protecting the freshwater mussels of the Green River and its tributaries within the park by implementing proper use and preservation of national park land and water resources. The NPS needs current data to continue to protect and conserve the unionid fauna within MACA and develop water and land use regulations within the park to maintain suitable aquatic habitats in the park.

Data and Methods

The measures of community structure used to evaluate the status of reference indicators for surface water communities within the framework of this report include diversity, distribution, and species changes. These ecological parameters can be represented quantitatively which is import in evaluating how resource conditions change over time and space. The assessment of the condition of the freshwater mussels in MACA is supported by several field surveys dating from the 1920s to recent years. Reference conditions are relative to historical reports and museum records of mussel fauna present within MACA. These records are the best obtainable reference conditions but are not representative of undisturbed or even minimally-disturbed conditions. Studies of freshwater mussels in the Green River do not exist prior to the impoundment of the lower segment and knowledge of physical and biological characteristics under unaltered stream conditions is lacking. As such, it is difficult to evaluate changes in freshwater mussel species composition or distribution associated with the presence of Lock and Dam #6 relative to natural conditions. Several studies have evaluated the ecological impacts of Lock and Dam #6 on biologic assets of the Green River (Widlak 1999, Grubbs and Taylor 2004, USACE 2004, Andrews and Koch 2014, Compton et al. 2017) and serve as a reference to probable conditions before the river was impounded.

Historical reports of unionid fauna in MACA include Walker (1925), Ortman (1926), Clench and van der Schalie (1944), Williams (1969), Clarke (1981, 1983), and Taylor (1983). Museum records for the park were obtained from several institutions accounting for 45 mussel taxa, with many samples contributed by Walker (1925) and Ortmann (1926). Ortmann (1926) reported 31 taxa in stretches of the Green below Cave Island and near Great Onyx Cave. Clench and van der Schalie (1944) surveyed the Nolin River prior to the construction of the Nolin Reservoir in 1963, but impacted by Lock and Dam #6 downstream and found only eight species. Williams (1969) reported 43 species including the invasive Asian clam (*Corbicula fluminea*) from segments of the Green, including the park. However, it is not clear which taxa were found on the park during this study since the collection sites and results were not presented. Clarke (1981, 1983) sampled three locations in the park (i.e., Dennison Ferry, Mammoth Cave Ferry to Cave Island, and the upstream end of Cave Island) and reported 25 mussel taxa. Cicerello and Hannan (1990) conducted a comprehensive survey of 33 sites supplemented by data from collections among several of the same sites plus an additional nine locations during 1987 and 1988 reporting a total of 47 species. This study informed the choosing of sampling locations by Cicerello and Rudd (1998). Cicerello and Rudd (1998) evaluated (1) effectiveness of using quadrat versus transect sampling techniques to monitor quantitative community characteristics such as species richness, abundance, diversity, and evenness among three sites (Green River Miles 198.6, 201.4, and 206) in the park, and (2) to evaluate if population density changed between sampling periods at two locations (Green River Mile 198.6 and 206). A total of 26 taxa were observed among the monitoring sites used in the study. Layzer (2002) surveyed mussels within the Green and found 26 species from riffle habitats in the park but zero in deep pools. Grubbs and Taylor (2004) examined the effects of impoundment on macroinvertebrate assemblages in Green and Nolin rivers within MACA. The results of the study are reported for macroinvertebrates collectively, such that specific measures of freshwater mussel diversity, distribution and species changes are absent. Within the park, a total of 105 and 62 macroinvertebrate taxa were found in portions of the Green and Nolin rivers, respectively (Grubbs and Taylor 2004). Hopkins (2009)

modeled the effects of land use and land cover (LULC), habitat fragmentation, and local geomorphic characteristics on distribution of rabbitsfoot mussels in the upper Green River system at the sub-catchment, upstream reach, and riparian buffer scales. In general, stream habitats with <10% agriculture, >60% forested, <0.5% developed land, >4% coarse-silty soils, and low (<30%) patch densities yielded the greatest concentration of rabbitsfoot in the study area (Hopkins 2009). In 2012 Shepard and others (2012) released 106 endangered pink mucket and unlisted black sandshell (*Ligumia recta*) juveniles at long-term monitoring sites in MACA. These sites are quantitatively assessed every five years, and upcoming reports on the status of these organisms will yield additional information for measures of mussel success in the reaches of the Green that flow through the park (Shepard et al. 2012).

The Center for Mollusk Conservation (CMC) initiated a long-term monitoring program for the freshwater mussel populations in the Green River in 2005. The initial monitoring station was located just upstream from MACA near Mundfordville, KY. This site was sampled in 2004, 2009, and in 2014 to determine species presence, abundance, and distribution patterns. Over the three sampling events, a total of 33 species were found (McGregor et al. 2015). Finally, personal communications with KDFWR Aquatic Scientist/Malacologist Monte McGregor reports historical presence of 58 freshwater mussel species in MACA, 6 of which have been extirpated and one species (the northern riffleshell) that may be extirpated from the Green as all recent records are relicts (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication). At the same time, there have been recent successful releases of several species into the Green River, including federally endangered catspaw (reintroduction), snuffbox, and pink mucket, as well as non-listed black sandshells and Green River system endemic mussel, the Kentucky creekshell. Reared mussels of these species have been released at six sites in the Green River within the park including four sites in the historically free-flowing sections as well as two locations in the formerly impounded reaches that have recently been restored to free-flowing conditions following removal of Lock and Dam #6 (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, October 2018, personal communication).

A mention of the work done on phytoplankton communities within the Green River at MACA should be included in this assessment of freshwater mussels as they are a vital food source among filter-feeding unionids, despite the fact that the community is not directly assessed within the framework as an indicator of the condition of surface aquatic communities in the park. Plankton are important to aquatic ecosystems as they provide primary and secondary trophic links in the aquatic food web. Large river systems tend to display true plankton communities (potamoplankton) while smaller order rivers have transient (tachyplankton) communities (Lind 1985). Among freshwater environments, it is understood that as water flow slows, pelagic organisms such as plankton have increased opportunity to grow and reproduce in the absence of disturbance. Alternatively, benthic macroinvertebrates play more critical roles among fast-flowing hydrologic environments. Furthermore, filter-feeding by mussels reduces plankton biomass, such that knowledge of plankton community structure can be used as a gauge for river recovery following infestation by exotic mussel species such as the Asian clam. Laughlin (2003) evaluated zooplankton, phytoplankton, and aquatic insert larvae in free-flowing, transitional, and impounded reaches of the Green River within MACA

from 2000–2002. Overall, plankton were scarce among samples taken during the study period and exhibited temporal differences. Higher zooplankton densities were only observed during the winter enhanced flow period (November–December) whereas phytoplankton densities were highest during summer months due to warmer water temperatures, increased photoperiods, and slower downstream transport rates during low flow periods. Discharges from Green River Lake transport zooplankton through the park, but with limited downstream reproduction. Conversely, phytoplankton levels in the stretch of the Green River within MACA were similar to those observed in Green River Lake. The zooplankton community was dominated by cladocerans and copepods while phytoplankton communities were predominately composed of members of the order Chlorophyta (97% of all sampled species). Blue-green (Cyanophyta) and golden-brown (Crysophyta) algae were found in low numbers during this period (Laughlin 2003). The limited evidence of zooplankton reproduction at downstream sampling sites indicates the presence of a transient plankton community. Laughlin concluded that a true plankton community does not exist in the Green River within MACA, but that a transient community is present. Finally, Laughlin (2003) highlighted the need for additional long-term plankton data based on the premise that such communities are based on external inputs (precipitation, nutrients, contaminants) which change temporally, and stressed the need for baseline plankton data for evaluation of river recovery following Asian clam infestation.

Reference Conditions/Values

Diversity

The Green River ranks sixth in freshwater mussel diversity among North American river systems (Haag 2012). Comparison of mussel inventories conducted over the past several decades suggests that mussel diversity has experienced moderate declines in terms of both species richness and evenness relative to historic conditions. However, diversity is expected to improve over the coming decades as a result of proactive measures by KDFWR to release and reintroduce several imperiled and formerly extirpated mussel species to the Green River combined with the restoration of a more natural riffle-run-pool flow regime following the failure and subsequent removal of Green River Lock and Dam #6 just downstream from the park.

Cicerello and Rudd (1998) found 26 mussel species as they compared quantitative community measures among quadrat and transect sampling techniques between at Green River miles 198.6, 201.4, and 206. Species richness, diversity, and evenness were similar for quadrats and transects at each of three sites. Changes in community measures among quadrats was also evaluated between sampling periods, river mile 198.6 was assessed in 1995 and 1996 while river mile 206 was sampled in 1995 and 1997 (Table 4.62). Species diversity, richness, and evenness were similar in both years at river mile 198.6. Diversity and evenness were both lower in 1996 than in 1995 at river mile 198.6. Diversity at river mile 206 was greater in 1997 than in 1995, as a larger around was sampled at river mile 206 in 1997 yielding more individuals and species. Evenness (E4) at river mile 206 was similar between sampling periods at river mile 206 as the ratio of very abundant to abundant species was unchanged. Evenness (E5) at river mile 206 increased in 1997 as the community became less dominated by a select number of species. For both sites, two to five species represented over 70% of the community. Common mucket (*Actinonaias ligamentin*), threeridge (*Amblema plicata*), and pimpleback (*Quadrula pustulosa*) were the most abundant and frequently encountered species while

all other taxa comprised less than 5% of the fauna (Tables 4.63a and 4.63b). Average faunal resemblance was 70.3% at river mile 198.6 and 61.4% at river mile 206.

Table 4.62. Mussel richness, diversity, and evenness in the Green River at MACA (Cicerello and Rudd 1998).

	Green River Mile 198.6		Green River Mile 206	
Measure	**1995**	**1996**	**1995**	**1997**
Total individuals	160	148	52	92
Total samples	60	70	40	60
Species richness	19	18	11	16
Area sampled (m^2)	15	17.5	10	15
Diversity (N1)	4.93	4.64	5.72	8.24
Diversity (N2)	2.48	2.29	3.89	5.67
Evenness (E4)	0.50	0.49	0.68	0.69
Evenness (E5)	0.38	0.35	0.61	0.65

Table 4.63a. Mussel percent abundance and occurrence frequency in MACA: Green River Mile 198.6 (Cicerello and Rudd 1998).

	1995		1996	
Species Name	**Abund.**	**Occur.**	**Abund.**	**Occur.**
Actionaias ligamentina	62.5	75.0	65.5	71.4
Amblema plicata	9.4	20.0	5.4	10.0
Cyclonaias tuberculata	0.6	1.7	0.7	1.4
Cyprogenia stegaria	1.3	3.3	–	–
Ellipsaria lineolata	1.3	3.3	–	–
Elliptio dilatate	1.3	3.3	1.4	2.9
Fusconaia subrotunda	1.3	3.3	1.4	2.9
Lampsilis cardium	–	–	0.7	1.4
Lampsilis ovata	2.5	6.7	4.1	8.6
Lasmigona costata	–	–	0.7	1.4
Leptodea fragilis	1.3	3.3	–	–
Ligumia recta	0.6	1.7	–	–
Megalonaias nervosa	–	–	0.7	1.4
Obliquaria reflexa	–	–	–	–
Pleurobema coccineum	–	–	1.4	2.9
Pleurobema cordatum	1.3	3.3	2.7	5.7
Plethobasus cyphyus	0.6	1.7	0.7	1.4
Potamilus alatus	–	–	1.4	2.9

Table 4.63a (continued). Mussel percent abundance and occurrence frequency in MACA: Green River Mile 198.6 (Cicerello and Rudd 1998).

	1995		1996	
Species Name	**Abund.**	**Occur.**	**Abund.**	**Occur.**
Ptychobranchus fasciolaris	3.8	8.3	4.1	7.1
Quadrula cylindrica	0.6	1.7	–	–
Quadrula metanevra	1.9	5.0	2.0	4.3
Quadrula pustulosa	6.3	15.0	3.4	7.1
Quadrula	1.3	3.3	0.7	1.4
Tritogonia verrucosa	0.6	1.7	–	–
Truncilla truncata	1.9	5.0	3.4	7.1

Table 4.63b. Mussel percent abundance and occurrence frequency in MACA: Green River Mile 206 (Cicerello and Rudd 1998).

	1995		1997	
Species Name	**Abund.**	**Occur.**	**Abund.**	**Occur.**
Actionaias ligamentina	46.2	47.5	34.8	45.0
Amblema plicata	21.2	20.0	19.6	25.0
Cyclonaias tuberculata	3.8	5.0	7.6	10.0
Cyprogenia stegaria	–	–	2.2	3.3
Ellipsaria lineolata	–	–	–	–
Elliptio dilatate	–	–	4.3	6.7
Fusconaia subrotunda	–	–	–	–
Lampsilis cardium	–	–	2.2	3.3
Lampsilis ovata	3.8	5.0	–	–
Lasmigona costata	–	–	–	–
Leptodea fragilis	–	–	–	–
Ligumia recta	–	–	1.1	1.7
Megalonaias nervosa	–	–	–	–
Obliquaria reflexa	5.8	7.5	2.2	3.3
Pleurobema coccineum	–	–	5.4	6.7
Pleurobema cordatum	1.9	2.5	–	–
Plethobasus cyphyus	1.9	2.5	1.1	1.7
Potamilus alatus	–	–	1.1	1.7
Ptychobranchus fasciolaris	1.9	2.5	1.1	1.7
Quadrula cylindrica	–	–	–	–
Quadrula metanevra	–	–	2.2	3.3
Quadrula pustulosa	3.8	5.0	10.9	13.3

Table 4.63b (continued). Mussel percent abundance and occurrence frequency in MACA: Green River Mile 206 (Cicerello and Rudd 1998).

	1995		1997	
Species Name	**Abund.**	**Occur.**	**Abund.**	**Occur.**
Quadrula	3.8	5.0	–	–
Tritogonia verrucosa	–	–	1.1	1.7
Truncilla truncata	5.8	7.5	3.3	5.0

In a recent report of long-term mussel monitoring McGregor and others (2015) reported 33 species (4,053 individuals) in the Green just upstream from the park. In all three sampling events, diversity was dominated by the common mucket representing 71%, 32%, and 36% of total abundance during sampling periods in 2004, 2009, and 2014, respectively. McGregor reports historical presence of 58 freshwater mussel species in MACA, 6 of which have been extirpated (cracking pearly mussel, scaleshell, white wartyback pearly mussel (*Plethobasus cicatricosus*), winged mapleleaf (*Quadrula fragosa*), rough rockshell (*Quadrula tuberosa*), and rainbow mussel (*Villosa iris*)). The northern riffleshell is considered possibly extirpated as no park records exist for these species over the past 20 years. Ten T&E species have been observed in MACA within the past 20 years including the spectaclecase, fanshell, snuffbox (*Epioblasma triquetra*), catspaw, pink mucket, ring pink, sheepnose, rough pigtoe, rabbitsfoot, and clubshell. Except for the clubshell, all T&E species present in MACA have been collected live within the past 15 years. Records for the clubshell are relicts, and this organism is thought to no longer occur in the park (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication).

In the late fall of 2016, Lock and Dam #6 on the Green River downstream of the park failed and subsequently the dam was removed, thus restoring the natural flow regime of the Green River in MACA with the exception of the western section approximately 11 kilometers still impounded by Lock & Dam 5, which is still intact at river mile 168. This event will have a significant impact on mussel fauna of the park and efforts to monitor the unionid assemblage in the aftermath of this event began almost immediately. Compton et al. (2017) have provided the initial assessment of the condition of many aquatic resources within the park and much attention has been given to mussel fauna in the report due to the valuable mussel diversity boasted by the stretch of the Green that flows through MACA. A total of 27 freshwater mussel species were encountered during the survey, including the federally endangered fanshell and sheepnose. Mussel richness and abundance was greatest among flowing habitats (Compton et al. 2017). The results of the survey are described by sampling location in Appendix F of this report.

Distribution

Cicerello and Hannan (1990) reported the presence of 47 species collected from 42 sites, with only 13 species observed in the segment of the Green River impounded by Lock and Dam #6. The relatively low abundance of mussels reported probably reflects habitat deterioration caused by the impoundment of the Green River. Higher densities were observed among sites 17–20 and sites 26–30. Collection site 17 reported the highest density of individuals of any site (299). Cicerello and

Hannan (1990) noted that rough pigtoe, orange-footed pearly mussel, northern riffleshell, pink mucket pearly mussel, fanshell, and rink pink (all federally endangered species) were not found in MACA in the pool upstream of the former location of Lock and Dam #6. Cochran (1993) noted that mussel density within MACA tends to be greater than regions downstream of Lock and Dam #5, but lower than those observed downstream of Lock and Dam #3 (Miller et al. 1994). Cicerello and Rudd (1998) found the common mucket and threeridge to have the greatest density at all sites sampled. Average density calculated from quadrats by Cicerello and Rudd (1998) for Green River miles 198.6, 201.4, and 206 were 9.07, 3.80, and 4.56, respectively. The same study also calculated average density from transects and found mean density to be lower at river miles 198.6 (6.62) and 206 (3.16), but higher at mile 201.4 (4.95) (Cicerello and Rudd 1998). Layzer (2002) surveyed mussels within the Green and found zero mussels in deep pool habitats while documenting 26 species (1,471 specimens) from riffle habitats in the park. A possible reason for the difference between habitats may involve the limited presence of certain fish species (e.g., darters) among deep pool habitats. These species prefer riffle habitats and act as hosts during the larval stage (glochidia) of the mussel lifecycle and assist in dispersal of glochidia. Without these fish, mussels cannot reproduce. The fish hosts require highly oxygenated waters, which are not characteristic of the deep pools created among the impounded reaches of the Green River (Olson 2006). Recent surveys just upstream from MACA report mussel densities with mean density by species ranging from 0.005 to 5.48/m^2 (see Table 4.64). Thirteen species were considered rare (0.1 mussels/m^2) were rare in 2014 (2 T&E), in 2009 there were 19 rare species (3 T&E), and 18 rare species (4 T&E) in 2004. The average mussel density over the entire monitoring period 2004–2016 ranged from 6.63 to 8.09/m^2. In 2005, only a single species exhibited densities >0.5/m^2 relative to three species in 2009 and 2014 (McGregor et al. 2015) (Table 4.64).

Recent surveys conducted by Compton et al. (2017) following the removal of Green River Lock and Dam #6 show that mussel diversity is much higher among the flowing sections of the Green River than in pooled or historically impounded areas. Only two of 27 mussel species encountered were observed in the impounded region (washboard and pink heelsplitter), 10 mussel species were observed among pooled reaches, and 14 mussel species were observed in flowing regions of the Green River at MACA (see Appendix F, Tables F-1 and F-2). Two federally endangered mussel species were encountered in formerly pooled areas by Compton and others. A fanshell specimen was collected at site GR21 near the downstream end of Boardcut Island, which represents the upper end of the pooled zone prior to failure and removal of Lock and Dam #6. A sheepnose specimen was collected at site GR22 which represents the lower end of the transition zone, near the formerly pooled end. Today, both sites are free-flowing (and were at the time the survey was conducted). Although these two sites were previously unsuitable for the endangered mussels under impounded conditions, they were found here relatively quickly after that stream flow changed (Compton et al. 2017; Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, August 2018, personal communication).

Table 4.64. Results of quantitative mussel sampling in the Green River upstream of MACA in 2004, 2009, and 2014 (McGregor et al. 2015).

	2004		2009		2014	
Species	**#/m²**	**%**	**#/m²**	**%**	**#/m²**	**%**
Actinonaias ligamentina	5.483	70.6	2.124	32.0	2.923	36.1
Alasmidonta marginata	–	–	0.017	0.3	–	–
Amblema plicata	0.378	4.9	0.382	5.8	0.538	6.7
Cyclonaias tuberculate	0.356	4.6	0.904	13.6	0.533	6.6
Cyprogenia stegaria	0.072	0.9	0.303	4.6	0.286	3.5
Ellipsaria lineolate	0.006	0.1	0.006	0.1	–	–
Elliptio crassidens	0.017	0.2	0.017	0.3	0.011	0.1
Elliptio dilatata	0.100	1.3	0.511	7.7	1.038	12.8
Fusconaia flava	–	–	0.006	0.1	–	–
Fusconaia subrotunda	0.189	2.4	0.185	2.8	0.242	3.0
Lampsilis abrupta	–	–	–	–	0.033	0.4
Lampsilis cardium	–	–	0.011	0.2	0.077	1.0
Lampsilis faciola	0.006	0.1	0.056	0.8	0.154	1.9
Lampsilis ovata	0.106	1.4	0.163	2.5	0.247	3.1
Lasmigona costata	0.044	0.6	0.028	0.4	0.060	0.7
Leptodea fragilis	0.006	0.1	0.028	0.4	0.016	0.2
Ligumia recta	0.006	0.1	0.017	0.3	0.049	0.6
Megalonaias nervosa	0.233	3.0	0.303	4.6	0.198	2.4
Obliquaria reflexa	0.039	0.5	0.051	0.8	–	–
Plethobasus cyphyus	0.039	0.5	0.006	0.1	0.022	0.3
Pleurobema cordatum	0.033	0.4	0.073	1.1	0.011	0.1
Pleurobema plenum	0.006	0.1	0.017	0.3	–	–
Pleurobema rubrum	0.000	0.0	–	–	0.005	0.1
Pleurobema sintoxia	0.111	1.4	0.337	5.1	0.401	5.0
Potamilus alatus	–	–	0.017	0.3	0.027	0.3
Ptychobranchus fasciolaris	0.100	1.3	0.073	1.1	0.192	2.4
Quadrula cyclindrica	0.028	0.4	0.017	0.3	0.005	0.1
Quadrula metanevra	0.183	2.4	0.489	7.4	0.324	4.0
Quadrula pustulosa	0.100	1.3	0.298	4.5	0.538	6.7
Quadrula quadrula	–	–	0.006	0.1	–	–
Stophitus undulatus	0.006	0.1	0.017	0.3	0.044	0.5
Tritigonia verrucosa	0.072	0.9	0.129	1.9	0.110	1.4
Truncilla truncate	0.056	0.7	0.045	0.7	0.005	0.1
# per m²	7.77	–	6.63	–	8.09	–
# species	27	–	31	–	27	–

Table 4.64 (continued). Results of quantitative mussel sampling in the Green River upstream of MACA in 2004, 2009, and 2014 (McGregor et al. 2015).

	2004		2009		2014	
Species	**#/m²**	**%**	**#/m²**	**%**	**#/m²**	**%**
overlapping species	23	–	23	–	23	–
# species <1% (rare)	15	–	17	–	13	–
# species <0.1% (extremely rare)	6	–	4	–	3	–
# unique species	0	–	3	–	2	–

Species Changes

Relative to historical accounts of the mussel fauna in MACA, contemporary records suggest that mussel diversity has experienced minor declines within the park. The earliest assessment of freshwater mussels in the park discovered 31 taxa (Ortmann 1926). Surveys completed in the 1960s revealed an increase to 43 unique mussel taxa (Williams 1969). In the late 1980s 47 mussel species were found in the park and four additional species were thought to be present based on acceptable literature and museum records, bringing the taxa in the park at the time to 51 (Cicerello and Hannan 1990). McGregor and team (2015) identified 33 mussel species in the Green River just upstream from MACA. Compton et al. (2017) encountered just 27 mussel species during a recent inventory. The current species list reports presence of 54 species of mussels in the park (NPS 2017c). Although the current park species list would suggest that mussel diversity has increased overall, this may not be an accurate characterization of the unionid assemblage at MACA since recent inventories report the number of species present between 27 and 33 (Compton et al. 2017, McGregor et al. 2015, respectively).

Additionally, some species known from historical records are no longer present in the portions of the Green River that flow through MACA. Examples include the elktoe and cracking pearlymussel, these taxa were formerly known to exist in the park, but recent surveys did not produce any live or fresh-dead specimens (Compton et al. 2017). Similar decline has been observed in the northern riffleshell, which was once abundant in the park but are now only found by rigorous sampling efforts and may be extirpated (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication). In 2004, the park mussel biologist, Stacy Surgenor, reported the northern riffleshell as the most imperiled mussel in the Green. Surgenor also noted that the snuffbox, once a common find, is not currently found in the park aside from “sub-fossil” shells. Several of the species (e.g., the rough pigtoe, clubshell, and pink mucket) reported by Ortmann (1926) are now protected under the Endangered Species Act and are considered rare today. These changes likely reflect habitat deterioration associated with the impoundment of the Green River for navigation purposes. Although several species have declined in numbers, it is difficult to evaluate change in population sizes relative to earlier accounts since these efforts were intended for museum collections and zoological descriptions rather than comprehensive inventory (Meiman 2006). However, more recent inventories can be compared to evaluate contemporary changes in mussel populations within the park.

The presence of exotic mussel species in the Green and Nolin rivers within the park present challenges to native Unionid communities. The Asian clam is extremely widespread and overly abundant within the Green River in MACA. The zebra mussel (*Dreisenna polymorphais*) established in the Green River about 176 km downstream from the park (Green River (RM 74) at the D.B. Wilson Generating Plant near Livermore, Kentucky (USGS 2018b). Although the zebra mussel has not yet been reported in park rivers, many experts believe it is only a matter of time before zebra mussel infestation occurs, whereas some experts contend that the spread of this species to MACA is unlikely (Meiman 2006). Zebra mussels would be a significant threat to endangered park mussels, if they do arrive (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, October 2018, personal communication).

Positive changes to the condition of the park mussel assemblage include successful mussel release and reintroduction programs from 2012 to present. Federally endangered pink mucket, catspaw, and snuffbox as well as unlisted black sandshell, wavy rayed lampmussel, and Green River system endemic, the Kentucky creekshell, have been released at existing monitoring sites in the park. Perhaps the greatest success has been observed for the pink mucket. The species has been released in numbers ranging from 100–300 individuals at each of four locations in the historically free-flowing sections annually from 2012 to present and individuals in the park alone now number close to 1,000. In a separate project, 117 pink muckets were released in the park in 2014 and these individuals have grown to ≥ 10 cm in size and will likely become reproductively viable in the near future. Prior to these releases, the pink mucket was known from only 15 extant individuals in Kentucky. The goal is to get pink mussel abundance in the park to 5,000 individuals. Kentucky State Malacologist, Monte McGregor, indicates that this target is within reach in the coming years. Similarly, 50 reared catspaw mussels were released at each of two sites in the park in 2017 and 200 individuals were released at each of these same sites in 2018. At present, there are approximately 500 catspaw mussels in the park. This is a major accomplishment as the species was thought to be extinct in 1996 and only one or two records exist for the catspaw in the Green River over the past 100 years. Efforts to reintroduce the snuffbox began in 2017 when 25 individuals were released at each of two sites in the park. These individuals were evaluated in 2018 and appear to be doing well. Similar to the pink mucket, the black sandshell was released in the Green River within MACA in 2014 and both species are now ≥ 10 cm in size. Wavy rayed lampmussels were released in numbers from 100–200 at each of four existing monitoring sites in the park during 2014 and are represented by at least 400 individuals at MACA today. The Kentucky creekshell has been included in recent release programs as well, 25 individuals were released at a single location in the park in 2018. McGregor notes that the mussel release and reintroduction program plans to continue to work with these and additional species with a goal of recovering 94% of the historic Green River mussel fauna and developing self-sustaining populations (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, October 2018, personal communication).

Several of the mussel species found in MACA have been reclassified to more accurately represent systematic taxonomy and for which the nomenclature has changed (Williams et al. 2017). Table 4.65 reflects these changes.

Table 4.65. Recent updates to taxonomy and nomenclature (Williams et al. 2017).

Species (Common Name)	Previous Nomenclature	Accepted Nomenclature
Spectaclecase	*Cumberlandia monodonta*	*Margaritifera monodonta*
Rabbitsfoot	*Quadrula cylindrica cylindrical*	*Theliderma cylindrica*
Northern riffleshell	*Epioblasma torulosa rangiana*	*Epioblasma rangiana*
Threeridge	*Amblema plicata*	*Amblema plicata*
Catspaw	*Epioblasma obliquata obliquata*	*Epioblasma obliquata*
White heelsplitter	*Lasmigona complanta complanta*	*Lasmigona complanta*
Spike	*Elliptio dilatata*	*Eurynia dilatata*
Pyramid pigtoe	*Pleurobema pyramidatum*	*Pleurobema rubrum*
Monkeyface	*Quadrula metanevra*	*Theliderma metanevra*
Wartyback	*Quadrula nodulata*	*Cyclonaias nodulata*
Pimpleback	*Quadrula pustulosa*	*Quadrula pustulosa*
Purple lilliput	*Toxolasma lividus*	*Toxolasma lividum*
Liliput shell	*Toxolasma parvus*	*Toxolasma parvum*

Condition and Trend

Based on the available data, it appears that diversity, richness, and evenness of the freshwater mussel assemblage at MACA are generally stable or are increasing over contemporary surveys. However, relative to historical reference conditions mussel diversity in the park has experienced moderate declines. Several species are doing quite well in the park including the common mucket, washboard and threeridge. Furthermore, the federally endangered spectaclecase, fanshell, snuffbox, pink mucket, ring pink, rough pigtoe, catspaw, and sheepnose mussels are present in the Green River within the park (Compton et al. 2017; Leroy Koch, Senior Biologist, USFWS, December 2017, personal communication; Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, December 2017, personal communication). The presence of numerous state and federally listed taxa suggest that MACA hosts a diverse assemblage and suitable habitat to support some of North America's most imperiled fauna. Although recent releases and mussel stocking efforts have increased the number of species that are now present relative to the past several decades, the rich mussel diversity documented for the Green River remains threatened. Several species reported from the earliest accounts of mussel fauna in the park are no longer present at MACA (e.g., the scaleshell, cracking pearly mussel, and possibly the northern riffleshell). Several species are experiencing declines in general numbers such that mussels once common are now rare or endangered (e.g., northern riffleshell, snuffbox, rough pigtoe, clubshell, pink mucket).

Reference values are somewhat lacking as records for the condition of the freshwater mussels in the segment of the Green River that flows through MACA are not available prior to the impoundment of the lower reaches by Lock and Dam #6. However, surveys conducted in recent decades can be compared to earlier surveys from the 1930s–1980s to evaluate recent changes under the historically impounded conditions for the Green River. A review of the aquatic ecological assets of the Green River and associated impacts of Lock and Dam #6 was published as part of a coordination act

between USACE and USFWS reported on the status of bivalves in the park relative to historical conditions to evaluate the ecological impacts of Lock and Dam #6 (Widlak 1999). The major conclusions were (1) construction of the navigation system on the Green River has reduced the quantity and quality of freshwater mussel habitat, (2) the Green River may be the only place where the ring pink, orange-footed pearly (*Plethobasus cooperianus*), and purple catspaw (*Epioblasma obliquata*) mussels continue to reproduce, and (3) restoring free flow conditions would enable recolonization of fish species that serve as hosts for and aid in dispersal of larval mussels, a critical service to mussel populations. Andrews and Koch (2014) expanded this to conclude (4) that favorable habitat for remaining population of the original mussel fauna generally exists in the vicinity immediately below the locks and dams and upstream from Lock and Dam #6. With the removal of Lock and Dam #6 conditions are expected to improve.

The single greatest threat posed to mussel fauna of the Green River in MACA was associated with the impoundment of the Green River and the alteration of natural flow regime in the park by Lock and Dam #6. Other significant threats to the mussel assemblage within the Green River are alterations to aquatic habitat by human land use practices and activities contributing to water quality declines (Cicerello and Hannan 1990). Many existing populations are small or isolated to the extent that discrete events carry the potential to completely eradicate standing populations. The impacts of widespread habitat loss, fragmentation, degradation, invasive species, and over harvesting have rendered Unionids among the most highly imperiled of fauna (Strayer et al. 2004, Haag and Williams 2014). Streams must be healthy enough (i.e., have suitable water quality) to support host fish species (Williams et al. 1993). Beyond that, mussel survival is closely linked to a number of biotic and abiotic factors affecting habitat across spatial and temporal scales (Vaughn and Taylor 2000, Strayer et al. 2004). The effects of dams and substrate alteration have been acknowledged as detrimental to mussel habitat for numerous reasons (e.g., USACE/TNC 2011b). Dams interrupt the natural flow regime of river systems, causing rivers to deviate from a riffle-run-pool system and instead exhibit long stretches of deep pools as a result of impoundment. This impoundment alters substrate composition allowing fine grained sediments to form thick deposits on the riverbed within impounded areas. Freshwater mussels have a preference for heterogeneous riverbed substrate, and the more homogenous environments fostered in impounded river segments present conditions that are not favorable to many mussel species. Processes contributing to increased sediment loading such as human land use practices, erosion, and flow impoundment were found to disrupt preferential mussel habitat (Williams et al. 1993). Furthermore, water in impounded regions tends to be warmer which can negatively impact spawning mussels directly and also influence the presence of the host fish that larval glochidia parasitize. More broadly, dams have been found to disrupt reproductive cycles by preventing movement of host fish. The removal of Lock and Dam #6 represents a promising potential for gradual restoration of the natural flow regime of the Green River within the park and may have positive outcomes with respect to the diversity and distribution of mussels in MACA (Table 4.66).

Level of Confidence and Data Gaps

The level of confidence regarding the condition of the freshwater mussels in the park is high. Multiple accounts of the mussel assemblage at MACA exist providing a thorough historical context.

Initial records date back to the 1920s (Ortmann 1926) and the most recent inventory of bivalves in and around the park was made in 2017 (Compton et al. 2017). However, a lack of sufficient reference conditions prior to impoundment of the Green and Nolin rivers is a data gap that presents a challenge. There has been much study into the impact of dams on mussel distribution and abundance, but actual field survey data for these measures for mussels in the park prior to impoundment of the Green River are absent.

Condition Summary

Table 4.66. Graphical summary of status and trends for mussels among the surface aquatic communities, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Surface aquatic communities	Freshwater Mussels		The condition of freshwater mussels in MACA warrants moderate concern. Overall freshwater mussels in North America are experiencing significant declines and are considered highly imperiled (Williams et al.1993, Master et al.1998, Haag and Williams 2014). Compared to historical accounts, the number of species present in MACA has declined over time (79 historically compared to just 27 in the Compton et al. 2017 survey). In addition to declines in species richness, the composition of the mussel assemblage is not evenly distributed among species. A small handful of mussel species represent a significant proportion of total diversity, suggesting that measures of evenness could be improved (Cicerello and Rudd 1998, McGregor et al. 2015, Compton et al. 2017). However, among contemporary surveys mussel are remaining fairly stable and even increasing in some cases thanks to reintroduction programs through KDFWR. Mussel distribution was shown to favor habitats that offered more free-flowing conditions (Cicerello and Hannan1990, Cochran 1993, Miller et al. 1994, Cicerello and Rudd 1998, Layzer 2002, USACE 2004, McGregor et al. 2015, Compton et al. 2017). At present faunal distribution in the Green River reflects the historical impounded conditions as Lock and Dam #6 removal was only recently completed in 2017. A positive finding is that two endangered mussel species (fanshell and sheepnose) were encountered among formerly pooled regions on the Green River that have been restored to flowing conditions following the removal of Lock and Dam #6 (Compton et al. 2017). Several species once commonly known to MACA are now rare or extirpated from the park suggesting these organisms may be highly sensitive to habitat degradation such as changes in composition of channel substrate and water temperature associated with impoundment of the Green River or other issues related to deterioration of water quality. However, due to the relatively stable taxa diversity in recent decades, presence of endangered mussel species in formerly pooled regions that have been restored to flowing conditions, and efforts to augment imperiled populations such as the ring pink mucket (Shepard et al. 2012),catspaw (Leroy Koch, Senior Biologist, USFWS, December 2017, personal communication), pink mucket, snuffbox (Monte McGregor, Aquatic Scientist/Malacologist, KDFWR, October 2018, personal communication) the status of freshwater mussels in the park is deemed to be improving. The level confidence in this assessment is high as sources of data are multiple, recent, and show similar patterns. With the removal of Lock and Dam #6 conditions are expected to improve.

Sources of Expertise

Leroy Koch (Senior Biologist, USFWS), Monte McGregor (Aquatic Biologist/Malacologist, KDFWR), Rick Toomey (Cave Resource Management Specialist and Resource Coordinator, MACA Division of S&RM) and Rick Olson (Park Ecologist, MACA Division of S&RM), provided expertise for this section.

4.13 Cave Communities

With over 650 km of cave passage (Gulden 2020), Mammoth Cave is home to a diverse assemblage of both aquatic and terrestrial obligate, cave-dwelling organisms, facultative subterranean species, and species that reside in the cave for part of their life cycle and/or use the cave for refuge (Soto and Pate 2016). Due to the variety of habitat and species that can use both surface and subsurface environments, MACA (MACA) and the greater south-central Kentucky karst area hosts one of the most biodiverse cave communities in the world (Culver et al. 2000). Of the approximately 160 recorded cave species, 52 are obligate cave dwellers and 19 are endemic to the Mammoth Cave area (Toomey et al. 2017, Rick Toomey, Cave Resource Specialist and Research Coordinator, MACA Division of S&RM, October 2018, personal communication) One of the cave obligate species is the Kentucky cave shrimp which is federally-listed as endangered (Federal Register, 1983). The Kentucky cave shrimp, cave microorganisms, the Allegheny woodrat, and cave crickets have been identified as indicators for assessing cave communities; specific measures are addressed for each indicator in their respective sections.

Cave communities as a whole appear to warrant moderate concern for several reasons: 1) The Kentucky cave shrimp is an endangered species with restricted distribution and several potential threats and stressors; 2) cave micro-organisms while critical to the cave ecosystem in nutrient cycling and as a food source, have the potential to negatively affect native cave biota creating moderate concern in relation to *Pseudogymnoascus destructans* (formerly *Geomyces destructans*) that can infect and cause death in bats, keystone species of the cave community; 3) the woodrat is critical to the cave community and its decline or loss could be detrimental to other members of the cave ecosystem; 4) though cricket populations appear to be stable to increasing, as a keystone species to the cave community, the cave cricket should remain a species of concern for resource managers. There is a lack of current (< 5 years) population data for the Kentucky cave shrimp and Allegheny woodrat. Though there has been extensive research conducted pertaining to the cave community at MACA and the specific indicators listed here, lack of current or long-term data across indicators makes assessment of trend unfeasible at this time. However, the confidence level in this assessment is considered moderate based on the findings reported in detail herein. The indicator for this section is the Kentucky cave shrimp.

4.13.1. Kentucky Cave Shrimp

Description

The Kentucky cave shrimp is a small, stygobitic crustacean endemic to the Mammoth Cave System (Soto and Pate 2016). Kentucky cave shrimp occurs only in specific habitats preferring pools and slow moving streams in base-level passages, abundant organic matter, and coarse to fine grain sand and silt sediments (USFWS 2010). These pools may be preferred as they are seasonally replenished with organic matter from flooding and afford protection from predation as they are isolated from large cave streams (Lisowski 1983). Aquarium tests show that the Kentucky cave shrimp is a non-selective grazer, though surface feeding has been observed in situ by Lisowski (1983), with slow growth rates and life spans ranging from 10–15 years (USFWS 1988). It is a federally-listed endangered species with about 3.9 kilometers of cave stream in the Echo River basin designated as Critical Habitat (Federal Register 1983, Leitheuser et al. 1985, USFWS 2010, Rickard Toomey, Cave

Resource Management Specialist and Research Coordinator, MACA S&RM, October 2018, personal communication). It is also listed as endangered by the state.

The Kentucky cave shrimp is a highly specialized organism reliant upon specific habitat conditions and hydrologic regime and like other sensitive aquatic macro- and micro-fauna, can be used to monitor water quality and/or habitat conditions, making it an important indicator of overall system health (Leitheuser et al. 1985). As karst systems are highly vulnerable to contamination from land use changes, spills, and run-off from agricultural, urban, and industrial areas due to rapid infiltration of surface water to the subsurface, the presence and distribution of the Kentucky cave shrimp can provide some measure of water quality and habitat degradation, as well as indirect assessment of the meiofauna and microorganisms that make up its food base.

Continued monitoring and assessment of this resource indicator is also important as perceived low population densities and limited distribution make the Kentucky cave shrimp vulnerable to extinction. This is of particular concern since many of the threats to water quality and habitat (agriculture, oil/gas extraction, quarry operations, Green River lock/dam management) and therefore the Kentucky cave shrimp, are beyond park boundaries but within the groundwater basins in which these shrimp are located (NPS 2014). Karst groundwater basins do not match surface watersheds based on topography and much of the recharge area for the cave streams in Mammoth Cave extends beyond the management and protection of MACA (Quinlan and Ray 1989, Soto and Pate 2016, White and White 2017).

Data and Methods

Literature that describes taxonimic classification, shrimp habitat requirements, life history, biology, as well as the most current population density estimates and distribution of the Kentucky cave shrimp, have been summarized in the USFWS species recovery plan (1988) and the USFWS 5-year review of the Kentucky cave shrimp (2010). USFWS (1988) was reviewed by 20 other government and civilian researchers. The USFWS 5-year review (2010) was authored by Dr. Michael A. Floyd, Kentucky Ecological Services Field Office, and peer-reviewed by Dr. Julian Lewis, Lewis and Associates, LLC, Mr. Rick Olson, MACA, and Mr. Ryan Evans, Kentucky State Nature Preserves Commission. As the USFWS 5-year review (2010) synthesizes all previous work and is the most recent peer-reviewd source, this assessment relied heavily on the information provided there and the expertise of those reviewers. Additional data sources are directly cited throughout the assessment and listed in the Literature Cited section of this report. Maps and summary statistics of population and distribution data were used to describe and qualitatively assess condition. Existence or likelihood of potential threats is also evaluated as to status, trend, and level of concern for the Kentucky cave shrimp.

Reference Conditions/Values

Known distribution of the Kentucky cave shrimp includes ten groundwater basins, covering roughly 262 square kilometers, with significant portions of these basins extending beyond the designated Critical Habitat and the MACA boundary (Figure 4.109). Protection of four of these basins, Ganter, Running Branch, Echo River, and River Styx, has been largely achieved as they lie entirely within the park, except for a small area on the southeastern boundary of the Echo River basin. There is flow

between Echo River and River Styx during certain hydrologic conditions but they are considered separate here for the purposes of identifying the full extent of cave shrimp habitat. Portions of Double Sink, Turnhole, Pike, and Mile 205.7 basins are also within MACA and therefore have some protection. However, Echo River and Double Sink do experience overflow from Turnhole Basin, and thus are sometimes exposed to risks from that basin (Meiman 2006). Suds and McCoy Blue Hole basins are entirely outside of the park boundary. Cave shrimp do occur in Lee Cave, which extends into both the Sand Cave and Turnhole Basins. However, Sand Cave Basin is omitted here as the Kentucky cave shrimp were found in a portion of the cave that drains to Turnhole Spring rather than Sand Cave Spring (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, October 2018, personal communication).

While research continues to better understand groundwater flow in the region and within the park, groundwater basins were identified through previous hydrologic work, primarily fluorescent dye tracing. Detailed descriptions of the hydrology of Mammoth Cave are available in Palmer (1981), Quinlan and Ray (1989), and White and White (2017). These basins as identified are still at risk from outside threats (agriculture, oil/gas extraction, limestone quarry operations, and on-site septic systems) as much of the groundwater recharge area lies outside of park protection (Olson 2017c).

Estimated population density of the Kentucky cave shrimp varies between survey locations with estimates ranging from 0.0006–0.262 shrimp per square meter for sites surveyed by Pearson and Jones (1998). Observations of total number of individuals observed in 1993–1995, with increasing observations attributed to improved survey methods, are presented in Table 4.67. Previous density estimates provided by USFWS (1988) ranged from 0.006 shrimp per meter to 0.66 shrimp per meter based on total shrimp detected during field surveys multiplied by the linear meters of survey and/or estimated available habitat preferred by this species. Distance of available habitat is based on known passage lengths within each basin and/or estimated using the potentiometric surface and overall size of each groundwater basin (Leitheuser et al. 1985). The most recent, yet provisional, population estimates for each groundwater basin are shown in Table 4.68 (USFWS 1988, USFWS 2010).

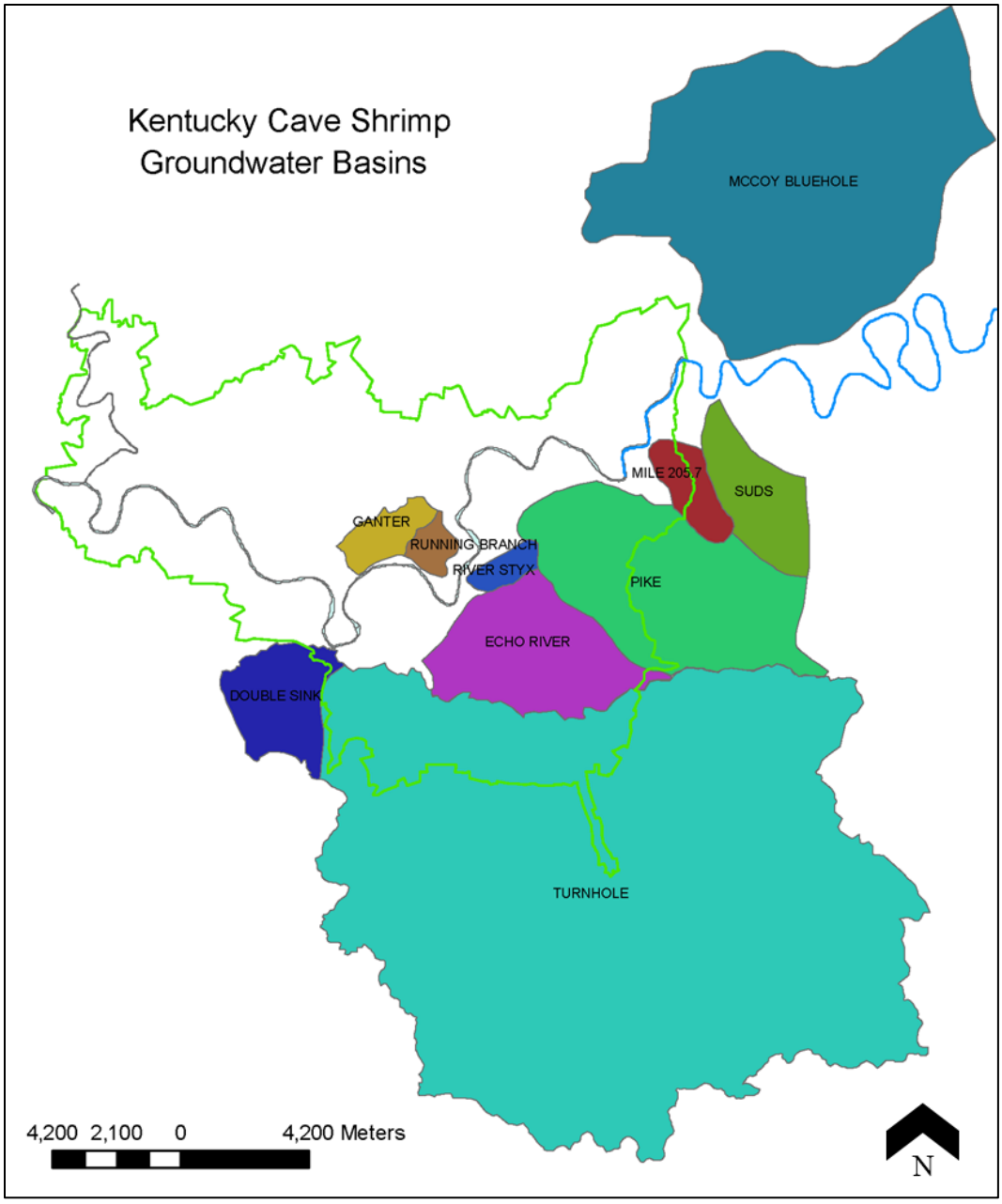


Figure 4.109. Current known range of the Kentucky Cave Shrimp. Green line represents park boundary. Modified from MACA NPS unknown author.

Table 4.67. Number of individuals observed during field surveys (Pearson and Jones 1998). Values in parentheses are population density estimates defined as number of individuals per 5,000 square meters. NS – not surveyed.

Location	1993	1994	1995
Colossal River	NS	1(4)	NS
Mystic River	8 (20)	33 (104)	233 (550)
Golden Triangle Area	NS	25 (727)	45 (1308)
Roaring River	NS	32 (12)	34 (13)
Shrimp Pools	0	0	4 (87)
Echo/Styx River	0	6 (8)	2 (3)

Table 4.68. Total population estimates per basin based on length of available preferred habitat – known and/or estimated from cave survey and potentiometric surface mapping (Leitheuser et al. 1985, USFWS 1988).

Location	Estimated population
Echo River	750
Ganter	150
Running Branch	300
Pike	5,000–10,000
Mile 205.7	50
Suds Spring	500
McCoy Bluehole	Unknown
Double Sink	Unknown
Turnhole	Unknown

In preparation for long-term monitoring of aquatic fauna, a pilot project to test methodology was initiated and included surveys for the Kentucky cave shrimp from 2001–2005 (Pearson 2009). One of the main goals was to demonstrate repeatability of techniques used by Pearson and Jones (1998), resulting in the ability to directly compare the 2001–2005 data set to the previous work in 1993–1995 (Pearson 2009). Their findings show lower abundance of individuals observed and accordingly lower estimated population densities, for Mystic River, Golden Triangle Area, and Roaring River during the 2001–2005 sampling effort. Holsinger and Leitheuser (1982a, 1982b) reported sighting an average of 140 individuals at Mystic River during multiple visits in 1981–1982 with the highest number of individuals on any one sampling date at Golden Triangle and Roaring River, 27 and 33, respectively. However, further comparison of the sampling locations in studies of Holsinger and Leitheuser (1982a, 1982b) and Pearson and Jones (1998) by Helf (Kurt Helf, Ecologist, CUPN, April 2018, personal communication) report abundance at 282 in 1981–1982 for Mystic River. The Echo River population appears stable based on comparison to previous data from both Holsinger and

Leitheuser (1982a, 1982b) and Pearson and Jones (1998), while numbers increased at the Shrimp Pools (Pearson 2009). Figure 4.110 below shows all recorded observations at MACA.

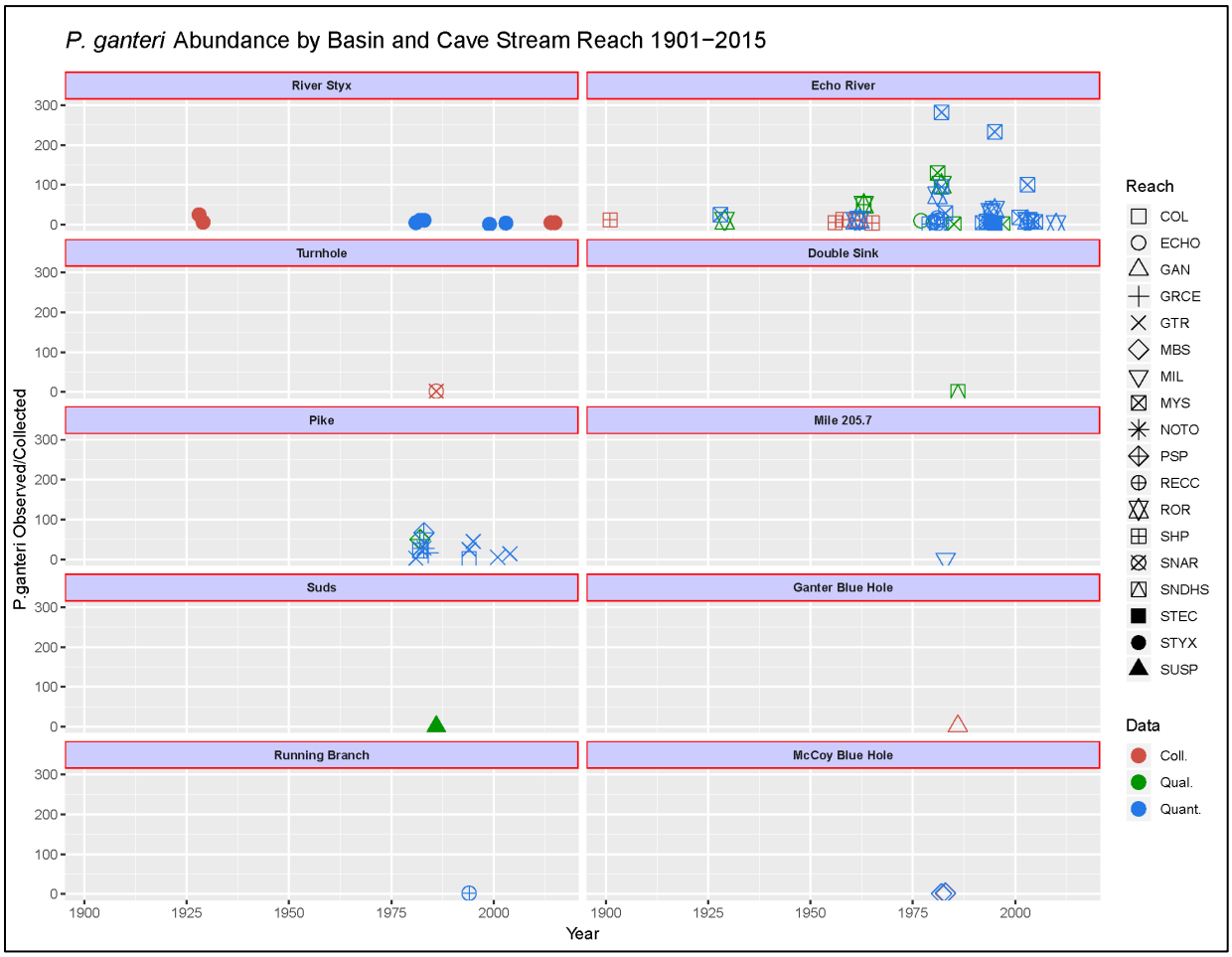


Figure 4.110. All known recorded observations (1901–2015) of *Palaemonias ganteri* in cave pools/streams/rivers in the ten basins in which they occurred as a function of the year the observations were made. All "Quant." data are observed abundances, all "Coll." data are collections of voucher specimens, for genetic analysis, or for filming purposes (released afterward), and all "Qual." data were assigned quantities to distinguish among the qualitative assessments in survey notes (e.g., "many shrimp" assigned a higher number than "shrimp noted"). Note: All data do not represent equal survey efforts of the identified cave pools, streams, or rivers. COL=Colossal River, ECHO=Echo River, GAN=Ganter Cave, GRCE=Grand Central Sump, GTR=Golden Triangle, MBS=McCoy Blue Spring, MIL=Mile 205.7 Spring, MYS=Mystic River, NOTO=Lower level stream in Northtown cave, PSP=Pike Spring, RECC=Reccius River, ROR=Roaring River, SHP=Shrimp Pools (Type Locality), SNAR=Snake River, STEC=Styx-Echo Reach, STYX=Styx River, SUSP=Suds Spring, SNDHS=Sandhouse Cave. (Kurt Helf, Ecologist, CUPN, October 2018, personal communication).

Condition and Trend

The current status of Kentucky cave shrimp populations and their distribution is basically unknown as no new data has been collected since 2005. However, MACA, in conjunction with the USFWS,

did collect tissue samples for genetic testing from four individuals captured in the Echo River basin but the results are not yet available (Mike Floyd, Wildlife Biologist, USFWS, February 2018, personal communication). Based on review of work completed more than 12 years ago, it appears that we may not fully understand population dynamics of this species even though surveys have extended its range significantly since the late 1970s. While Kentucky cave shrimp numbers remained relatively stable or increased between the surveys conducted by Leitheuser and others in the 1980s and Pearson and Jones in the early 1990s, it should be noted that survey methods, specific locations surveyed, and analytical methods did vary between researchers making this comparison tenuous and does not reflect present condition or status of this species. The most recent figures from Pearson (2009) are lower for certain survey locations and while that may present some evidence for concern, more importantly it reveals the need for additional monitoring and research of the Kentucky cave shrimp, especially with regard to population variability. Fortunately, CUPN's long-term cave aquatic biota monitoring protocol published in August 2018, provides methodology that accounts for difficulty in detection for species such as the Kentucky cave shrimp, using state of the art N-mixture and occupancy modeling (Helf et al. 2018). As planned, these efforts would provide better population estimates and address the data gaps identified in this assessment.

Cave environments are generally known to have overall low biomass due to the fact that organic material must be brought into the system through either organisms that use both surface and subsurface environments, animals that accidentally enter the cave system, or nutrient rich waters via infiltration or back-flooding of the Green River in the case of Mammoth Cave (USFWS 1988, Helf and Olson 2017). Accordingly, low population densities are expected for cave-dwelling species such as the Kentucky cave shrimp and as such stand-alone data do not create significant concern. However, without more current information trends in population or distribution cannot be assessed at this time.

Though trend assessment is limited by lack of current information on abundance and distribution, threats to water quality and habitat conditions of the Kentucky cave shrimp are known and have been summarized in the USFWS 5-year review (2010). While these threats are assumed, as preferred environmental conditions for this species are still largely unknown, aquatic macroinvertebrates are often recognized as important biological indicators, sensitive to water quality conditions and disturbances in habitat (Leitheuser et al. 1985, Helf and Olson 2017). Groundwater contamination continues to be the greatest threat to aquatic cave communities at Mammoth Cave and the Kentucky cave shrimp specifically (USFWS 2010). Sources of contamination that threaten water quality include non-point source pollution from urban run-off and agriculture, inadequate sewage treatment, traffic accidents involving toxic chemicals along Interstate 65, limestone quarry operations, and oil and gas extraction (USFWS 2010, Powell 2016, Olson 2017b). Siltation from agriculture, poor land use practices, and change of hydrologic regime by the damming of the Green River, potentially resulting in habitat degradation and/or loss, is also a concern as it may decrease the amount of available habitat for interstitial fauna, a significant portion of the food base for the Kentucky cave shrimp and the cave community in general (USFWS 2010). Due to the nature of karst landscapes and the aquifer system of Mammoth Cave region, pollutants can rapidly enter subsurface waters and

travel to downstream locations within the park where there is potential to have negative effects on water quality and therefore cave shrimp populations.

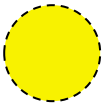
Since the most recent surveys in 2001–2005 region-wide mitigation efforts to improve water quality have occurred and have likely improved conditions for the continued existence and sustained populations of the Kentucky cave shrimp. Further, advances have been made with respect to water quality and habitat protection (Powell 2016). Sanitation services have continued to expand throughout the Mammoth Cave region decreasing on-site septic disposal systems in both rural and urban areas surrounding the park and the potential for untreated effluent to enter sensitive groundwater basins. Since 2005, development of karst hazard maps and implementation of best management practices by the Kentucky Department of Transportation are addressing siltation from road construction activities and run-off from maintenance and seasonal operations, such as deicing, to better protect groundwater resources. These policies also provide guidance for emergency response and mitigation of traffic accidents involving toxic chemicals that may enter karst groundwater supplies. Preliminary research from Albert Meier indicates that the United States Department of Agriculture (USDA) Conservation Reserve Enhancement Program (CREP), which restored over 40,000 hectares of agricultural lands to native habitat, serving as riparian and karst feature buffers, appears to have had some effect in decreasing siltation during flood events also (Albert Meier, Executive Director, Green River Preserve, November 2017, personal communication). However, the funding for the CREP program is scheduled to end in 2019 and return of these lands to crop and/or livestock production may allow increased siltation during storm events. Most recently, the removal of Lock and Dam No. 6, located on the Green River just downstream of the park, and changes in the operation of the Green River Dam are anticipated to restore a more natural and historic flow regime to base level passages, the preferred habitat of the Kentucky cave shrimp (Olson 2006). Again, due to the nature of karst groundwater systems and much of the known recharge area of basins being located outside park boundaries, these regional efforts are consequential to both aquatic and terrestrial cave communities within MACA and deserve consideration.

Level of Confidence and Data Gaps

The level of confidence in the reference condition findings is considered low as more recent data (<12 years) is unavailable at this time. While information about reference conditions is available, status and therefore, related trends cannot be assessed due to lack of current data on population and distribution. Fortunately, CUPN's long-term cave aquatic biota monitoring protocol, currently under review and scheduled to be implemented in late 2018, provides methodology that accounts for difficulty in detection for species such as the Kentucky cave shrimp, using state of the art N-mixture and occupancy modeling (Helf et al. 2018). As planned, the monitoring protocol would provide rigorous, statistically defensible population estimates for Kentucky cave shrimp in selected cave stream reaches including their critical habitat in Roaring River. The CUPN protocol methods will also address fundamental data gaps regarding their reproductive success, habitat associations, and environmental requirements all of which are critical to fully understanding their status and trends (USFWS 1988). However, data gaps also exist for primary information about reproductive success and specific environmental requirements of this species, both of which are critical to fully understanding the status and trend of cave shrimp populations at MACA (USFWS 1988)(Table 4.69).

Condition Summary

Table 4.69. Graphical summary of status and trends for the Kentucky cave shrimp, including rationale and reference condition.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Cave communities	Kentucky cave shrimp		As an endangered species with restricted distribution and several potential threats and stressors, the Kentucky cave shrimp warrants moderate concern. The 2015 USFWS 5-year review for the Kentucky cave shrimp states that recovery potential remains low, with a Recovery Priority rating of 5. The USFWS rating, 1 being the highest, 18 the lowest, is based on "degree of threat, recovery potential, taxonomic distinctiveness, and presence of an actual or imminent conflict between the species and development activities" (USFWS 2015). Reference conditions established from studies by Holsinger and Leitheuser (1982b, 1983), Leitheuser et al. (1985), and Pearson and Jones (1998) show stable population estimates between these studies. Subsequent surveys by Pearson (2009) suggest slightly lower abundance at three of the five survey locations and stable to increasing numbers at the remaining two. However, differences in methodology and lack of current data prohibits analysis of trend and provides minimal confidence in current condition assessment.

Sources of Expertise

Kurt Helf (Ecologist, CUPN), and Rick Toomey (Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM) provided expertise for this section.

4.13.2. Cave Microorganisms

Description

Microbial communities are a critical component of cave environments, not only in regard to biomass and diversity, but also the many biological and geological processes they initiate and support (Lavoie 2017). In fact, Lavoie (2017) hypothesizes that inter-terrestrial microbial biomass is greater than all biomass on the surface of the earth. These communities, based solely on size, include bacteria, algae, protozoa, and fungi. They are especially important in low nutrient, subsurface environments such as Mammoth Cave where studies have shown their role, directly and indirectly, in the food base for cave fauna primarily through chemical/nutrient cycling (Lavoie 2017). This appears to be especially important in deep cave habitats were organic matter is highly limited or unavailable (Helf and Olson 2017). Vanderwolf et al. (2013), summarizing many previous authors, hypothesizes that fungi and bacteria are the major food source for troglobitic invertebrates and protozoa. Recent studies have also

shown microbes to be instrumental in geological processes such as speleothem development, limestone dissolution, and mineral deposition (Barton and Northup 2007, Vanderwolf et al. 2013, Lavoie 2017). Communities are often highly localized and therefore sensitive to changes in atmospheric conditions, water quality, and habitat disturbance, allowing researchers to indirectly monitor environmental conditions (Lavoie 2017). Presence of certain bacteria, algae, and fungi can also be used to indicate human impact on the cave environment (Lavoie and Northup 2006). As karst systems do not function in isolation from surface activities, alterations in quality and quantity of air, nutrients, and water entering the cave can influence the cave environment and therefore the microorganisms living there. As such, understanding regional hydrology and karst drainage basins is key to protecting and managing the microbial communities in Mammoth Cave.

Data and Methods

Data on species richness, community composition, and distribution of cave micro-organisms was pooled from various sources as cited throughout this section. However, this assessment relied heavily on research by Kathleen Lavoie and her co-authors (1982, 2006, 2015, 2017) as well as information provided by the Science and Resource Management Division at MACA. As research of the microbial community at Mammoth Cave has been limited in scope and extent, species richness (number of species) is reported for each sub-group of microorganisms and distribution of each group is assumed to occur throughout the system where preferred microhabitats and food sources exist. Community composition is only evaluated in regard to community structure and function for bacteria.

Reference Conditions/Values

As this is a large and diverse group, the subcategories of bacteria, algae and cyanobacteria, protozoa, and fungi are discussed independently in regard to reference condition and role in the greater cave community.

Bacteria

Bacteria are considered ubiquitous as they occur in all habitats, including both aquatic and terrestrial subsurface environments found in caves (Saiz-Jimenez 2012, Lavoie 2015). Until more recently, this group has received minor attention from speleologists as the primary ecological role of bacteria is the decomposition of organic matter, which would appear to be minimally available in cave settings where there is no light and low nutrient input (Lavoie 2015). However, research has found that a diverse bacterial community, capable of utilizing a wide range of environmental conditions, does exist at MACA and currently at least 27 species of bacteria have been identified (Flierman and Schmidt 1977; Feldhake 1986; Rusterholtz and Mallory 1994; Elliot et al. 2000; Frisch et al. 2003; Lavoie 2015, 2017). These organisms are an important part of the food web in nutrient cycling and the microbial biomass they produce for secondary consumers (Lavoie 2015, Helf and Olson 2017).

Community food web structure and the rich biodiversity at MACA has been attributed to the abundance of particulate organic matter (POM) from the surface that enters via water, animals, and humans and “feeds” cave- dwelling organisms. Research by Compson (2004) on carbon and nitrogen isotopes of stygobiont (obligate, permanent residents of subsurface aquatic habitats) tissues, however, indicates that bacteria are the primary food source as carbon isotopes were enriched compared to detritus. This concept of bacteria as an ultimate food source (Figure 4.111) is important

as disruption of these important communities has the potential to affect subsurface aquatic organisms. The diversity of bacterial taxa and the energy sources they can utilize, especially in deep cave habitats, is likely the main driver of biodiversity within the cave community at MACA (Helf and Olson 2017).

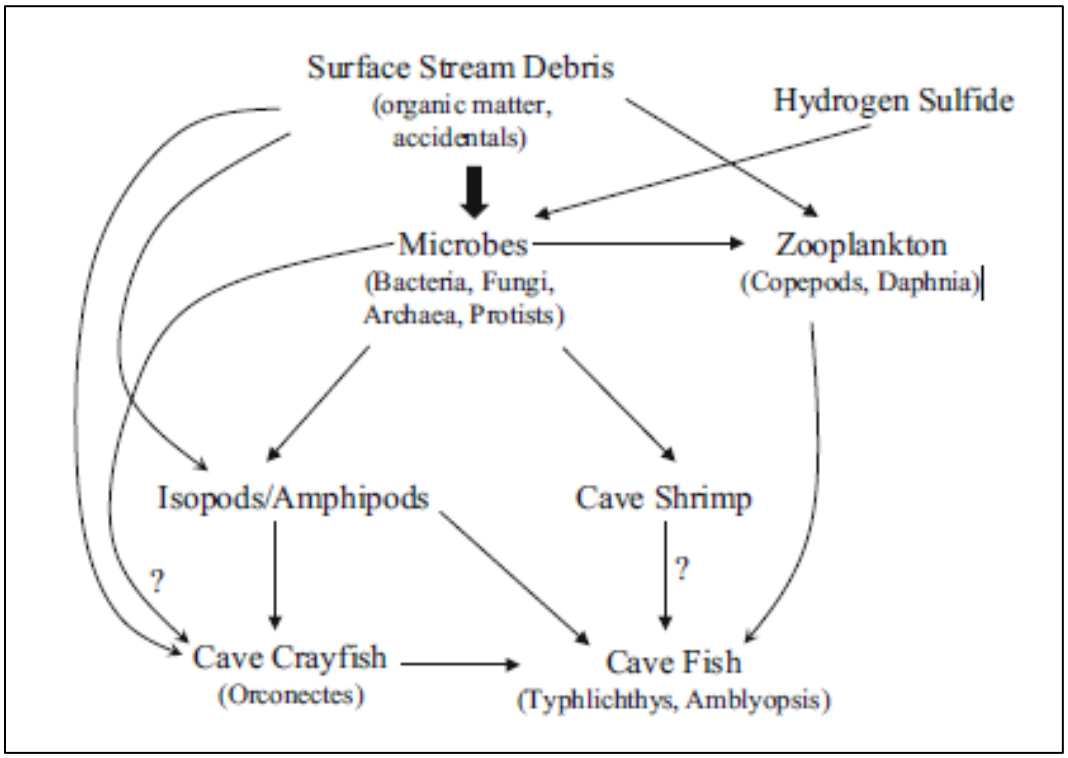


Figure 4.111. Hypothesized food web for aquatic cave habitats. Modified from Barr and Kuehne (1971) by Helf and Olson (2017).

It has largely been assumed that metabolic activity and biomass of bacteria in the cave environment is low compared to overlying soils and initial studies at MACA by Feldhake (1986) supported this hypothesis. However, Rusterholtz and Mallory (1994) showed that 53–58% of the bacteria present in aquatic sediments were metabolically active and represented a diverse group similar to surface microbes, with 42% unidentified and no dominant species. More recently, Byl et al. (2013) found distinct microbial community patterns associated with the level of cave passage. Looking at microbial organic chemical utilization from water samples collected at different levels in the River Styx drainage basin, Byl observed higher activity in upper level passages, similar to surface streams and decreased activity and slower adaptation to chemicals tested in communities in lower levels of the cave. This supports that microbial communities in caves are affected by surface input, with increased metabolic activity in passages closest to the surface and suggests that these communities may vary with season and rainfall. Understanding community structure and preferred environmental parameters of microbes has the potential to indicate water quality conditions.

With advances in technology, genomic and molecular techniques are expanding our knowledge base of bacterial communities at MACA. Studies by Fowler et al. (2001, 2009) extracted DNA directly

from cave sediments and biofilms collected from cave streams and pools and used 16S rRNA gene sequencing of clones to identify bacteria species. Genetic matching in both studies found that the dominant species are Proteobacteria, a large group of common soil species, however novel strains were identified. In the 2009 study, samples were collected from two locations at MACA; Owl Cave (OC) which has increased organic input from agricultural activities in drainage basins that extend beyond the park boundary, and Eyeless Fish Trail (EFT) considered to be a pristine stream with low nutrient loading (Helf and Olson 2017). Total DNA collected from each location differed greatly with 3463 nanogram/gram (ng/g) from OC but only 476 ng/g from EFT, with 34 and 38 clones respectively. Proteobacteria dominated at both sites representing 58% of the population at OC and 79% at EFT. Phlya and Proteobacteria class distribution at OC resembles that of known soil populations and the OC exhibits greater species diversity than EFT (Figure 4.112). These findings support the lower nutrient, low impact setting of EFT compared to OC with higher surface input.

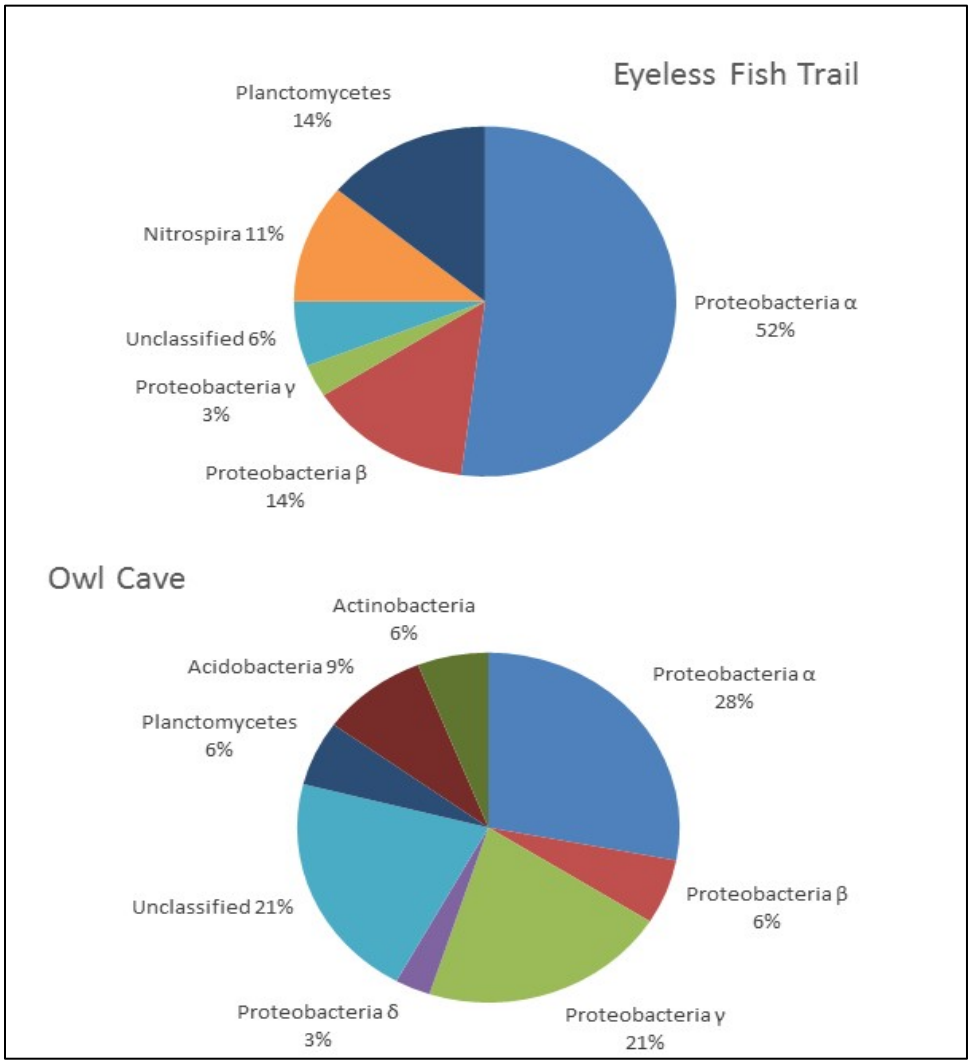


Figure 4.112. Community composition: Bacterial phyla and class distribution at Eyeless Fish Trail and Owl Cave. Modified from Fowler (2009) in Lavoie (2017).

Not only is the difference in community composition between the sampling sites of particular interest but also the nature and function of each bacterial group as this can indicate possible environmental processes and conditions (Pronk et al. 2009, Barton 2015). *Nitrospira,* a nitrogen fixer and important to maintaining low ammonia and nitrite levels in aquatic habitats*,* was only found at EFT, and *Planctomycetes*, a rather unusual group of bacteria which also includes nitrogen oxidizers, were twice as prevalent at EFT compared to OC (Fowler et al. 2009, Lavoie 2017). The presence of these groups may indicate, as suggested by Fowler and others (2009), a more pristine, oligotrophic environment (Barton 2015, Lavoie 2017). Key bacterial taxonomic groups can also indicate environmental impact from anthropogenic sources as demonstrated by Hermans et al. (2017) in agricultural soils and indicated in the comparison of high and low nutrient (considered an indicator of contamination) locations in Fowler's study. There is some evidence that associates *Gammaproteobacteria*, more abundant at OC*,* and *Deltaproteobacteria* and *Acidiobacteria*, only found at OC, with hydrocarbon and other organic contamination (Paisse et al. 2008, Niepceron et al. 2013, Barton 2015) According to several researchers (Fredrickson 1991, Barton 2006, Byl et al. 2012) microbes can metabolize a variety of organic contaminants and microbial community diversity may be important to the amelioration of groundwater conditions. It should be noted that while assumptions at the Phyla level may be useful, bacterial community structure and dynamics is likely to be much more complex and their use as bio-indicators, while promising, is not well understood and deserves additional research (Pronk et al. 2009, Barton 2015).

In addition to their ecological role in the cave environment, microbes can also influence geological processes through the chemical reactions they initiate and sustain, on a local to landscape scale (Northup and Lavoie 2001, Lavoie 2017). Through inorganic nutrient cycling, microbes and particularly bacteria, can participate in mineral deposition, speleothem formation, and speleogenesis through enhanced calcite dissolution (Northup and Lavoie 2001, Barton and Northup 2007, Palmer 2007, Lavoie 2017). While there is no research indicating microbial contributions to speleothem formation at MACA, Elliot et al. (2000) collected data at Charon's Cascade that implies that acid-producing bacteria influence limestone dissolution and therefore cave and aquifer development at MACA.

Other studies of the geomicrobiology of MACA include both nitrogen- and sulfur-based systems. One of the earliest microbial studies was conducted by Fliermans and Schmidt (1977), suggesting that population densities of *Nitrobacter* in Mammoth Cave soils are high enough to potentially be responsible for the nitrate soil enrichment that supported historic saltpeter production. However, additional research by Olson and Krapac (2001) implicates guano over other processes. As for sulfur-based studies, Thompson and Olson (1988) identified sulfur-oxidizing bacteria, which use chemosynthesis to produce organic carbon, in Sulfur River within Parker Cave, located in the sinkhole plain southwest of the park. Hydrogen sulfide rich waters exist at a depth of approximately 150 meters throughout the Mammoth Cave region and under sufficient artesian pressure can rise and impact hydrologic conditions. Angert and others (1998) conducted genomic testing of organisms from Sulfur River and found these bacteria to be most closely related to organisms found at deep sea hydrothermal vents and other sulfur-rich environments. Though Parker Cave is located outside of the

park boundary, the nutrient-rich waters of Sulfur River drain into the park and provide biomass to subsurface communities that would otherwise not be available (Helf and Olson 2017).

Aside from the sulfurous brines found in Parker Cave, natural sulfur inputs appear to be uncommon at MACA. To date only one other occurrence of naturally sulfur-enriched waters, though low in comparison to Sulfur River, has been located in Mammoth Cave at Marianne's Pass, where minor seeps feed thick microbial mats which support a thriving community of invertebrates including springtails, crickets, and beetles (Olson 2013, Lavoie 2017). Considering the extensive network of passages, there is potential that other seeps such as these exist and support additional chemotrophic bacterial communities (Olson 2013). Hydrocarbon deposits in the region may also provide an energy source for these organisms and as discussed previously in this section, bacterial community composition can reflect this impact. Further investigation using new technologies is needed to better understand how microbes are influencing biological and geological processes and vice versa at MACA.

Algae and Cyanobacteria

Algae and cyanobacteria are phototrophic microorganisms that most often appear in natural cave environments at sunlit entrances and are considered an accidental member of most cave ecosystems as they are typically transported into caves by water or inadvertently by animals and humans. A major exception to this is artificially illuminated show caves where lighting systems provide sufficient energy to support microbial communities. Introducing light into the cave environment can have major impacts on the native biota in altered temperature and relative humidity by the lights and the visitors who frequent those locations, displacement and/or competition of cave-adapted organisms, and degradation of speleothems and other substrates as well as being aesthetically displeasing (Smith and Olson 2007, Mulec and Kosi 2009, Saiz-Jimenez 2012, Falasco et al. 2014, Lavoie 2017.) Organisms that grow within the cave in response to this artificial light are referred to as lamp flora and pose a challenge to show cave managers across the globe (Lavoie 2017). Typically, harsh chemicals such as bleach have been used to remove lamp flora but this can have negative consequences for native biota, can be detrimental or unfeasible to use on sensitive cave formations, and has been found to be ineffective on some cyanobacteria species (Mulec and Kosi 2009).

Mammoth Cave has long been a tourist destination. The use of electric lighting on many of the main tourist routes creates conditions for lamp flora to exist in the dark zone of the cave in several areas. Studies prior to 2007, identified 73 species of algae and cyanobacteria within Mammoth Cave (NPS 2018f, 2018i). Subsequent research by Smith and Olson (2007) found similar community structure to previous findings with cyanobacteria dominating the affected areas, followed then by green algae and diatoms. However, there was very little overlap otherwise, as only four of the species identified had previously been recorded at MACA. The discovery of 25 species that had not previously been identified at Mammoth Cave in a single study (Smith and Olson 2007) indicates the potential for additional species and/or algal communities to exist. It should be noted however, that any algal community found beyond the naturally lit areas of the cave (i.e., near entrance) is considered problematic and indicates an altered cave ecology. As these communities develop more diversity and extent, they may represent an increasing threat to native cave communities (Rick Toomey, Cave

Resource Management Specialist and Research Coordinator, MACA Division of S&RM, September 2018, personal communication). As Smith and Olson (2007) aptly point out, understanding population structure and species biology is necessary in order to implement best management practices in the control of lamp flora. Currently, 102 species of algae and cyanobacteria have been identified within Mammoth Cave (NPS 2018f, 2018i).

In 2005, narrow spectrum yellow light emitting diodes (LED, 595 λ) were installed in the Frozen Niagara section to control or eliminate lamp flora growth (Smith and Olson 2007). Formations in this section of the cave exhibited "a healthy lamp flora colony" prior to installation and upon subsequent sampling less lamp flora growth was observed on the LED lighted formations. Similar results are cited by both Mulec and Kosi (2009) and Saiz-Jimenez (2012) in independent reviews showing that changing the intensity, duration, or wavelength of cave lighting can reduce and/or inhibit lamp flora presence and growth. Lavoie (2017) citing Smith and Olson (2007) reports that no cave fauna was found in the Frozen Niagara section when white lights were being used but the switch to LED lighting made the area suitable and has subsequently been re-inhabited. Lighting was also modified in 2007 in Mammoth Dome and New Entrance Domes down to Grand Central Station and more recently in 2017, at Lower Historic, Snowball Room through Boone Avenue, and Houchins Narrows (Toomey et al. 2009, Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, May 2018, personal communication); however, using a different light source than placed in Frozen Niagara as described by Smith and Olson (2007). Though no formal pre/post lighting modification surveys were conducted, visual surveys by NPS staff indicate slower growth in the New Entrance and Mammoth Dome areas (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, May 2018, personal communication). As such, exploring lighting options appears to be a better approach to preventing lamp flora growth compared to more invasive techniques involving chemicals or mechanical removal. Management of lamp flora in lighted passages of Mammoth Cave is important not only to the visitor experience but the preservation of natural conditions and native communities in these areas of the cave.

Protozoa

Protozoans are motile, unicellular, heterotrophic microorganisms and play an important role in the subsurface aquatic environment at Mammoth Cave as consumers of bacteria and a food source for higher consumers such as the blind cave fish and the endangered Kentucky cave shrimp (USFWS 2010, Lavoie 2015). Sigala-Regalado et al. (2011) points out that protozoa can tolerate a wide range of environmental conditions and do not appear to be randomly distributed but occur in preferred microhabitats, which for most species is the aquatic environment. However, Lavoie (2015) reports on other studies that numbers may be high in other wet to moist environments like soil and guano. There is currently a lack of evidence to indicate that any protozoan is truly troglobitic but according to Gittleson and Hoover (1970) there do appear to be particular genera associated with cave waters. They found in their synthesis of worldwide studies, that 77% of cave protozoa belong to only 57 genera. Surveys of the Mammoth Cave System suggest a similar relationship with 82% of identified protozoa in only eight main orders that closely parallel surface protozoan communities (Thompson and Olson 1988).

This parallel of surface to subsurface communities is due to the method of introduction of protozoa, as they are most often transported into the cave environment via surface waters by infiltration, direct seepage, or back-flooding, though when in a cyst life stage may be transported into the subsurface by animals, humans, and/or air currents (Sigala-Regaldo et al. 2011). Lavoie (2017) found diversity to be highest where surface water directly enters the cave. Barr (1967) hypothesized that protozoa, along with other microbes, may also be found in drip waters and in thin films of wet cave walls. However, Lavoie (2015) cites unpublished data by Shelia Seale that show protozoa in all pools and streams sampled in Mammoth Cave but none in drip water samples. This would indicate that direct transport is the most likely method of introduction and implies, as with most cave biota, that surface water quality and climatic events have the potential to impact protozoa populations and community composition. In fact, Poulson and White (1969) speculate that it is possible to trace polluted waters by observing the structure of protozoan communities, therefore making them potential biological indicators of water quality, an ever-present issue in karst systems and of concern at Mammoth Cave as drainage basins extend beyond the protection of park boundaries.

Jones (1965) and Gittleson and Hoover (1970) identified 40 species of protozoa at MACA. Their survey locations were primarily limited to along the historical tour routes of the cave (NPS 2018f, 2018i).

Fungi

Fungi are essential decomposers, mutualists for other cave species, recyclers of organic matter, and vectors for pathogens in cave environments (Shapiro and Pringle 2010). They also provide a food source for cave invertebrates and can supply inorganic nutrients through solubilizing lithic substrates (Benoit et al. 2004). Due to their relative high energy demands, their presence and distribution are limited to areas with nutrient contribution from the surface either through direct surface water inputs, back-flooding, air currents, animals such as woodrats, bats, and cave crickets, as well as humans (Dickson and Kirk 1976, Lavoie and Northup 2006). The greatest diversity of fungi is typically found at entrances where they are introduced into the system and have sufficient organic matter on which to grow (Shapiro and Pringle 2010). While many fungal species appear to be opportunistic, other species are associated with specific substrates and organisms such as crickets and beetles (Shapiro and Pringle 2010). According to Lavoie (2017) no unique cave fungi have yet been identified. Previous studies conducted by Vanderwolf et al. (2013) found fungi to be identical to surface forms but hypothesized that some species, adapted to low nutrient availability and stable, low temperature environments, may be troglobitic.

Studies of fungal communities at MACA have been limited. Lavoie (1982) looked at successional decomposition of dung in the cave environment as well as the competition between bacteria, fungus, and invertebrates for this resource. As expected, there was increased diversity and abundance of fungi where food is readily available, most often cave entrances. Later, Lavoie and Northup (2006) compared low and high impact sites within the park in regard to human activity (entrances to tourist caves, along tourist trails), and found that fungi presence was higher in areas associated with water input but the difference in low and high impact sites was not statistically significant. Shapiro and Pringle (2010) also compared fungal communities in regard to disturbance in nearby Dogwood Cave

and Diamond Caverns, both hydrologically connected to the Mammoth Cave System, finding that sites with no or very little human disturbance have none to very few fungi and that species richness increased with minimal to moderate disturbance. High disturbance areas had the lowest species richness. Northup et al. (2000) made a similar conclusion during her studies in caves in New Mexico, that human visitation can change organic inputs causing reduced biodiversity and sometimes eliminating native species. However, additional research is needed to assess this resource and its use as a biological indicator for ecosystem health at MACA.

Of most recent concern and maybe the best-known fungus present at MACA is *Pseudogymnoascus destructans (Pd)* (formerly *Geomyces destructans*) that causes WNS in bats (Toomey et al. 2013, Lavoie 2017). This species was introduced from Eurasia where scientists assume bats co-evolved with the fungus developing a resistance; however, it is considered an invasive species in North America where numerous bat species are not resistant. The fungus infects and then irritates the skin, ultimately waking the bats from hibernation early when food is not available, causing death by starvation of most bats infected with the fungus. *P. destructans* was first identified in Kentucky in 2011 and its presence verified at MACA in 2013 in Long Cave, MACA's largest bat hibernaculum (Toomey et al. 2013) and other *Myotis* hibernacula. The continued spread of *Pd* is expected as the fungus can be transported via bat to bat contact or through the introduction of spores from animals and/or humans entering caves. Efforts made by MACA to decrease introduction and spread of the fungus are reported by Toomey et al. (2013). WNS has caused significant population loss to four species of bats at the park; see section on bats for details. Presence and distribution of this fungus could indicate threats to segments of the bat population at Mammoth Cave as well as other members of the cave community that may depend on guano as a food source (Thomas and Toomey 2017).

Also noteworthy is the parasitic fungus *Beauveria amorpha*, referred to as the "marshmallow fungus" as it produces enzymes that allow its hyphae to penetrate into the body of an insect and fill the body cavity, when environmental conditions are optimal, the fungus then grows out of the softer tissues and covers the exterior of the insect with a white coating. Benoit et al. (2004) suggests that parasitic fungi "may have the potential to impact cave ecosystems by reducing cave cricket populations." This potential threat is especially important to consider as cave crickets are a keystone species at Mammoth Cave due to the subsurface communities they support in their transfer of organic material (food base) into the cave system (Poulson et al. 1995b, Helf 2003). However, this species is native to Mammoth Cave and is not considered a significant threat, since its occurrence appears to be stable and does not seem to impact cricket populations.

Currently, at least 26 species of fungus are known to occur within Mammoth Cave. However, Lavoie (1982) also observed seven species of *Dueteromycetes* and one *Plectomycetes*, though these cannot be compared to the current list as genus or species names were not provided. Sampled communities within the cave appear to be dominated by Ascomycota, followed closely by Basidiomycota (NPS 2018f, 2018i). These two groups make up the majority of identified fungi and are found in terrestrial cave environments across the globe Vanderwolf et al. (2013).

Condition and Trend

In general, it is assumed that cave microorganisms are stable in regard to presence and distribution at MACA since a variety of environmental conditions do exist that appear to support a diverse microbial community. However, current conditions are largely unknown with the exception of select lamp flora communities and *P. destrucans.* Trend in distribution for *P. destrucans* is commented on here but is also indirectly evaluated in section 4.9 of this report as the cause for WNS in certain bat species.

As stated previously, stressors to cave microorganisms can include any change in quality and quantity of air, nutrients, and water entering the cave. Threats to water quality were discussed in detail in section 4.4 of this report and are primarily from sources outside of park boundaries. Visitor/human use, changes in climate and weather patterns, and fire management practices also have the potential to alter species richness, diversity, and community structure as these activities can directly influence the quality and composition of air, nutrients, and water that enter Mammoth Cave.

Bacteria

Research indicates that diverse bacterial communities exist in a variety of subsurface environmental settings found at MACA and given the generally stable cave environment it could be assumed that these communities are also stable. Also considering the size of Mammoth Cave, we can assume there may be more species and unique assemblages yet to be identified. Available data does provide some historical reference conditions however, there is not comparable data for trend analysis. Though not seen as a threat for this particular indicator but rather the natural cave biome, sewage leaks from developed areas within the park have previously introduced bacterial contamination to the cave environment (Olson 2017c). Though improved in 2004, possible sewage system failure should be considered a potential threat to the water quality, native cave biota, and visitor health safety (Olson 2017c).

Algae and Cyanobacteria

Though this group of microorganisms may provide a limited food source for other cave species, it is mostly recognized as a resource management problem in electrically lit passages at MACA. Though there are other areas of the cave that exhibit thriving lamp flora communities and white lighting has only recently been modified, the Frozen Niagara area appears to have been rehabilitated compared to the condition prior to the original reduction of lighting and physical removal of lamp flora in this area (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, May 2018, personal communication). Nonetheless, management efforts show declining trends in lamp flora where white light has been replaced by yellow LED lighting, indicating improving conditions in regard to removal of non-native biota and the return to natural cave conditions. A recent setback involving technical issues with new lighting panels being left on for extended period did occur but overall extent of lamp flora at Frozen Niagara has been reduced (Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, May 2018, personal communication). Anecdotal evidence from park staff suggest that growth is slowing at New Entrance and Mammoth Dome areas. There is no other research to support current condition or trend analysis, but we can assume that lamp flora populations are declining with

use of yellow LED lights and continue to exist and exclude native biota from locations where white light is being used in the cave.

Protozoa

While more research is needed to understand the specific ecological role and current condition of protozoa in Mammoth Cave, we know that these organisms are an important food source, especially for aquatic invertebrates, including the endangered Kentucky cave shrimp (USFWS 2010). As cave systems are low nutrient environments, these first level heterotrophic organisms are essential in the subsurface food web and may assist in the control of bacterial communities. As no new data on the presence or distribution of protozoa is available, the current condition and trend of this sub-group of micro-organisms cannot be assessed and represents a data gap for this indicator. The environmental threats to the aquatic biota of the cave community are discussed in detail in section 4.4 of this report in relation to cave shrimp and represent the same stressors that could be or have affected protozoa populations since the surveys of Jones (1965) and Gittleson and Hoover (1969, 1970).

Fungi

Aside from *P. destructans,* current condition and trend cannot be assessed for the subterranean fungal community at MACA. Presence of fungi can indicate human impact, however, fungi do play an essential role in decomposition and recycling of nutrients. Threats and/or stressors to this indicator are assumed to be minimal as subsurface communities appear to be "resupplied" through transport of spores by water, air, animals, and humans from the surface.

It is assumed that P. destructans was introduced to the park by migrating bats or (less likely) humans that transported the spores and was not present prior to 2012. It has since been found at numerous locations in the park and is assumed to be present throughout the cave system and regionally (Thomas and Toomey 2017). Though distribution of this fungus is expanding, the trend should be considered as deteriorating since this is a cause of WNS in bats. In fact, recent bat counts show dramatic declines, associated with the introduction of WNS, of more than 50% for four species on the park, including the federally-endangered Indiana bat, and almost a total loss (93%) of little brown bats at Colossal Cave, considered one of the three primary bat caves on the park (Thomas and Toomey 2017). Described in the 4.9 section of this report, trends in bat populations show that the fungus is spreading and continuing to influence bat mortality of certain bats species.

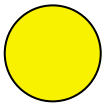
Level of Confidence and Data Gaps

Confidence in condition findings is considered moderate as diverse microbial communities have been identified and we know they continue to exist through visual surveys of bacterial colonies, fungi, and algae by park staff as well as the continued breakdown of organic matter throughout the cave (Table 4.70). In general, it is assumed that cave microorganisms are stable in regard to presence and distribution at MACA since a variety of environmental conditions do exist that appear to support a diverse microbial community. Data indicate deteriorating conditions in regard to the spread of *P. destructans* but conditions appear to be improving as lampenflora may be growing slower with lighting modifications. However, trend cannot be assessed at this time due to lack of current and/or comparable data on species richness, community composition, or distribution. This lack of current

information should be recognized as data gap not only for the assessment but continued management of cave microorganisms.

Condition Summary

Table 4.70. Graphical summary of status and trends for cave micro-organisms (bacteria, algae, protozoa, fungi).

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Cave communities	Cave micro-organisms		Species richness, community composition, and assumed distribution, as well as known biology and function were used to qualitatively assess the status of this indicator. Data for trend analysis is not available. Cave micro-organisms while critical to the cave ecosystem in nutrient cycling and as a food source, have the potential to negatively affect native cave biota creating moderate concern in status and future trends. Fungi such as *P. destructans* can infect and kill bats, keystone species of the cave community. Declining numbers of bats attributed to WNS shows that *P. destructans* is continuing to spread among bat populations and therefore expanding distribution of the fungus (Thomas and Toomey 2017). Lamp flora not only reduce the quality of the visitor experience but are also out-competing and/or excluding native biota in electrically lit passages. However, this problem is localized to toured passages and lighting modifications appear to be inhibiting growth and supporting shifts in taxa (Soto and Pate 2016). Bacteria and protozoa populations are assumed stable with no data to indicate improving or deteriorating conditions. However, identified stressors to cave conditions (changes in air/water quality, nutrient input, and human use) may pose threats to microorganism populations which form the food base for the cave community. Confidence in assessment is considered moderate as microorganisms are assumed present where preferred habitat and energy sources exist and past studies show diverse populations of all sub-groups—bacteria, algae and cyanobacteria, protozoa, and fungi.

Sources of Expertise

Rick Toomey (Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM) and Rick Olson (Park Ecologist, MACA Division of S&RM), Kurt Helf (Ecologist, CUPN),

and Kathleen Lavoie (Microbiologist, State University of New York Plattsburgh) provided expertise for this section.

4.13.3. Woodrats

Description

The Allegheny woodrat is a small, native rodent of the Eastern United States which has experienced significant declines over the past few decades primarily in the northern and western reaches of its range (Monty and Feldhamer 2002). In fact, the woodrat is considered a G3/G4 species of concern by the US Fish and Wildlife Service, has experienced dramatic declines in Illinois, New Jersey, and Ohio, is listed as endangered in Indiana, and appears to no longer inhabit Connecticut or New York (Monty and Feldhamer 2002). As healthy populations appear to still exist in Kentucky, MACA could be an important center of distribution for this species.

The preferred habitat of the Allegheny woodrat is forested lands that provide variety of mast (nuts and seeds) and herbaceous materials for foraging and includes suitable nesting sites in cliffs, rocky outcrops, and caves (Barbour and Davis 1974). The Allegheny woodrat is relatively anti-social, typically nesting alone, building globular nests primarily with shredded bark (Lavoie 1982, Monty 2002). Food caching is also common. Though they are considered food generalists there is some indication that landscape changes affecting preferred food sources (type and abundance of mast) may affect presence and distribution and even be linked to declining numbers (Balcom and Yahner 1996, LoGiudice 2006). Early studies by Rhoads (1894) imply that woodrats are "intolerant of coexistence with humans" and they do not appear to re-populate adjacent to residential and/or agricultural areas (Monty 2002, LoGiudice 2006). Their feeding and nesting behavior may also make them susceptible to disturbances caused by cave access and visitation (Thomas 2008). As woodrats nest in caves and forage in surrounding forests at MACA, they are valuable contributors of organic matter to the cave environment, supporting both microorganisms and invertebrates that in turn create the food base for many other species. Indeed, Woodman and others (2007) report that woodrat population parameters ranked third in Cave Nutrients pathways as assigned during MACA's Long-term Ecological Monitoring and the Cave Nutrients pathway ranked second in importance out of 18 ranked pathways in the park. Their importance to the cave ecosystem, sensitivity to human activity, potential for preferred food sources, and regionally declining populations make them a mammal of particular interest at MACA as a useful indicator of both surface and subsurface communities.

Data and Methods

Population estimates, derived from the Lincoln-Petersen Chapman method using data from live capture sampling from 1997–2002 and 2004–2007, were used to evaluate status and trend of this indicator. Data provided by Thomas (2003) are from long-term monitoring conducted at MACA from May 1997 to March 2002 in collaboration with the Kentucky Department of Fish and Wildlife in fulfilment of Cooperative Agreement G5530020001. These data represent woodrat population estimates based on twenty sampling locations (undisclosed) at MACA. Other data calculated from trapping results includes parasite infection rates, movement distances, sex ratios, age class ratios, mean weights, genetic diversity, and food habits (Thomas 2003). These parameters are selectively

discussed and evaluated as they relate to overall condition and trend or reveal potential threats and stressors.

Data from 2004–2007, reported by Thomas (2008), represents a more intensive sampling regime as 59 locations at MACA were montiored (Figure 4.113). In addition, Thomas compared managed versus unmanaged cave locations. The premise for this comparison is that woodrats may be less likely to inhabit locations with regular human use or caves where entry is difficult and therefore woodrat presence and distribuiton may have implications for visitor use and cave resource management. Managed caves are defined as having physical structures such as doors or electric lighting. Unmanaged caves are without physcial structures, or at most bat-friendly gates, and are off-limits to public visitation. The 50 unmanged caves were sampled twice per year in the first two weeks of both May and November. The nine managed caves were sampled every other month, if no woodrat use was detected. Managed caves with woodrat use were only sampled once every six months. Data for the managed caves, whether sampled bi-monthly or semi-annually, were combined to represent two six months periods for analysis. The "May" data represents numbers collected during trapping sessions conducted in May, July, and September, and "November" those collected in November, January, and March. Approximate sampling locations, as not to disclose actual cave locations, are shown in Figure 4.113. Detailed sampling protocol is outlined in Woodman et al. (2007).

In both studies, woodrat population size was estimated using the Lincoln-Petersen-Chapman method based on capture-recapture frequencies observed within a 2-night trapping session. For mobile animals, mark and recapture methods are effective for estimating population size (Pollock et al. 1990, Brittian and Bohging 2009). The design is that woodrats are captured, marked, and released on the first day of sampling and then population is estimated based on the number of subsequent recaptures. The assumption being that the larger the population the lower the number of recaptures. Thomas used this method as described by Pollock et al. (1990), to obtain population estimates (N_c), approximately unbiased estimates of its variance (var N_c), and an approximate 95% confidence interval assuming normality (closed population) for N_c. It should be noted that this estimate assumes no loss of marking or tags of captured individuals. Thomas (2003) reports that during the first two years of the capture-recapture study, almost 24% of woodrats lost one or more ear tags, and almost 10% lost more than one ear tag. This could affect early population estimates but seems minor as some portion of the individiuals that lost their "mark" where still identifiable as recaptures. Marking protocol changed to ear tattooing during the middle of that study and for the 2004–2007 monitoring program, so this assumption should not have been violated in calculations following the new methodology.

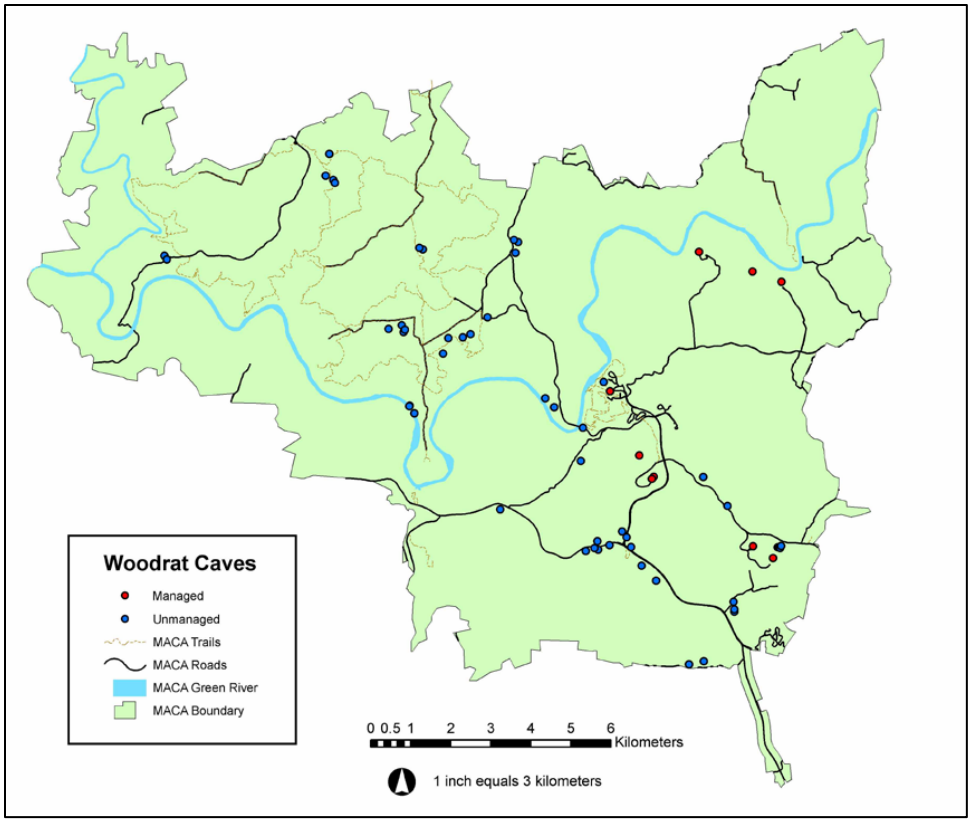


Figure 4.113. Map of Allegheny woodrat trapping locations at MACA (Woodman et al. 2007).

Reference Conditions/Values

Prior to 1997 the woodrat was represented at MACA by two park museum specimens (Thomas 2013). A 5-year study conducted from 1997 to 2002 reports a mean population estimate of 8.4 woodrats and represents available reference conditions (Thomas 2003). In total, fifty-three woodrats (22 females:31 males) were captured 386 times (186 females:200 males) at MACA. Population estimates at MACA ranged from 19.4 in January 1998 to 3.0 in September 1999 and again in May 2000 (Figure 4.114). The sharp decline observed in early 1998 may be attributed to poor mast crop production regionally, though populations did not appear to recover with increased mast production the following years (Garland 1999, 2001). Mean population estimates show an initial decline to an eventual stable low at MACA (Thomas 2003). Though no formal monitoring was conducted from March 2002–November 2004, Woodman et al. (2007) reports 15 live captures in 2004 but no other metrics or statistics were reported. Subsequent sampling in 2005–2007 provides data for condition and trend analysis and are discussed in the following section.

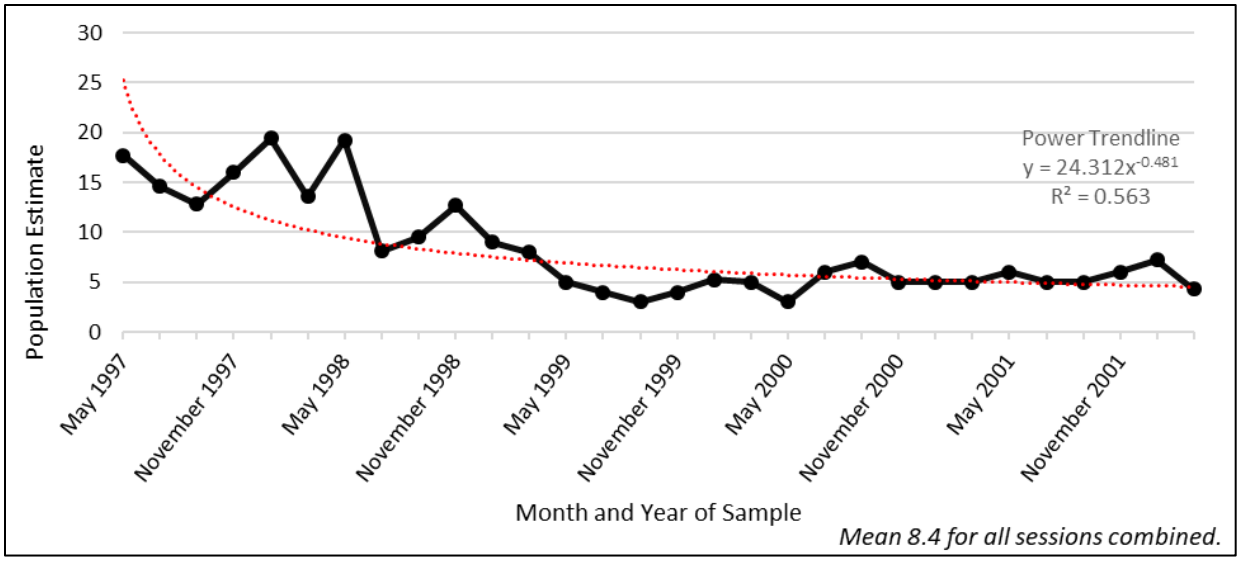


Figure 4.114. Allegheny Woodrat Population Estimates (Lincoln-Petersen-Chapman method per 2-night sampling session) at MACA. Modified from Thomas (2003).

Condition and Trend

Allegheny woodrat monitoring at MACA was conducted from November 2004–March 2008 using the same sampling methods as the previous 5-year study by Thomas (2003) but was extended to include trapping locations at 50 unmanaged caves and nine managed caves. Protocol for woodrat monitoring at MACA is discussed in detail in Woodman et al. (2007). The mean population estimate, using only data from unmanaged caves for both 6-month sampling periods of each year, was 9.9 in 2005, 7.2 in 2006, and 8.7 in 2007 (Thomas 2008). When combined into a 3-year period, the total mean population estimate is 8.6 woodrats. Compared to the 1997–2002 total mean population estimate of 8.4, the condition of woodrats with regard to population appears unchanging. Though declining numbers were observed initially, the woodrat population seems to have stabilized at MACA, however these data were collected more than 10 years ago.

Nine managed caves were monitored for woodrat use and individuals were captured at all but one of these locations (Carmichael Entrance) during the three-year monitoring period. No woodrats were captured in Austin Entrance or Crystal Cave after November 2004 and only one individual was captured in Historic Entrance during the entire monitoring period. Table 4.71 below shows the number of individuals captured at each location as well as percent of managed caves used each year. While results in 2004 seemed promising, subsequent sampling through 2008 shows a general decline in use of managed caves by woodrats. Although this assumes no influence of small sample size, both in number of caves and woodrats, as well as the specific caves chosen. Even though numbers appear to be declining, the fact that woodrats are still frequenting areas with heavy visitation and electric lighting, such as Frozen Niagara and New Entrance, is a sign that suitable cave habitat and/or surrounding surface food sources may play a bigger role than human disturbance in respect to woodrat use.

Level of Confidence and Data Gaps

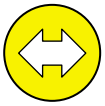
Granted the duration of monitoring, consistency of methodology, stable population estimates, high genetic diversity, and no documented dramatic changes to overall land use or potential woodrat habitat within MACA since monitoring was suspended in 2008, it is assumed this indicator is stable in regard to status (Table 4.72). Trends show an initial decline in woodrat population estimates, with the most recent data showing a stable low, so condition is considered unchanging. Overall confidence in condition assessment findings is moderate. A significant amount of population data does exist for this indicator however monitoring stopped in 2008 and represents a ten-year data gap at the time of this report. Additional research on threats to the Allegheny woodrat population at MACA could address larger ecological questions and issues regarding, not only the conservation of woodrat populations, but management of both surface and subsurface resources.

Table 4.71. Number of individual Allegheny woodrats captured in managed caves at MACA. Modified from Thomas (2008).

	Sampling Period						
Cave Name	**November 2004**	**May 2005**	**November 2005**	**May 2006**	**November 2006**	**May 2007**	**November 2007**
Austin Entrance	1	0	0	0	0	0	0
Carmichael Entrance	0	0	0	0	0	0	0
Crystal Cave	1	0	0	0	0	0	0
Frozen Niagara	2	1	1	1	1	0	0
Great Onyx	1	1	0	1	0	0	0
Historic Entrance	0	0	0	0	0	1	0
New Discovery	0	0	0	0	1	0	1
New Entrance	1	1	1	1	1	1	1
Violet City	1	0	0	2	1	0	1
% Caves with woodrat use	**66.7**	**33.3**	**22.2**	**33.3**	**44.4**	**22.2**	**33.3**

Condition Summary

Table 4.72. Graphical summary of status and trends for the Allegheny woodrat at MACA.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Cave communities	Allegheny woodrat		A mean population estimate of 8.4 was determined during Allegheny woodrat monitoring from 1997–2002 and represents reference conditions for this indictor (Thomas 2003). A mean population estimate of 8.6 was calculated during subsequent monitoring from 2005–2007 (Thomas 2008). Based on these estimates, duration and quality of data, and assuming no significant changes to potential woodrat habitat and food sources, this indicator is considered stable in regard to status. Initial data trends do show a decline in population since monitoring started in 1997 but numbers appear to have settled at a stable low. Concern for woodrat populations at MACA is moderate. The woodrat is critical to the cave community in the diversity and amount of organic matter it contributes to the trophic system and its decline or loss could be detrimental to other members of the cave ecosystem. Though habitat and food sources are abundant, diverse, and protected, there are serious potential threats to an already declining or small population. As the reason for declining populations of this species has yet to be determined and may involve complex, synergistic effects of several stressors, this population should continue to be of interest to resource managers. In fact, the woodrat is considered a G3/G4 species of concern by the US Fish and Wildlife Service, has experienced dramatic declines in Illinois, New Jersey, and Ohio, is listed as endangered in Indiana, and has been extirpated in Connecticut or New York (Monty 2002). As healthy populations appear to still exist in Kentucky, MACA could be an important center of distribution for this species. Confidence in this assessment is moderate. Sufficient data for reference conditions exist and have been compared to the most recent available data to determine status and trend. However, monitoring was suspended in 2008 and represents a ten-year data gap creating some uncertainty in current condition.

Source of Expertise

Steven Thomas (Monitoring Program Leader, CUPN) provided expertise for this report.

4.14.4. Cave Crickets

Description

Cave crickets are omnivorous insects commonly found in caves throughout MACA. They are considered a keystone species due to their role as a source for fixed energy to the cave ecosystem via guano, eggs, and carcasses which support troglobitic invertebrate populations that can include rare and endemic species (Poulson and Culver 1969, Lavoie et al. 2007). Helf (2003) also points out that cave crickets are the definition of a "key foundation species" in that, besides providing nutrient rich food to other specialized invertebrates, they are found in most caves in all seasons and are the largest, most abundant terrestrial invertebrate in the cave community. In fact, Poulson (2017) suggests that cave crickets are responsible for the high biodiversity of the subsurface community at Mammoth Cave.

Cave crickets regularly forage outside of the cave, primarily as a scavenger of rotting organic matter, fungi, and dead insects (Helf et al. 2015, Lavoie et al. 2007). Upon returning to the cave, crickets mainly inhabit entrance or near entrance areas where they deposit guano and eggs that support three separate communities depending on location and activity– entrance roosts where guano accumulates, in-cave reproductive areas, and the "traffic routes" in between (Lavoie et al. 2007). Each community supports detritivores and higher level predators which can include troglomorphic springtails, beetles, millipedes, spiders, and the cave salamander. The in-cave reproductive areas also support the carabid beetle which specializes in predation of cave cricket eggs and in turn is also a source of energy to the cave system, in guano and as prey for a variety of species including mites, a pseudoscorpion, a dipluran, and a spider (Lavoie et al. 2007). Crickets also support surface communities as prey for mice and numerous other predators and there is some evidence that their presence and abundance influences predator populations and distribution in both subsurface and surface communities (Viele and Studier 1990, Helf 2003, Lavoie et al. 2007).

Cave entrances are the natural staging area for crickets to assess surface conditions prior to exiting the cave to forage in the evenings. This is especially important as cave crickets are very sensitive to climatic conditions and changes in those conditions both large (regional/seasonal precipitation patterns, temperature extremes) and small scale (in-cave microclimate). Numerous studies that indicate that foraging behavior, reproduction, abundance, density, and in-cave distribution of cave crickets are affected by both surface and subsurface temperature and relative humidity (Studier et al. 1987, Nielsen 1989, Downing and Hellman 1989, Studier and Lavoie 1990, Cyr et al. 1991, Poulson et al. 1995a, 2000, Yoder 2002, Helf 2003). Meteorological parameters can affect surface productivity and foraging conditions and are correlated with the amount of guano, eggs, and carcasses available to the terrestrial cave community. Poulson et al. (1995a) found that a reduction in guano resulted in a long-term decline of guano-associated community populations. In addition, human activity such as entrance modifications, can change cave conditions (temperature, relative humidity, access, and air flow) and has been shown to affect cave cricket abundance and distribution (Poulson et al. 2000).

Given their importance to the trophic structure and sensitivity to environmental parameters, cave crickets appear to be a useful bio-indicator of cave ecosystem health (Helf et al. 2015). Continued

monitoring of this species could also prove valuable as an early warning sign of deteriorating conditions and therefore the management and protection of this critical resource (Helf et al. 2015). Consequently, MACA resource managers ranked cave crickets first in proposed long-term monitoring of vital signs at MACA (Leibfreid et al. 2005). They are also recognized as critical to status and trends of nutrient inputs, ranking fourth in the top ten significant resource management questions at the park and are included in the Cave Nutrients pathway, second in importance out of 18 pathways identified at the park (Helf et al. 2015).

Data and Methods

While other research on the cave cricket is presented as to support this assessment, evaluation of this resource relied heavily on population and community composition data provided by Poulson et al. (1995b, 1996, 1997, 2000) and Lavoie, Helf, and Poulson (unpublished data 2017). Data were gathered via visual census at nine cave entrances, counting all visible crickets in cave passages by 10 meter increments, ranging from 40 to 160 meters into the cave passage, until less than 1% of the censused population was represented, (Poulson et al. 1997). Data were also collected on size class, using a ranking system from 1–4, with 4 representing adult, reproductively mature crickets. Size classes were determined by visual estimation of hind femur length (Size 1=6–10 mm, 2=>10–15 mm, 3= >15–20 mm, 4=>20–24 mm); periodic checks on visual estimates were made by measuring hind femur length. Meta-populations, or the populations of crickets at spatially subdivided cave entrances, were identified as sources or sinks by the ratio of juvenile to adult (i.e., size classes 1+2/3+4) crickets to determine if a population was growing, stable, or decreasing (Poulson et al. 1995b). Habitat quality, defined as the spatial relationship of foraging and reproductive areas to cave entrances, also played a role in characterizing source and sink populations. Sampling methodology is further described by Poulson et al. (1995b, 1997).

Reference Conditions/Values

Cave cricket populations have been periodically monitored both directly and indirectly from 1971–1994 and then more intensively from 1994–1997, these data represent reference conditions that can be compared to the long-term monitoring conducted from 1997–2017 (Poulson et al. 1995a, 1995b, 1997, 2000, Lavoie Helf and Poulson unpublished data 2017).

The cave cricket has long been recognized as an important member of the terrestrial cave community especially in regard to the specialized and diverse invertebrate populations that it supports with guano, eggs, and corpses (Barr 1967). As such, the cave cricket has received considerable attention from researchers at MACA regarding biology, behavior, and population size and structure (Studier et al.1988, Poulson et al. 1995b, 1997, Lavoie 2007, Helf 2003, Helf et al. 2015). Focusing on adult-sized crickets (based on size) only, Hellman (1989) reports a population estimate of 976 (+/− 209.4) in the Frozen Niagara area in October 1987 as part of a mark-recapture study. Though his results were somewhat inconclusive in regard to population density and his February estimate was extremely low (70.6 +/−35.9), subsequent studies show that the Frozen Niagara area supports a similar size, if not larger, cricket population (Poulson et al. 1997). There also appears to be some agreement with Neilson (1989), who while studying intracave movement, recorded population counts in Floyd Collin's Crystal Cave (also named Historic Crystal) ranging from 255–367 which falls in the range

for adult crickets, 106–1145 found by Poulson et al. (1997). In addition to visual counts, though not reported in the paper directly, Griffith (1991) calculated population densities for cave crickets in Great Onyx of 0.06–0.25 adult crickets per square meter at a deep cave site, 1.6 km from the only entrance accessible by humans. More interesting, however is the significant positive correlation in the number of adult crickets and adult beetles shown in that study.

Poulson et al. (1995a) argues that species richness and abundance of the cricket guano community may be used as index of cave cricket abundance. Surface foraging conditions affect cave cricket reproduction and guano deposition and so their dependent cave communities indirectly reflect cave cricket population size. Cricket guano community diversity and abundance increased, decreased, and then slightly recovered from 1971–1994 in both White (Figure 4.115) and Little Beauty caves. There were some dramatic declines in the mid to late 1980s with signs of recovery in White Cave in 1992 when cricket counts above a single sampling plot showed an increase to 13 from 7 crickets in 1989 and a jump to 49 in 1994. In Little Beauty, overall numbers are reported as 1114 in 1973, 461 in 1987, and 562 in 1994, showing a similar trend.

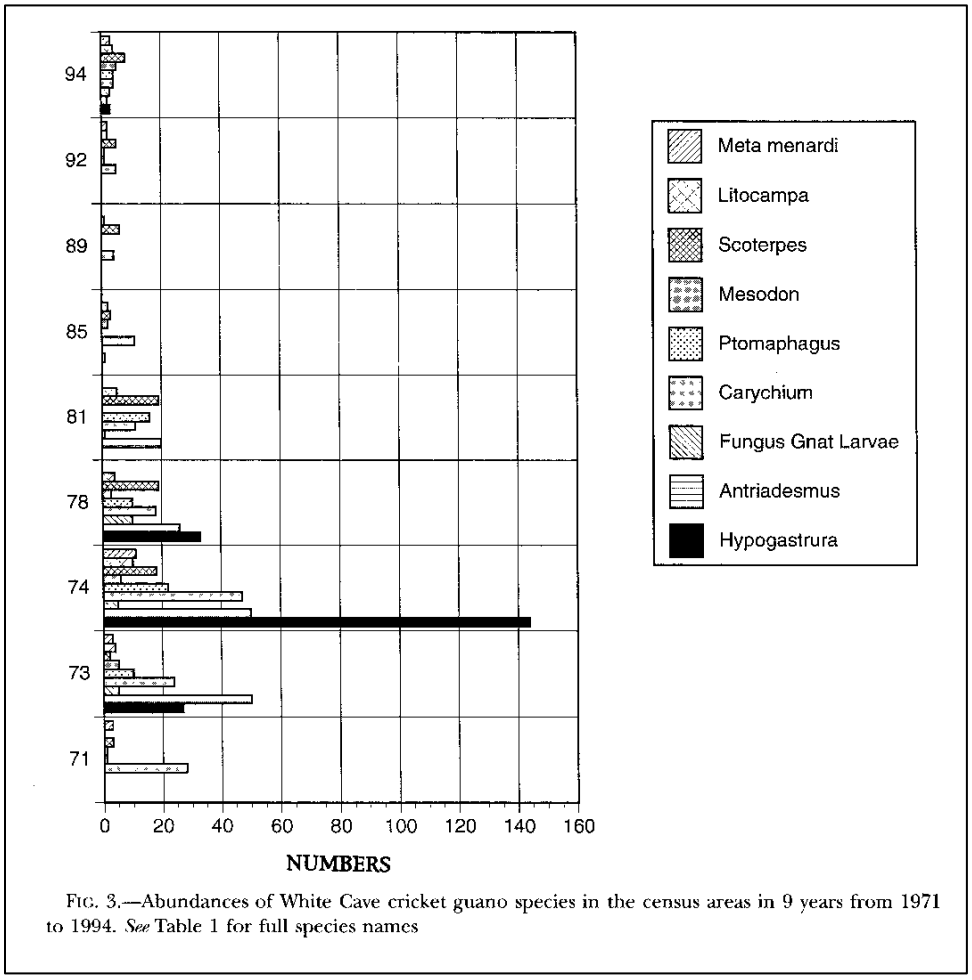


FIG. 3.—Abundances of White Cave cricket guano species in the census areas in 9 years from 1971 to 1994. *See* Table 1 for full species names

Figure 4.115. Abundance of cricket guano community species in White Cave from 1971–1994 (Poulson et al. 1995a). Y-axis is year of sampling, omitted by original author.

Overlapping with guano community studies in 1994 and extending into 1997, Poulson et al. (1995b, 1996, 1997, 2000) conducted cricket counts at nine cave entrances at MACA: Austin (A), Carmichael (C), Frozen Niagara (FN), Great Onyx (GO), Historic Crystal (HC), Little Beauty (LB), New Discovery (ND), Violet City (VC) and White (W). Poulson et al. (1995b) provides detailed descriptions of each location and exact extent of each entrance area surveyed. This study was initiated based on the scheduled retrofitting of five of the entrances (A, C, FN, GO, HC, VC). Overall, population sizes generally increased at all nine entrances across the study period, however most of this increase was represented by "sub-adult" and adult crickets (size class 3 and 4, respectively), with mean numbers per cave of 1,026, 1,998, 1,645, and 2,670 (Poulson et al. 1995b, Lavoie et al. 2007). Authors determined based on the 1994–1997 census, that while entrance modifications did initially cause declines at some locations, all entrance populations recovered, though the Austin site did not reach the all-time high observed at the other caves and individuals appeared to be starving based on crop surveys of crickets present. All of this evidence, paired with previous work by the authors, appears to support that annual local weather and habitat quality, both surface and subsurface, are greater factors in cricket population compared to entrance modifications (Poulson et al. 1997). This is not to say that anthropogenic stressors are not present or affecting cricket populations.

In addition to direct counts, individuals observed were classed by size to determine population structure at each entrance. Five of the census locations were identified as sink populations (A, FN, GO, LB, W), with a low ratio of small to large crickets implying low reproduction and immigration to these sites, and four as source populations (C, HC, ND, VC), where high ratios of small to large crickets suggest a growing population and emigration from these sites (Figure 4.116, Poulson et al. 1997, Lavoie et al. 2007). It should be noted, however, that over time cave cricket entrance populations can switch their status from sink to source and vice versa (Figure 4.116). These data support prior research indicating risks incurred while foraging on the surface (e.g., predation) are dependent on local conditions and life stage and so may inform resource management strategies.

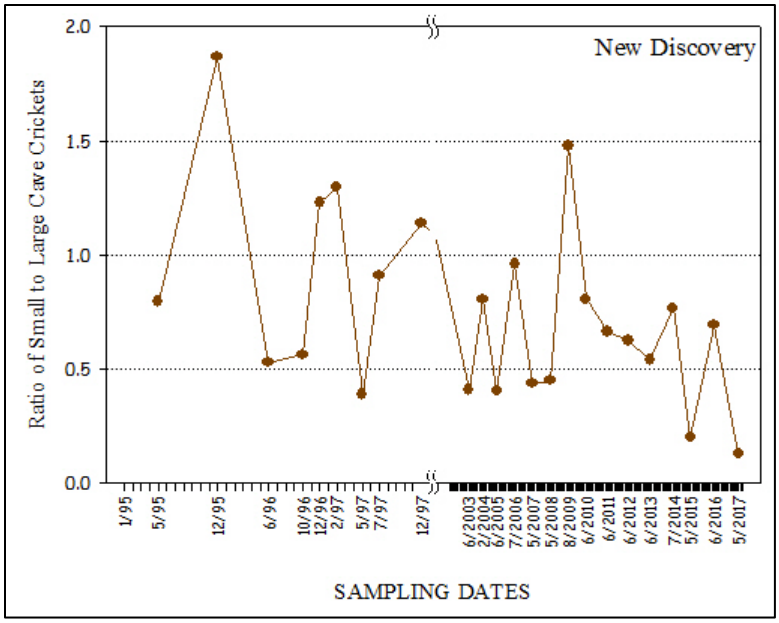


Figure 4.116. Ratio of small to large cave crickets at the New Discovery entrance. (Lavoie, Helf, and Poulson unpublished data 2017).

Condition and Trend

Data collection at all nine of the cave entrances chosen for study by Poulson et al. (1995b) has continued to present day, with only a short data gap from 1998–2002 for most sites, through the efforts of Lavoie, Helf, and Poulson (unpublished data 2017); however, no formal reports or analysis of this data is currently available. Lavoie, Helf, and Poulson (unpublished data 2017) provided total cricket numbers for the 2003–2017 census, these results are qualitatively described herein.

As initially indicated by Poulson et al. (2000), the most detrimental effects of entrance retrofitting seem to have occurred at the Austin entrance with only recent evidence of recovery. There appears to have been a gradual decline in population since 1996 with numbers rarely reaching pre-modification highs, though 2017 results do look promising for increasing population at this location. Populations at the remaining eight entrances appear to have experienced gradual declines in the early 2000s with numbers starting to rebound in 2010 (see, for example, Figure 4.117). Cricket populations appear to be stable at Carmichael, Frozen Niagara, Great Onyx, and New Discovery and on the rise at Historic Crystal, Little Beauty, Violet City, and White. All locations seem to have recovered from any initial effects of retrofitting based on visual interpretation of census graphs. Though beyond the scope of this assessment, correlation of population with climatic data could potentially provide insight into the potential causative factors of fluctuations in population according to previous findings by Poulson et al. (1995b, 2000).

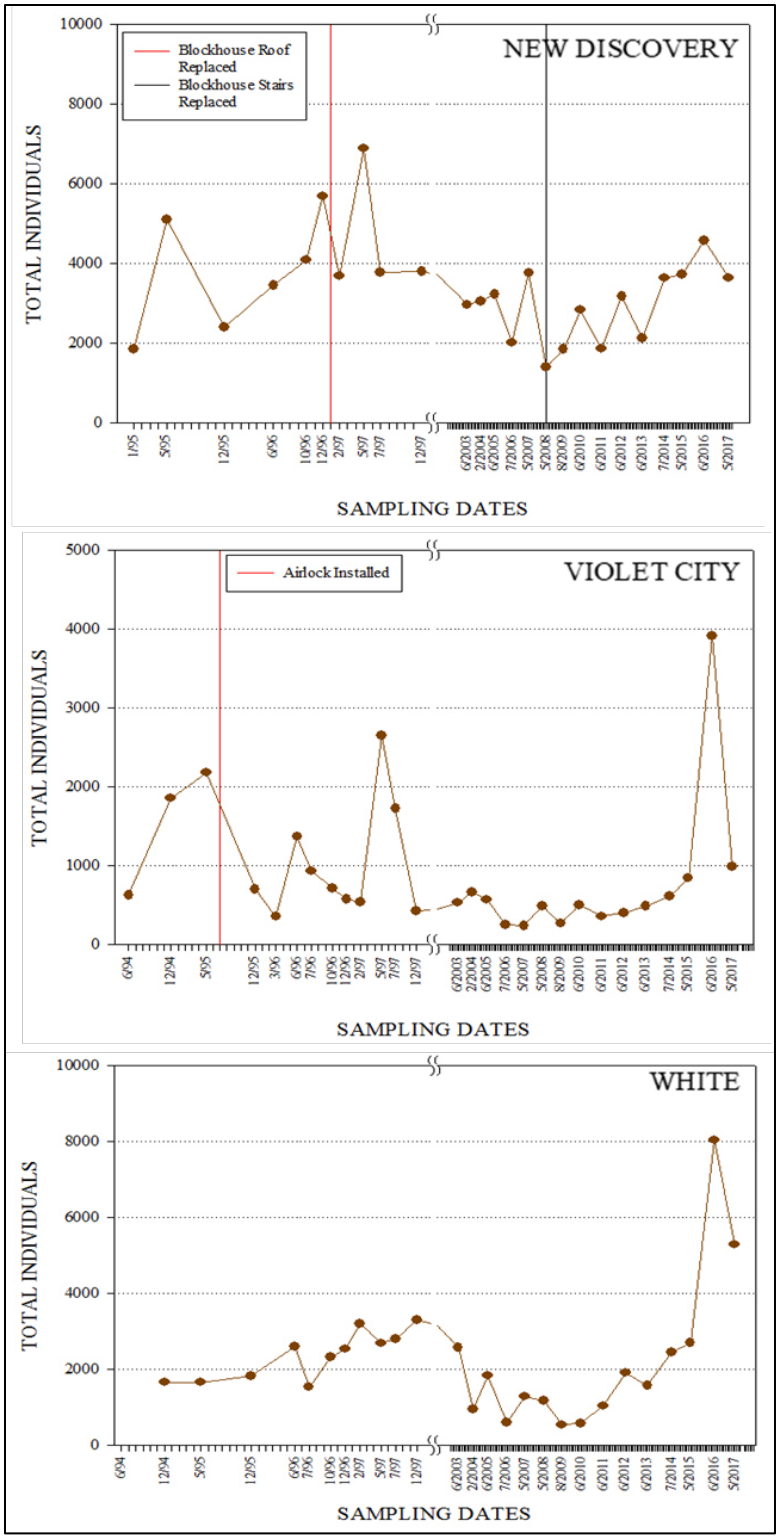


Figure 4.117. Cave cricket census at New Discovery, Violet City, and White 1994–2017 (Modified from Lavoie, Helf, and Poulson unpublished data 2017). Note: All graphs are not on the same scale.

While cricket population numbers appear to be stable and/or increasing at MACA, there are potential threats to this keystone species that may affect the entire cave community trophic structure (Poulson et al. 1995b, 2000; Kurt Helf Ecologist, CUPN, March 2018, personal communication). One of these threats is natural variation and/or climate change resulting in drought or extended periods of extreme winter temperatures where preferred food sources are limited in the summer or foraging and movement between source and sink populations are restricted, respectively (Poulson et al. 1995a, 2000). Management of both surface and subsurface habitat quality (cave modification, prescribed fire regime, etc.), is also of great concern in respect to foraging and requirements for roosting habitat and reproductive areas (Poulson et al. 1995a, 2000). Other stressors include lack of food sources for juveniles as they move from reproductive areas, possibly fungal infections (*Beauveria amorpha*), and increased predation for all size classes due to narrow or few entrance/exit openings (Poulson et al. 1995b, 2000; Kurt Helf, Ecologist, CUPN, March 2018, personal communication).

As for management implications, continued assessment of the source and sink structure in the cave cricket metapopulation could assist MACA in strategies to decrease these risks as well as development of possible recovery approaches should the cave cricket become endangered (Poulson et al. 1995b). The cave cricket has a long lifespan and only has to feed every 10–12 days, therefore populations can survive during poor food or climate years, however if a dramatic loss were to occur at any one location, local extinction would be possible as risk of reproductive failure is increased in smaller populations, especially at potentially isolated sink populations (Poulson et al. 1995b, 2000). As the cave cricket is a critical member of the cave food web and has a relatively narrow range of habitat and climatic requirements, monitoring is pertinent and recommended for the continued management of this species at MACA.

Level of Confidence and Data Gaps

Though long-term monitoring with consistent methodology was used in collection of population data, the level of confidence in this rating is moderate based on lack of statistical trend analysis and further interpretation of source and sink population dynamics. Additional data on population structure and dynamics is needed to fully understand the observed fluctuations as well as implement proper long-term monitoring and suitable management strategies, when needed (Poulson et al. 2000). Completion of a database that meets the needs of the CUPN's cave cricket monitoring protocol (Helf et al. 2015), the primary goals of which are to identify changes in statistically rigorous estimations of cave cricket entrance populations and their responses to contingent climatic conditions and other stressors, is anticipated around late winter/early spring 2019. The cave cricket monitoring protocol is currently in full implementation at fifteen cave entrances in MACA which includes all entrances discussed in this section. Data collected during sampling events include photomonitoring of all cave cricket clusters intersected by 30 randomly located transects, grab sampling of meteorological data at cluster locations, and continuous sampling of cave temperature and relative humidity by automated data loggers (Helf et al. 2015). These long-term data will contribute to the development of informative models of relationships between cave cricket entrance population dynamics and key environmental factors and management actions by MACA resource managers (Table 4.73).

Condition Summary

Table 4.73. Graphical summary of status and trends for cave crickets.

Resource	Indicator	Condition Status/ Trend	Rationale and Reference Conditions
Cave communities	Cave cricket		Population data collected for more than 20 years shows stable to increasing numbers at all locations surveyed and therefore warrants a status rating of good. Lack of statistical trend analysis and further interpretation of source and sink population dynamics assign a moderate confidence level to this rating. Though this assessment appears to be favorable, as a keystone species to the cave community, the cave cricket should remain a species of concern for resource managers.

Sources of Expertise

Kurt Helf (Ecologist, CUPN) and Kathleen Lavoie (Microbiologist, State University of New York Plattsburgh) provided expertise for this section.

Chapter 5. Discussion of Natural Resource Condition Assessment Findings and Considerations for Park Planning

5.1. Introduction

For a park of its size—only about 21,000 hectares—MACA has a relatively complex set of resources to understand and protect (Figure 5.1). In addition to the physical and biological surface resources that one might expect in a park of this size and location, there is the vast network of caves that stretch for hundreds of kilometers beneath the park and surrounding landscape. The watershed of the upper Green River that the park helps to protect is considered a nationally significant biodiversity hot spot (Master et al. 1998) (Figure 5.2) and the cave holds extensive and direct evidence that this area was one of only a few locations in the world at which the domestication of plants, and thus agriculture itself, was established by ancient people (Crothers 2017). The geologic, hydrologic, biological, and cultural resources here are intimately intertwined, as are indeed the surface and underground landscapes of the park.

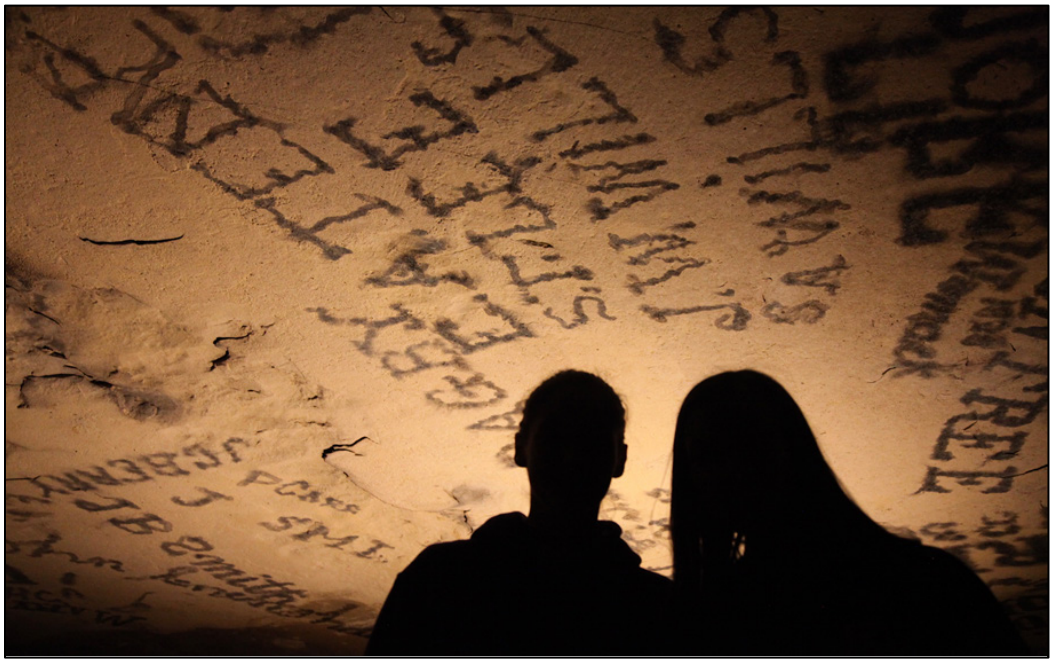


Figure 5.1. In addition to the global significance of its geological features, MACA preserves exquisite detail of thousands of years of human history (photo by Chris Groves).

The authors of this report collectively have more than 75 years of experience in working closely with park resources in research, teaching, conservation, and just enjoying the park itself. However, for each of us individually our time has to some degree been focused on our individual pursuits whether it be geology, chemistry, or history. In this NRCA, however, we have been able to synthesize a wide spectrum of experience to better understand both the nature of the park and its resources and the work of the park scientists and managers, who along with NPS partners, have created the basis for this understanding.

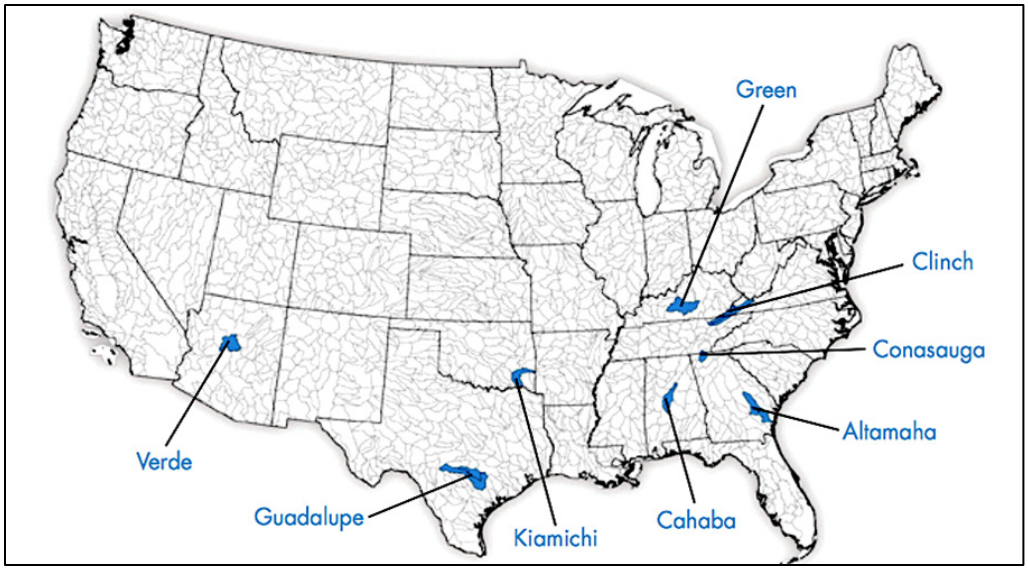


Figure 5.2. About 160 kilometers of Kentucky's upper Green River basin, which includes the section that flows through MACA, has been designated among the most important biodiversity hot spots in the country (Master et al. 1998).

Although of course there are always challenges and stressors, we are in full agreement that this is a well understood, well cared for, and carefully protected national park. In cycles of waxing and waning resources to do so, through our work we more fully than ever appreciate and laud the scientists, administrators, support staff and partners—largely volunteers—who have made this happen over more than seven decades as a national park.

The purpose of this chapter is to provide a "bigger picture" summary of condition findings by park areas and topics of interest to park managers" (NPS 2010d) by a synthesis of what we have learned in this analysis described in detail in Chapter 4. We start by creating a framework through which we relate our natural resource findings to the park's significance, fundamental resources, and values. These discussions include a summary of current conditions, concerns from threats and stressors, and important scientific needs and data gaps.

5.2. Connecting the Natural Resource Condition Assessment to Park Purpose, Significance, and Fundamental Resources and Values

The purpose of MACA (NPS 2014) is "to preserve, protect, interpret, and study the internationally recognized biological and geologic features and processes associated with the longest known cave system in the world, the park's diverse forested, karst landscape, the Green and Nolin rivers, and extensive evidence of human history; and to provide and promote public enjoyment, recreation, and understanding." We have prepared this Natural Resource Condition Assessment to evaluate the current status of these features and processes as part of the park's ongoing planning process. As such, it is necessary to define the relevance of these elements by tying them to the park's purpose and significance statements, which were most recently defined in MACA's Foundation Document (NPS 2014). Table 5.1 shows the ways in which the 13 major topics of our assessment relate to the park's 1) significance and 2) fundamental resources and values.

Table 5.1. Relationships of natural resource condition assessment topics to the elements of MACA significance as well as fundamental resources and values as defined by the park's 2014 Foundation Document (NPS 2014).

Element	Natural Resource Condition Assessment Topics	Surface air	Cave air	Geology and soils	Hydrology/ water resources	Human use	Night skies	Native communities	Impacts of fire management	Bats	Birds	Herpetofauna	Surface aquatic communities	Cave communities
Park Significance	Globally significant karst resources	–	X	X	X	X	–	–	–	X	–	–	–	X
	Exceptional diversity of landforms, habitats, life forms, and functions	–	–	–	–	X	–	X	X	X	X	X	X	X
	Well-preserved cultural resources spanning 12,000 years	–	–	X	–	X	–	–	–	–	–	–	–	–
	Green River and its nationally-significant biodiversity	–	–	–	X	–	–	–	–	–	–	X	X	X
	200 years of recreational and educational opportunities	–	–	–	–	X	–	–	–	–	–	–	–	–
Fundamental Resources and Values	World class karst	–	X	X	X	X	–	–	–	X	–	–	–	X
	Scientific Exploration and Discovery	X	X	X	X	X	–	X	–	X	X	X	X	X
	Underground Time Capsule	–	–	X	–	X	–	–	–	–	–	–	–	–
	12,000 years of human interactions with the land	–	–	X	X	X	–	X	–	–	X	X	X	–
	Water shapes the landscape	X	–	X	X	–	–	–	–	–	–	–	–	–
	Opportunities for connections to the resources	X	X	X	X	X	X	X	–	X	X	X	X	X
	Biodiversity	–	–	–	–	–	–	X	–	X	X	X	X	X
	Natural resource quality and function	X	X	X	X	X	X	X	X	X	X	X	X	X

5.3. Natural Resource Condition Summary

In this chapter, we provide condensed descriptions of the resource assessments for the 13 major topics that provide the framework for how we have organized MACA's natural resources. The details of the assessments, data sources we have used, experts with whom we have consulted, threats, stressors, data gaps, and rationales for the levels of confidence we have expressed in each of the assessments are provided in Chapter 4. Table 5.2 is a summary of our evaluations of the 13 major topics with a brief statement of the rationale with which we have reached these conclusions. The "stoplights" are color coded where green indicates that a given resource, in our judgment, is in good condition, while yellow and red indicate reason for moderate or significant concern, respectively. The circles around them are coded to the confidence we have expressed in our conclusions based on the amount and quality of the data available. Heavy lines indicate high confidence, lighter lines medium confidence, and dashed lines low confidence. The arrows show upward, downwards, or stable trends, while no arrow indicates that there is insufficient evidence to ascribe a trend to the data.

In general, our task has been to identify and evaluate existing data in whatever form it is currently available. This is what we have done, with the exception of the hydrology/water resources section where we have organized a relatively large quantity of raw water quality data collected in the park under the auspices of the Water Quality Monitoring Program (Meiman 2006) and have completed trend analyses on a selection of parameters through to the most currently available data. This included both surface and underground water. Among all of the park's resources, water serves as a kind of "glue" that ties together the atmosphere and landscape, the surface and underground, and the physical and biological worlds. We judge that it is especially important to understand the condition of, threats to, and trends of the park's water resources, because land use activities over and area of about 6,734 square kilometers of the drainage areas of the Green and Nolin Rivers provide potential threats to MACA's water and the resources that in turn depend on it.

The summary table (Table 5.2) is followed by a summary of each of the 13 topics in sections 5.4 through 5.16. These each include an overall topic assessment, as well as a summary discussion of the indicators we chose and the conditions of those indicator resources.

Table 5.2. Natural Resource Summary Table.

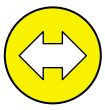
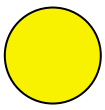
Resource	Condition Status/ Trend	Summary of Overall Condition Rating
Surface air quality		While there are still significant concerns with visibility and nitrogen deposition, in general air quality at MACA continues a decade long improvement trend largely due to better regional coal combustion practices. Ozone with respect to both human and vegetation health is of moderate concern but improving, as is sulfate deposition. Confidence is in the assessment is high.
Cave air quality		The natural radon concentrations in the air of MACA caves are of significant concern, but there is no threat to the public and staff impacts are controlled by monitoring and personnel management. Carbon dioxide and cave meteorological conditions pose no threats. Conditions are generally stable and there is medium confidence.

Table 5.2. Natural Resource Summary Table.

Resource	Condition Status/ Trend	Summary of Overall Condition Rating
Geology and soils		In general, geologic conditions are stable though there is a range in the assessments across different indicators. Cave and alluvial sediments are subject to contamination from off-park sources, and oil development near the park's southwest boundary has impacted park water quality. Past impacts to bedrock units from quarrying and cave minerals from vandalism compared to past conditions are improving. Although most geologic data are clear, uncertainly about the impacts of a major 1960s dioxin spill upstream from the park remains a significant data gap and we judge that therefore overall confidence in our overall assessment is medium.
Hydrology/water resources		There are a number of outside influences impacting precipitation, surface water and groundwater that are largely outside of the park's influence, but in general waters are within the appropriate for their designated uses. While there is concern for the impact of mercury in precipitation, the improving trend considers that Lock and Dam #6 was removed from the Green River in 2017, with positive benefits.
Human use		Because of proactive and science-based approach that MACA and CUPN have taken to understand ameliorate potential resource threats from visitor activities, we have high confidence that impacts from entrance modifications, passage modification, roadwork and tourism develop are negligible and stable. There is moderate concern from impacts from visitor vandalism through graffiti on cave walls.
Night skies		MACA qualifies for the International Dark Sky Association's Silver Tier status which signifies that while not pristine, here are "exemplary nighttime lightscapes." With three data collection programs, most of the park has a Bortle Scale of 4, and SQM values measured at 52 locations in 2017 averaged over 21. Conditions are expected to improve through planned MACA light management and clearing skies with improving air quality.
Native communities		This symbol represents an "average" of conditions between native animals (moderate concern, high uncertainty, upward trend) and native plants (moderate concern, high certainty, and downward trend). MACA hosts rich and diverse assemblage of species, especially plants and this includes rare plants. Large carnivores may be returning to the park, but native vegetation is threatened by invasive species and exotic pests/disease.
Impacts of fire management		Most restoration objectives based on assumed pre-settlement conditions as well as currently identified and mapped or modeled vegetation types are being met. Overall, there has been preservation of preferred over story canopy, reduced shade tolerant and exotic species, increases in native herbaceous cover, and reductions in total fuel loads.
Bats		Although the conditions and trends vary by cave and species of bats, numbers of bats are very small compared to historical populations, and now some species are being devastated by the impacts of WNS.

Table 5.2 (continued). Natural Resource Summary Table.

Resource	Condition Status/ Trend	Summary of Overall Condition Rating
Birds		There have been many avian surveys of the park, and we did not identify particular serious threats to birds at MACA so they seem to be in good condition. We did not identify any recent upward or downward trends. As the last systematic survey was more than 10 years ago, we have medium confidence in this rating. Although data are available based on the Monitoring Avian Productivity and Survivorship Program, additional analyses of these data remain to determine trends.
Herpetofauna		Herpetofauna appear to be in fair, but deteriorating condition with need for moderate concern based on declines in the number of salamander, lizard, and snake species present. The condition of the frogs and toads remains largely unchanged from historical conditions but a few species of salamanders are experiencing declines. In general, amphibians seem to be doing better than reptiles. Little can be said regarding trends in diversity or distribution among these groups as monitoring efforts have not been equal across years and sampling techniques are not randomized. Therefore, statistical trend analysis of these populations cannot be assessed accurately.
Surface aquatic communities		The overall condition of the surface aquatic community merits moderate concern. Most communities evaluated exhibit high species richness, but low evenness. Fish and mussel populations appear to be improving. More fish species are now present in the Green River in MACA than ever before although there are some exotic species. Presence of several rare and endangered mussels in the habitats offered by the Green River and successful efforts to reintroduce the endangered ring pink mucket to the Green River. The level of confidence in this assessment is high as it relies on well-documented historical records, recent and long-term monitoring efforts of park fauna using intensive surveys and these show similar patterns among and between. A positive, dramatic change in conditions related to surface aquatic fauna occurred in November 2016 with the unplanned breaching, and subsequent removal, of Lock and Dam #6 (see Section 4.4).
Cave communities		With medium confidence, we express moderate concern for cave communities, using Kentucky Cave Shrimp, microorganisms, woodrats and cave crickets as indicators and note that long-term data are not sufficient to identify trends. The shrimp is federally endangered. There are stresses on woodrats, bats and crickets. Cricket population appears to be stable to increasing.

5.4. Surface Air Quality Resource Brief and Narrative

5.4.1. Condition Rationale

We used four indicators (Table 5.3) to evaluate the quality of surface air at MACA, including visibility, ozone, nitrogen deposition, and sulfur deposition. Our assessment conforms with the NPS guidance document *Guidance for Evaluating Air Quality in Natural Resource Conditions Assessments* (NPS 2015) and uses data and analysis from the *Park Conditions and Trends* (NPS

Table 5.3. Summary of overall surface air quality conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Visibility	Haze index		Although there are statistically significant improving trends in both best and worst haze conditions, conditions remain in the area of significant concern.
Ozone	Human health: Annual 4th-highest 8hr concentration		Human health risk from ground-level ozone warrants moderate concern at MACA though conditions have improved.
	Vegetation health: 3-month maximum 12hr W126		Vegetation health risk from ground-level ozone warrants moderate concern at MACA. Plants at MACA are at high risk for ozone damage, though the trend in the W126 metric has improved.
Nitrogen	Wet deposition		Wet nitrogen deposition warrants significant concern at MACA based on the 2011–2015 estimated wet nitrogen deposition of 4.3 kg/ha/yr.
Sulfur	Wet deposition		Wet sulfur deposition warrants moderate concern at MACA based on estimated wet sulfur deposition of 3.0 kg/ha/yr, although the 2006–2015 trend improved.
Surface Air Quality Overall			–

2017b). There are very high quality data for these from the Houchin's Meadow Atmospheric Monitoring Site just the south of MACA near Cedar Springs (Figures 4.1 and 4.2). The station participates in a number of programs including 1) the Interagency Monitoring of Protected Visual Environments (IMPROVE) that aids in monitoring of visibility conditions in Class I air sheds (Pohlman and Maniero 2005), 2) the NPS Gaseous Pollutant Monitoring Program (GPMP) and NPS Ecological Effects Programs within the NPS Air Resources Division for ozone, 3) and the National Atmospheric Deposition Program National Trends Network (NADP NTN) in cooperation with EPA's Clean Air and Status and Trends Network (CASTnet) for sulfur and nitrogen deposition. For decades, air quality at Mammoth Cave has been seriously impacted from regional coal burning for electricity along with industrial and mobile emissions, and in 2015 the park had the 10th worst air pollution of the national parks (NPCA 2015). Improvements in coal combustion technology have created significant improvements in air quality over the last decade and this trend is expected to continue (Table 5.3).

5.4.2. Management Considerations

Although MACA continues to have serious air pollution problems, the situation has improved in the last ten years in some parameters, including rainfall acidity, sulfate, visibility, ozone, and wet

deposition with amelioration of the impacts of regional coal combustion. These include technological improvements at the plant level, use of cleaner coal from Wyoming's Powder River Basin, and increased use of natural gas to replace coal for largely economic reasons. Details of these air quality parameters are discussed in both Section 4.1 on Surface Air Quality (visibility, ozone, nitrogen deposition and sulfur deposition) and Section 4.4 Hydrology/Water Resources for the pollutants dissolved in rainfall (acid rain, specific conductance, and mercury) but are discussed here together.

MACA has an excellent record of collaborative, high quality data collection through various programs described in section 4.1 at the Houchin's Meadow Air Quality Station and it is very important to continue this tradition to get the high-quality data that can both show the need for action to improve air quality and to show whether the interventions are having the intended effects. Mercury remains a concern, and useful additions to the existing suite of measurements when resources permit would be methylmercury as well as resuming participation in the National Atmospheric Deposition Program's (NADP) mercury litter fall study that operated at the station in 2007–2014.

5.5. Cave Air Quality Resource Brief and Narrative

5.5.1. Condition Rationale

We used three indicators (Table 5.4) to evaluate cave air quality in the park, including radon, carbon dioxide (CO_2), and cave meteorological conditions. Radon is a colorless, odorless radioactive gas produced by geologic materials that contain small amounts of uranium, which is a radioactive element. Because of the radiation produced as radon subsequently decomposes, exposure to the gas presents an elevated risk of lung cancer under conditions where it can build up such as homes, mines, and caves. We evaluated conditions based on ^{222}Rn progeny (a particular form of radon plus the other radioactive substances that form from its decay) considering both air concentrations and employee cave exposure. With medium confidence, we conclude that concentrations warrant significant concern, but the more practical concern of exposure only generated moderate concern, as this can be controlled by personnel assignments. Both measures are steady.

Concentrations of CO_2 gas are commonly elevated in limestone caves for a variety of naturally occurring reasons that include biological processes in the soil, geochemical processes within the water flowing through the cave, and interactions with the limestone bedrock. Although there are not existing reference conditions by which to evaluate CO_2, a high-resolution, multi-year study of CO_2 at several locations in Mammoth Cave concluded with high confidence that levels are very typical for the region's caves and below that which would create any health concerns for either staff or visitors. There is no evidence that there are either upward or downward trends.

Cave meteorological conditions include measurements of temperature, wind speed, and relative humidity (Table 5.4, Figure 5.3).

There are no standardized reference conditions for such observations, but we can observe whether there are impacts to resources that may result from human modifications of entrances or passages. While there is not threat to human or ecological health (except for occasionally uncomfortably cold temperatures in the first few hundred meters of the Historic section of Mammoth Cave on very cold days), there have been damages to cultural resources influenced by the fact that the entrance has been

modified from its original geometry and this assessment suggests moderate concern but stable conditions, with high confidence.

Table 5.4. Summary of overall cave air quality conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

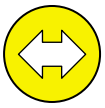
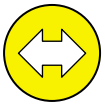
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Radon (^{222}Rn)	Derived air concentration (WL)		Levels commonly exceed 0.3 WL which requires continuous monitoring of air and record keeping for staff exposure levels. There are no long-term upward or downward trends.
	Annual limit on intake (WLM)		Exposure commonly exceeds 1 WLM but employees are monitored and assigned surface duties at 3.5 WLM. Currently, this is uncommon.
CO_2	Concentration in parts per million (ppm)		All high-resolution data from a five-year study of representative Mammoth Cave air were below 2,000 parts per million. Park staff reported no cases of visitors complaining about air quality.
Cave meteorology	Temperature, relative humidity and air flow		There are no standardized reference conditions for cave meteorological conditions, but there are limited threats to biological or physical resources currently due to human alteration of cave air flow, and no threats to visitors or staff. There is concern for impacts to cultural resources in the Historic Area.
Cave Air Quality Overall			–



Figure 5.3. Air temperature, relative humidity and air flow can have significant impact on sensitive species in caves. This instrument collected continuous data at a small cave on the north side of the Green River in MACA (NPS photo by Steve Thomas).

5.5.2. Management Considerations

Depending on the configuration of entrances to a particular cave, including connections to the surface too small for people but through which air can flow, air, water vapor and other gasses can move through caves creating form of underground weather. Airflow, temperature, and relative humidity can impact environmental conditions, including key cave species and communities. The impact of air conditions on resources can be an important management issue, especially when this has been influenced by an alteration of entrances or passages. In the main cave system, there are many entrances and air moves readily through the passages. Many artificial entrances were constructed through the years for tour or exploration purposes, and in the 1990s a program successfully installed airlocks at the human-made ones, and to some extent restored the natural airflow regime to the cave.

The Historic Entrance to Mammoth Cave has been altered several times from its original configuration, and this got considerable attention in January of 1994 when extremely cold temperatures—at one point as low as minus 16º Fahrenheit—caused frigid air to blow forcefully into the Historic Entrance for several days. Because of snow and ice with the associated storm the park and cave were closed for several days, and when tours resumed it was found that a huge slab of rock—20 meters long and 6 meters wide—had fallen on the cave tour trail and destroyed parts of the early 1800s saltpeter mining artifacts. Since that time there has been a series of measurement programs to quantify airflow in that part of the cave (Jernigan and Carson 2010, 2011) including

mathematical modelling (Jernigan 1997). There remains concern about impacts to cultural resources from condensation related to air mixing, in particular air flow exchanging between Main Cave and Gothic Avenue, and data collection there continues.

Although CO_2 concentrations in the cave are elevated about 3–5 times the typical outside background levels, this is very typical for limestone caves in Kentucky and not a cause for concern. Radioactive radon gas presents a concern for park management, but this is naturally occurring and so there is not a feasible intervention to lower the levels. The park is adequately managing radon exposure, although an analysis of the radon data has not been done since 2002 to understand if any trends are occurring and we identify this as a data gap. In the 1970s–1990s research was done at MACA to develop a more detailed understanding of radioactivity exposure through investigation of research on radon which, in addition to measuring radon gas and radon progeny, determined unattached fractions of radon and radon decay products, measured the various radon progeny concentrations using the more robust Tsivoglou method as opposed to the simplified Kusnez method to speciate radon byproducts, and determined equilibrium ratios between radon and radon decay products (Bobby Carson, MACA S&RM, Division Chief, October 2017, personal communication). If resources would permit in the future, such continued work would be useful.

5.6. Geology and Soils Resource Brief and Narrative

5.6.1. Condition Rationale

We used six indicators (Table 5.5) to evaluate the condition of geological features and soils in the park, including bedrock units (Figures 5.4 and 5.6), alluvial sediments, cave minerals (Figure 5.5), cave sediments, economic mineral resources, and soil.

Evaluation of both bedrock units and soils shared that with high confidence these resources are in good, stable condition. While there are not standard reference conditions with which to evaluate these, we can establish whether there are conditions or processes through which these would be threatened, and there are not. There are also are no state or federal standards for either alluvial or cave sediment quality. In general, however, MACA sediments in Green and Nolin Rivers and some underground rivers are to some degree impacted by land use outside of the park, although they are in good condition compared to other regional drainage systems. There is uncertainty with regard to the potential threat posed by a known source of dioxin upstream from MACA on the Green River, and this is considered to be a significant data gap. Cave minerals are for the moment adequately protected from vandalism, and major damage to minerals in Crystal Cave from an extensive vandalism event in 1996 are being repaired in a long-term, volunteer restoration program and so these are considered to be improving. We expressed high confidence in this assessment. There is no current extraction of economic minerals in the park, however there are potential resource threats from oil production adjacent to the park.

Table 5.5. Summary of overall geology and soils conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

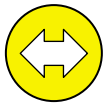
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Bedrock units	Threats from mining or other source of deterioration		There is not a standard reference condition for the condition of bedrock units. Bedrock in MACA is adequately protected by land management practices and there is no mining in the park.
Alluvial sediments	Contamination by metals, organochlorines and organophosphates		There are no state or federal standards for sediment quality. In general MACA sediments are in good condition compared to other regional drainage systems. There is uncertainty with regard to the potential threat posed by a known source of dioxin upstream from MACA on the Green River.
Cave minerals	Threats from vandalism		Although there is not a standard reference condition to evaluate the condition of cave minerals, speleothems and other minerals are adequately protected from vandalism at MACA. A long-term restoration effort is underway in Crystal Cave
Cave sediments	Contamination by metals, organochlorines and organophosphates		There are no state or federal standards for sediment quality. Although in general MACA sediments were good compared to other regional drainage systems, metals likely from I65 and agricultural chemicals, in particular the herbicide atrazine, are being transported by cave sediments.
Economic mineral resources	Impact to park resources from resource exploitation outside of MACA		Although there is no threat *to* economic mineral resources in MACA, there is a potential for threats to Park resources *from* exploitation of these resources near the park.
Soil	Threats from erosion or other conditions that would threaten soil quality		Although there is not a standard reference condition for the condition of soil, soil is adequately protected by land management practices in the park.
Geology and Soils Overall			–



Figure 5.4. The Mississippian-aged Girkin and Ste. Genevieve Limestone in Audobon Avenue in the Historic Area of Mammoth Cave (photo by Art Palmer).



Figure 5.5. MACA's caves have a variety of evaporate minerals that in many cases grow out from the cave walls. Many of these were mined by the Native American thousands of years ago, but these gypsum crystals in Great Onyx Cave are in passages that they did not explore (photo by Chris Groves).



Figure 5.6. The northwest end of the park holds some of MACA's most remote and rugged areas, where the relatively thick Pennsylvanian sandstone of the Caseyville Formation forms steep cliffs (photo by Chris Groves).

5.6.2. Management Considerations

In general, resources related to geology and soils are in good condition and adequately protected by current management practices. One consideration that MACA should continue to be mindful of is related to oil production in the Arthur community, in some cases with wells, pipelines, and storage tanks very close to the boundary of the park. Oil from at least one spill has flowed into the park contaminating surface and groundwater. Groundwater flow routes in that area have been determined through dye tracing by Western Kentucky University scientists. Oil production fluctuates with crude oil prices, and while there has been little new production in some years, this could change under future conditions.

While there is contamination of sediment in both surface and groundwater, in large part this comes from land use outside of the park and so is generally outside of park management control. However, in our opinion a particularly significant data gap was identified by Meiman (2006) who conducted the project "Chemical Analysis of Toxins in Stream Sediments" during FY01–02 during which he found four (of four) sediment samples upstream from MACA that were positive for congeners (different forms) of the highly toxic chemical dioxin. This has resulted from a train wreck in 1967 carrying barrels of concentrated Agent Orange (ELPO 2017), a defoliant containing dioxin that was used extensively in the Vietnam War. Barrels of the chemical were dumped into a sinkhole near the town of Horse Cave which connects through the karst drainage system of the Gorin Mill Drainage Basin to Gorin Mill and Hicks Springs (Ray et al. 1998a, 1998b) on the Green River. Meiman found four positive detections of octachlorodibenzo-p-dioxin (OCDD) and one for 1,2,3,4,6,7,8-heptachlorodibenzo-p-dioxin (HpCDD). Although these springs are immediately upstream from Park on the Green River and there is potential for bioaccumulation in fish and invertebrates, the potential risk to the park from the identified concentrations is uncertain, and these may be at typical background levels. A two-year follow up study was planned for more detailed sediment analysis as well as analysis of mussel tissue in FY06–FY07 but was never carried out. We recommend that this analysis be completed.

5.7. Hydrology/Water Resources Brief and Narrative

5.7.1. Condition Rationale

We used three indicators to evaluate water quality in the park (Figure 5.7, Table 5.6), including precipitation, surface water, and groundwater. The park is fortunate to have had an extensive and comprehensive evaluation of its water resources in 2005 (Meiman 2006) and the information in this section draws significantly from that work. Additional water quality data have been also collected since that publication and is considered. The two considerations that one can make to evaluate water resources in any area, including MACA, include water quantity and water quality and there are sufficient data to draw conclusions about the current health of water resources of the park. Although in general there are no standardized reference conditions for precipitation water quality, we conclude with high confidence that there is need for moderate concern, although conditions are improving. There is a high-quality atmospheric monitoring station just outside of the at the Houchin's Meadow site (Figures 4.1 and 4.2) which participates in the National Atmospheric Deposition Program National Trends Network (NADP NTN), the program for Interagency Monitoring of Protected Visual Environments (IMPROVE), and EPA's Clean Air and Status and Trends Network (CASTnet). The

concern comes from mercury concentration, although all other indicators (acidity or pH, specific conductance (SpC), and sulfate concentrations) have improved substantially over the past decade because of regional improvements in coal combustion practices and this trend appears to be continuing. We conclude that surface water resources in the park warrant moderate concern. There is a very good data set with measurements going back as far as 1992 (Meiman 2006) that characterize different classes of water in the park and so we have high confidence in the assessment. Although we have concluded that the park's waters meet their designated uses, there are continuing stressors to the waters of the park based on agricultural, urban, and transportation land use outside of the park, and these are in general therefore outside of MACA's ability to influence. These threats are in general chronic, but there is potential for acute problems based on the transportation routes of Highway I65 and the CSX railroad. We indicate an improving trend because of a major change that removed one of the most significant resource impacts in the park—the breaching and removal of Lock and Dam #6 beginning in November 2016.

Groundwater in Mammoth Cave has an unusual situation in that the underground river system within and around MACA has been designated according to surface water criteria, as Cold Water Habitat as well and State Outstanding Resource Waters. According to the Kentucky Waterways Alliance (Kentucky Waterways Alliance 2020):

> Outstanding National Resource Waters (ONRWs) are waters that receive special protection against degradation under Kentucky's water quality standards and the federal Clean Water Act. Waters eligible for ONRW designation include waters that are part of a national or state park, wildlife refuge or wilderness areas, special trout waters, waters with exceptional recreational or ecological significance, and high quality waters that have not been significantly modified by human activities.



Figure 5.7. WKU hydrologists Steve Kenworthy and Narcissa Pricope collect flow data in Mammoth Cave's Logsdon River, one of the main stems of the underground river system of the Turnhole Basin (photo by Chris Groves).

Table 5.6. Summary of overall hydrology/water resource conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Precipitation	pH, SO_4, SpC, mercury		There is not a standard reference condition precipitation water quality. However, with changes in regional coal combustion technology and practices, rainfall chemistry has improved greatly over the past decade and this trend is likely to continue. Overall, we list moderate concern due to mercury levels.
Surface water	*E. coli,* SO_4, dissolved oxygen, pH and SpC		In general, MACA waters meet the criteria for their designated uses, although there are continuing stressors to the waters of the park based on agricultural, urban, and transportation land use outside of the park. The impoundment from Lock and Dam #6, has been removed.
Groundwater	*E. coli,* pH, SO_4, and SpC		The underground river system with and around MACA has been designated according to surface water criteria, as Warm and Cold Water Habitat as well and State Outstanding Resource Waters. There is some chronic impact from agriculture and other land use. Acute problems have occurred with accidents on I65 and the CSX railroad.
Hydrology/Water Resources Overall			–

5.7.2. Management Considerations

In this NRCA, discussion of precipitation water quality is found in both Section 4.1 Surface Air Quality and Section 4.4 Hydrology/Water Resources, and relevant discussion of management considerations related to precipitation is found in 5.4.2.

With respect to surface water and groundwater, quality in general meets the criteria for the designated uses for each of the different water classes. The park is fortunate to have data from a relatively long-term monitoring program designed and initiated by then Park Hydrologist Joe Meiman (Meiman 2006) in 1992. This is a monthly, synoptic monitoring program with two years on and two years off based on the US Geological Survey's National Water-Quality Assessment (NAWQA) Program. We highly recommend continuation of this program. The potential for either acute or chronic contamination of the park's water resources from land use in the 6,734 square kilometers that drains to the park constitutes one it's most significant threats. The better water quality and its trends are understood, the more effectively they can be protected.

5.8. Human Use Resource Brief and Narrative

5.8.1. Condition Rationale

We used five indicators (Table 5.7) to evaluate the ongoing impacts of human use on the surface and underground resources of MACA: 1) graffiti, 2) entrance modification, 3) passage modifications, 4) roadwork, and 5) tourism development.

While there are no standardized reference conditions for the indicators in the section, overall we judge with high confidence that overall the park's resources are in good condition with respect to threats from human use. However, there is moderate concern about vandalism in the form of graffiti on cave walls continues to occur from time to time, and while it is it relatively infrequent, there is a potential threat of damage to historic or even archeological resources (Figure 5.8). There is also moderate concern about impacts to cultural and biological resources in the vicinity of the Historic entrance based on the fact that this entrance has been modified from its original configuration, including a large rock fall related to cold air flow in 1994 that partially destroyed saltpeter mining artifacts. In general, there is little to no concern for resource impacts from roadwork and planned new tours, as long as electric and not gas lanterns are used. However, there is planned cave trail work coming up and there has been damage previously by constructions teams so this should be monitored carefully. *Lampenflora*, localized plant communities that colonize areas adjacent to cave tour lights, are still a significant concern on some cave tour routes and although several measures have been implemented and the situation is improving, there is more to be done.

Table 5.7. Summary of overall human use impact conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

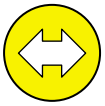
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Graffiti	Presence and new occurrences		New graffiti is occasionally made on the walls of MACA's caves and visitors are sometimes cited and fined. It is not frequent, but damage to historic or archeological resources could be significant.
Entrance modifications	Ongoing impacts		Other than the ventilation shaft there are no entrance modifications underway or planned and that is covered when not in use for projects. There is moderate concern about resource impacts from the modified condition of the Historic Entrance, discussed in the "Cave Meteorology section above.
Passage modifications	Ongoing impacts		Passage modifications are planned for parts of the Grand Avenue Tour, and noting that contractors have been responsible for damage in previous efforts, this would should be carefully monitored to ensure minimal threat to cave resources.
Roadwork	Ongoing impacts		Potential threats have been adequately studied and where necessary, ameliorated.

Table 5.7 (continued). Summary of overall human use impact conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Development of tourism	Ongoing impacts		Based on current plans for the development of three tours on existing but currently unused cave tour paths, little or no new resource impact is anticipated.
Surface trail conditions	Condition and ongoing impacts		A 2009–2014 survey of 63.1 kilometers of trails on the north side of the Green River in the park showed serious trail deterioration, principally from use by horses. Trails improve where maintained and deteriorate where are not, and the park made progress on several trail restoration projects during the study period.
Human Use Impacts Overall			–



Figure 5.8. Vandalism through writing graffiti on cave walls continues to be a concern at MACA. Here in the Historic Section of Mammoth Cave modern writing has damaged historic signatures from the 1800s (photo by Chris Groves).

5.8.2. Management Considerations

For the most part, impacts to the park's resources are well controlled by current management practices. Indeed, developing a science-based understanding of potential impacts of human activities is an area where the staff of MACA's Division of S&RM have been proactive. For example, a well-thought out sampling program showed that the impacts of salt road treatment during icy winter storm conditions, certainly important for staff and visitor safety, has a negligible effect on either water quality or potential damage to endangered species. These kinds of studies to generate data to objectively answer resource management questions is highly encouraged.

This topic is an area where the inputs of park staff from the S&RM, Law Enforcement, and Interpretive Divisions has been especially helpful. Although impacts from human use are all judged to be stable and at worst with areas of only moderate concern, we learned that cave damage from graffiti is still occasionally made on cave walls and there is ongoing discussion about best management practices among park staff. Planned new tourist activities will take park visitors into new cave areas that are not currently shown, and staff recommended that electric lanterns, rather than gas lanterns, be used to minimize air quality impacts. For the cave trail work planned for parts of the current Grand Avenue tour, close and careful supervision of the construction crews is also important to minimize potential damage.

A resource of concern that deserves additional study is the deterioration that has been shown to have occurred on surface trails. Although the volume on soil loss on some impacted trails has been quantified, and it has been shown that proactive trail maintenance can have positive effects, there may be other impacts, such as to water quality, that are less well understood We recommend that a broader, qualitative and quantitative evaluation of the environmental impacts of trail use at MACA be considered as a priority.

5.9. Night Sky Resource Brief and Narrative

5.9.1. Condition Rationale

To evaluate the indicator of night sky quality we used two measures (Table 5.8), the Bortle Scale (Bortle 2001) that synthesizes a number of factors with a nine-value scale based on the darkness and the magnitudes of different objects that can be seen with the unaided eye or various telescopes, and the Unihedron Sky Quality Meter (SQM). The SQM is a type of light meter but with the ability to measure selective wavelengths to simulate what would be seen by human night vision. Each reading measures the value at a single location, pointed straight at the zenith.

We conclude that that MACA's dark sky quality is in good condition (Figure 5.9) based in the IDA's criteria which have allowed MACA to be assigned to Silver Tier Status.

The 2008 survey Night Sky Report data are shown in Table 4.31. An explanation of the data and relevant terms is at NPS (2016c). Relevant to the condition assessment, the Bortle Scale was 4 and the SQM has a value 20.69. This is a "synthesized SQM", which is calculated from the full sky data in a way that matches the value that would have been taken with a Unihedron Sky Quality Meter with typical methods.

Overall considerations of the collective data from these surveys taken over ten years at various locations through the park leads to the conclusion that most of MACA is in Bortle Class 4 with small areas in the southern part of the park in Class 5. Most SQM readings in the 2017 survey were over 21.00 (Figure 4.83) and with these considered together in combination with meeting a range of required criteria, the park has qualified for Silver Tier Status (IDA 2018) designation from the International Dark Skies Association.

Table 5.8. Summary of overall night sky conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Night sky quality	Bortle scale		Most of the park has a rating of Bortle scale 4 with some fringe areas along the southern boundary with values of 5. This supports IDA Silver Tier Designation. The conditions are expected to improve with planned light management and clearing skies as a result of improving air quality at MACA.
	Unihedron sky quality meter (SQM)		Average SQM values from 52 locations in the park in 2017 are greater than 21.00. This supports IDA Silver Tier Designation. The conditions are expected to improve.
Night Skies Overall			–



Figure 5.9. The Milky Way galaxy from Sloan's Crossing Pond (NPS photo by Dave Spence).

5.9.2. Management Considerations

This section was a wonderful topic to write about, and one of the few where we conclude that not only is the resource in good condition, but is improving. The park just naturally is fortunate to be have relatively dark skies for its location in the eastern US, based on its geography and the distribution to local communities, but the management has also been creative and proactive in investing the time and resources to develop its dark skies designation application, and using this as outreach to local communities. This is a synergistic win-win situation, even to the point where local communities such as Park City can simultaneously improve environmental conditions, and potentially reap economic benefits by having tourists spend money at night as well as during the day! We encourage the park to continue to build on this idea, and potentially expand the collaborative discussions with local communities to join in on these lighting changes. Rick Toomey from MACA's S&RM Division has suggested the Kentucky Trimodal Transpark in northern Warren County, a large and growing local industrial and manufacturing complex, might make a good candidate partner.

As mentioned above, we judge that the condition of the night sky resource is improving, because of the changing conditions of light management both within the park and through cooperation in the local businesses and communities, combined with the fact that air visibility conditions are improving with enhanced air quality as discussed in Section 4.1. Though continued efforts to work on light

management with other local partners, this is a rare resource that not only is improving, but where those improvements can potentially even be sped up!

5.10. Native Communities Resource Brief and Narrative

5.10.1. Condition Rationale

We used two indicators to evaluate the health of the park's native communities, including 1) plant communities and 2) animal communities.

MACA and CUPN have worked with botanists from NatureServe and the Kentucky State Nature Preserves Commission (KSNPC) to conduct vascular plant inventories, including several efforts to catalogue rare plants in particular (Figure 5.10, Table 5.9). With high confidence, we conclude that there is a high diversity of plant species, including several important rare species, but there is reason for moderate concern. There are at least 172 species of invasive plants in the park (Appendix D), which compete with native vegetation for space, light and nutrients. The park is very concerned with controlling these, but with current resources this effort largely relies on volunteer labor provided by student and intern groups. There are also exotic pests and disease that threaten native plant species, including the emerald ash borer that has killed millions of ash trees since being introduced to the US, and which has been very recently confirmed in the park.

The condition of native animals at MACA appears to be improving slightly but still warrants moderate concern. Sufficient data is not available for trend analysis, but a few qualitative inferences can be drawn. Although exotic and invasive species which threaten native plant and animal communities may be increasing. Some species that have been long extirpated from the park (e.g., mountain lion and American black bear) are returning to the area. The return of these large carnivores will require specific management approaches to preserve park resources. The park also hosts a reasonable diversity of medium-sized carnivores, although many are considered rare on the park. Raccoons, coyotes, and skunks are considered common on the park and are present where suitable habitat and food sources exists. Efforts to restore river otters to the area in the early 1990s appear to have been successful, with numerous records of this species collected from the park in recent years although the species is still considered rare at MACA (Thomas 2013). There are no quantitative data on deer or the impacts they may be having on native vegetation.



Figure 5.10. There is a diverse community of native plants at MACA. This spider lily (*Hymenocallis occidentalis*) was photographed in a small upland wetland in the park (NPS photo by Milo Pyne).

The level of confidence in this assessment is low due to several data gaps. As, research on these groups has been fairly limited, Additional study and long-term monitoring of these and other native animal species is recommended for more accurate characterization.

Table 5.9. Summary of overall native community conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Plant communities	Species richness and diversity		Overall, MACA protects a very rich and diverse assemblage of native plants, over a heterogeneous range of landscape conditions, including important rare plants. We have high confidence of this assessment following a number of systematic surveys by MACA and CUPN. There is concern because of the current and expected influences of invasive plants and exotic insect pests and disease.

Table 5.9 (continued). Summary of overall native community conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Animal communities	• Invasive and/or Exotic Mammals • Deer • Medium-sized Carnivores • Large Carnivores		The condition of native animals at MACA appears to be improving slightly but still warrants moderate concern. Sufficient data is not available for trend analysis. Although exotic and invasive species which threaten native plant and animal communities may be increasing, some species that have been long extirpated from the park (e.g., mountain lion and American black bear) are returning to the area. The park also hosts a reasonable diversity of medium-sized carnivores, although many are considered rare on the park. Raccoons, coyotes, and skunks are considered common on the park and are present where suitable habitat and food sources exist. Efforts to restore river otters to the area in the early 1990s appear to have been successful. There are no quantitative data on deer or the impacts they may be having on native vegetation. The level of confidence in this assessment is low, due to several data gaps.
Native Communities Overall		–	–

5.10.2. Management Considerations

We cannot protect what we don't understand, and accordingly MACA and CUPN have put a high priority on vascular plant surveys to get a handle on the species that the park protects, with an emphasis on rare plants. There is a variety of different geologic, hydrologic, soil, and land use conditions that resulted in a relatively diverse natural vegetation community.

The principal challenge comes from invasive plants and exotic pests. These are focus areas towards which, if resources at some time became available, they could be well invested. S&RM staff, often leveraging their efforts with the help of students, interns, and other volunteers work to eliminate invasive plants but it is simply an overwhelming task. Certainly, a dedicated team for this task would allow the park to make more regular and sustained progress in keeping up with this overwhelming challenge.

Similarly, there are treatments to help ameliorate some invasive pests but these can also be labor intensive and therefore expensive. Identifying effective strategies to marshal resources in advance of the invasions could be another priority. For example, hemlock trees in the Appalachians and other areas are being killed by a small insect, the wooly adelgid, but this can be treated with soil application of insecticides such as Imidacloprid or Dinotefuran. It is, however, a tree by tree process that must be done every few years while the possibility of infection exists. The beautiful, isolated stands of hemlock trees in the Bylew Creek basin and other coves of the park's upper reaches of the

Nolin River have apparently not yet been affected, and the adelgids may or may not make it here. But these are very special trees and having a plan (and resources if possible) in case makes sense.

5.11. Fire Management Resource Brief and Narrative

5.11.1. Condition Rationale

The impacts of fire management strategies and practices (Figure 5.11) on the resources of MACA were evaluated by considering continuing impacts to those resources (Table 5.10). Restoration objectives are based on assumed pre-settlement conditions as well as currently identified and mapped or modeled vegetation types, and we conclude with medium confidence that restoration objectives are being met, with the exception of Indian Grass grasslands. Overall, there has been preservation of preferred over story canopy, reduced shade tolerant species, increases in native herbaceous cover, and reductions in total fuel loads.

5.11.2. Management Considerations

Along with night skies this is the second of the two resources in this assessment—those forest resources impacted by controlled burning—that we judge to be in good condition and improving. Following decades of declining forest health as a result of a total fire suppression management regime, in 2002 the park implemented the 2001 Fire Management Plan and began prescribed burning. No burning has been implemented in several years, pending completion of a new fire management plan.



Figure 5.11. WKU student Chris Carroll assists with a 2010 controlled burn on Jim Lee Ridge (NPS photo by Vickie Carson).

Table 5.10. Summary of overall impact of fire management conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Fire effects (prescribed burning)	Ongoing impacts		Restoration objectives are based on assumed pre-settlement conditions as well as currently identified and mapped or modeled vegetation types are being met with minimal uncertainty, with the exception of Indian Grass grasslands. Overall, there has been preservation of preferred overstory canopy, reduced shade tolerant species, increases in native herbaceous cover, and reductions in total fuel loads.
Impacts of Fire Management Overall			–

5.12. Bats Resource Brief and Narrative

5.12.1. Condition Rationale

We used five indicators to evaluate the conditions of bats in MACA, including 1) diversity, 2) community composition, 3) distribution, 4) reproductive success, and 5) species changes and in all cases our conclusions are made with high confidence (Figure 5.12, Table 5.11). Bats are critical components of surface and subsurface ecosystems. Cave-roosting bats import organic matter into the nutrient-deficient cave environment in the form of guano (Culver and Pipan 2009), and this supports highly specialized communities of cave invertebrates. Outside the cave, bats play a critical role in controlling nocturnal insects and serve as a major asset to pest management in agricultural and forest settings (Thomas 2015). The bat species that occur on the park are exclusively insectivores, and their consumption of insects is of great benefit to surface ecosystems (Thomas and Toomey 2017).

Many bat species are experiencing population declines in association with a variety of threats. Several species that occur on the park are federally listed as endangered, threatened, or species of concern under the Endangered Species Act (Thomas et al. 2016). Among the most serious resource issues at MACA, as well as much of the eastern and central US and Canada, is the impact of WNS that has caused the deaths of millions of bats since 2006. It was first documented in the park in 2013. Because of significant declines in some species including the federally protected Indiana and northern long-eared bats as wells as others, although the numbers of species are so far holding about steady, we have serious concern for diversity of bats in the park moving forward. Community composition and species distribution are also significant concerns, both with clear downward trends. There were already much smaller numbers of some species of bats compared to historic numbers before the arrival of WNS in the park (Thomas and Toomey 2017), but the situation is increasingly dire with the progression of the disease. We conclude with high confidence that bats are reproducing successfully in the park and that there are no data to suggest that this condition is not holding steady, although with WNS there is ample reason for concern moving forward. Females of eight rare or endangered bat species, including gray and Indiana bats, are known to form maternity colonies and

MACA or adjacent areas. During the summer of 2004 and 2005 reproductively 11 bat species present in MACA. Thalken and Lacki (2017) report pregnant or lactating female northern long-eared bats present in 30 tree roosts, and nursery colonies of Rafinesque's big-eared bats have been reported in at least eight caves in the park. There are other consistent data.



Figure 5.12. CUPN scientist Bill Moore examines several bats including little brown (*Myotis lucifigus*) and Indiana (*Myotis sodalis*) bats during a winter survey in MACA's Bat Cave (NPS photo by Rick Toomey).

Table 5.11. Summary of overall bat conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Diversity	Species richness and evenness		Species richness has so far remained about steady through there is significant concern that this could change under the influence of WNS. The relative abundance of species that contribute to this richness has changed over time, and some species that were once common on the park are now less common or rare.
Impact of White-nose Syndrome	Changes in bat diversity and/or distribution resultant of WNS		Compositions have changed from those based on historical records and there is significant concern that this could be further impacted under the influence of WNS.
Distribution	Numbers locations/sites where bats are present		At several locations in MACA bat numbers are much smaller than those from historical records.
Reproductive success	Evidence of reproductive activities		At least eight rare or threatened bat species have maternity colonies in or near MACA, and other signs of reproductive activity have been documented.
Threatened and endangered species	Federally listed bat species		MACA hosts two endangered bat species (Indiana bat and gray bat), and one threatened species (northern long-eared bat). With the devastating impacts of WNS it is expected that the number of threatened and endangered species may increase.
Bats Overall			–

5.13. Birds Resource Brief and Narrative

5.13.1. Condition Rationale

We used two indicators to evaluate the condition of the bird populations at MACA, 1) species diversity, and 2) productivity and survivorship (Figure 5.13; Table 5.12). We have high confidence in our conclusions with regard to diversity, because there has been a range of bird inventories done to get snapshots of the number of species that are in the park. Productivity and survivorship are less well understood because of data that have not yet been analyzed.

Overall, we conclude that avian resources are in good condition, and there is no evidence of either positive or negative trends.



Figure 5.13. A worm-eating warbler (*Helmitheros vermivorum*) breeding in MACA. These warblers winter in southern Mexico, Central America, and the Caribbean, and their range has been reduced by habitat loss (Robbins et al. 1989) (Photo by Blaine Ferrell).

Table 5.12. Summary of overall bird conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Birds	Species diversity		There have been many avian surveys of the park, and we did not identify particular serious threats to birds at MACA so they seem to be in good condition and we did not identify any recent upward or downward trends. As the last systematic survey was more than 10 years ago, we have medium confidence.
	Productivity and survivorship		Although data may be available based on the Monitoring Avian Productivity and Survivorship Program, additional analyses of these data remain to determine trends.
Birds Overall		–	–

5.13.2. Management Considerations

In places in the park, including the Mammoth Cave System, throughout the park's history bat numbers have been much lower than evidence suggests than had historically been the case. Then in 2006 WNS was discovered in New York and reached MACA in 2012 with catastrophic impacts. The park's management of this environmental crisis has been well thought out and implemented. By being very proactive in developing and implementing protocols to monitor and control the spread of WNS *in advance* of the disease reaching the park, its arrival received relatively little widespread attention because the policies and actions continued as they had been. Continuing to monitor the health of different species of bats in and around the park is the right strategy along with post-cave decontamination to help limit the spread of the fungus, until such time that breakthroughs are made in treatments to prevent, ameliorate or cure this ailment among individual bats. This is a very active area of research.

5.13.3. Management Considerations

This is a resource in good condition that has been well studied. There is one data gap that the timing appears be right for investigating. While there has been more than a decade of data collection through the Monitoring Avian Survivorship and Productivity (MAPS) program, these data have not been analyzed since 2010 and so there is currently not sufficient information to evaluate the trends that would be revealed by such analysis. Discussion with scientists from the MAPS program (Kate Slankard, Nongame Avian Biologist, KDFWR, February 2018, personal communication) indicate that such analyses should be done about every ten years, and so is due for the MACA MAPS station data.

5.14. Herpetofauna Resource Brief and Narrative

5.14.1. Condition Rationale

The herpetofauna of MACA includes the amphibian and reptile populations present in the park. These organisms are ectotherms with characteristically efficient metabolisms (Pough 1980).

Amphibians and reptiles often comprise a high percentage of the vertebrate biomass within ecosystems, although many are reclusive and rarely observed (Burton and Likens 1975, Congdon and Gibbons 1989, Pentranka and Murray 2001). These organisms also serve as important predators and prey (Gibbons and Dorcas 2004, Taylor et al. 1988) making them important trophic links. Thus, biodiversity and condition of herpetofauna populations reflect ecological well-being and serve as measures for evaluating anthropogenic impact on the environments that serve as habitat for amphibians and reptiles (Vitt et al. 1990, Knutson et al. 1999, Gibbons et al. 2000).

We used four indicators to evaluate the condition of herpetofauna in the park (Table 5.13, Figure 5.14), 1) frogs and toads, 2) salamanders, 3) lizards, and 4) snakes. Species presence, abundance, and distribution were used in this qualitative assessment of herpetofauna conditions in MACA. Herpetofauna appear to be in fair but deteriorating condition with need for moderate concern based on declines in the number of salamander, lizard, and snake species present. Little can be said regarding trends in diversity or distribution among these groups as monitoring efforts have not been equal across years and sampling techniques are not randomized. Therefore, statistical trend analysis of these populations cannot be assessed accurately. In general, amphibians seem to be doing better than reptiles.

Table 5.13. Summary of overall herpetofauna conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Herpetofauna	Frogs and Toads		Frogs and toads appear to be doing better than salamanders and newts. All species of frogs and toads known to historically exist in the park have been found by survey within the past three years apart from the upland chorus frog which has not been observed in MACA since 2006 (MacGregor 2007). The level of confidence in this assessment is high as it relies heavily on recent, long-term monitoring efforts within the park that exhibit similar trends (MacGregor 2007, 2010, 2011, 2012, 2013b, 2014, 2016b).

Table 5.13 (continued). Summary of overall herpetofauna conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Herpetofauna (continued)	Salamanders		The salamanders of MACA appear to be in fair, but deteriorating condition with need for moderate concern. Five of 16 salamander species historically known to MACA have not been found within the past 10 years. Emerging infectious diseases are linked to declines in amphibian populations globally, and preliminary results of recent studies in MACA suggest that a high percentage of eastern newts tested from pond and wetland areas were positive for *Batrachochytrium dendrobatis*, the amphibian chytrid fungus responsible for the disease chytridomycosis. The level of confidence in this and the reptile assessments is moderate as it relies on recent, long-term monitoring efforts within the park. However, because sampling techniques focused on non-random locations expected to support salamander habitat, statistical trend analysis is not feasible.
	Lizards		Lizard populations in MACA have remained relatively stable through time, several species may have been extirpated. Consequently, species richness is decreased and an uneven distribution of individuals among the species present. The condition of lizards with respect to diversity is declining slightly based on recent, long-term monitoring. The level of confidence in this assessment is moderate (see above).
	Snakes		The snakes of MACA warrant the need for moderate concern. Relative to other herpetofaunal groups on the park, snakes appear to be the most imperiled. Several species are at risk for extirpation. Though a new park record for the queen snake was added in 2005. Threats are associated with loss of open habitats. Snake fungal disease (SFD) may also threaten snake communities in the park.
Herpetofauna Overall			–



Figure 5.14. A cave salamander (*Eurycea lucifuga*) near the entrance to Great Onyx Cave on Flint Ridge (Photo by Chris Groves).

5.14.2. Management Considerations

Thanks largely to the efforts of John MacGregor of the Kentucky Department of Fish and Wildlife Resources (KDFWR) and Bill Moore of CUPN, there is a long history of detailed information about the amphibians and reptiles in the park, although the spatial distributions of sampling have not allowed statistical treatment of trend analysis. These surveys should continue as resources permit, but otherwise this is not a resource that required active management. Changes in the species distribution through time has largely been a natural response to changing landscape conditions as farmland has transformed to forest through NPS land management.

5.15. Surface Aquatic Communities Resource Brief and Narrative

5.15.1. Condition Rationale

We used two indicators to evaluate the condition of surface aquatic communities at MACA (Table 5.14), 1) fish, 2) freshwater mussels (Figures 5.15 and 5.16). Although amphibians are also an important indicator group with which to evaluate surface aquatic communities, we have included that discussion in Section 5.14 on Herpetofauna. With high confidence, we judge that the overall condition of the surface aquatic community merits the need for moderate concern. In terms of diversity, most communities evaluated exhibit high species richness, but low evenness. The conditions of fish and mussel populations appear to be improving. More fish species are now present in the Green River in MACA than ever before, although there are some exotic species. The Green River within the park is designated an unoccupied critical habitat unit (CHU) for the diamond darter,

one of the top 12 most imperiled fish in the southeast. Many non-game species exhibit high abundances, and the Green River within MACA has received an “excellent” fishery rating for smallmouth bass, and even contains some trophy-size individuals. Presence of several rare and endangered mussels in the habitats offered by the Green River and successful efforts to reintroduce the endangered pink mucket to long-term monitoring stations in the Green River within the park are positive signs for the condition of the mussel fauna of the park.

Table 5.14. Summary of overall surface aquatic community conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Fish	Diversity, distribution, and species changes		Fish populations appear to be improving. More fish species are now present in the Green River in MACA than ever before, although there are some exotic species. The Green River within the park is designated an unoccupied critical habitat unit (CHU) for the diamond darter, one of the top 12 most imperiled fish in the southeast Many non-game species exhibit high abundances, and the Green River within MACA has received an “excellent” fishery rating for smallmouth bass, and even contains some trophy-size individuals. The level confidence in this assessment is high as sources of data are multiple, recent, and show similar patterns.
Mussels	Diversity, distribution, and species changes		The condition of freshwater mussels in MACA warrants moderate concern. Although freshwater mussels in North America are experiencing significant declines, compared to historical accounts, the number of species present in MACA has increased over time. Species richness is relatively stable through time. Considering that the occurrence of more mussel taxa with efforts to augment imperiled populations the status of freshwater mussels in the park is deemed to be improving. The level of confidence in this assessment is high as sources of data are multiple, recent, and show similar patterns. With the removal of Lock and Dam #6 conditions are expected to improve.
Surface Aquatic Communities Overall			–



Figure 5.15. Kentucky Department of Fish and Wildlife Resources Aquatic Scientist Christopher Owen studies mussels for a survey project in MACA's Green River (Photo by Monte MacGregor).



Figure 5.16. The Green River contains the most diverse population of freshwater mussels in North America and one of the most diverse in the world. (Photo by Monte MacGregor).

5.15.2. Management Considerations

Although the caves of the park draw the most attention of the various resources here, the high biodiversity of the Green River is also a resource of national significance. Although there are some concerns, we judge that conditions are improving and that the surface aquatic communities are being well managed. The intense research into the conditions of mussel populations in the Green River and the advancement that have been made in mussel rearing by Monte MacGregor and colleagues at the Center for Mollusk Conservation at the KDFWR, as well as partnerships with WKU's Green River Biopreserve, and certainly bright spots in resource management at MACA. Such collaborations should be continued and nurtured in every possible way.

5.16. Cave Communities Resource Brief and Narrative

5.16.1. Condition Rationale

MACA and the greater south-central Kentucky karst area hosts one of the most biodiverse cave communities in the world (Figure 5.17; Table 5.15; Culver et al. 2000, NPS 2014). Of the approximately 160 recorded cave species, 52 are obligate cave dwellers and 19 are endemic to the Mammoth Cave area (Toomey et al. 2017; Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, March 2018, personal communication) One of the cave obligate species is the Kentucky cave shrimp which is federally-listed as endangered (Federal Register 1983).

We used four indicators to evaluate the status of cave communities at MACA, 1) Kentucky cave shrimp, 2) Allegheny woodrats, 3) cave microorgansims, and 4) cave crickets. We conclude with medium confidence that cave communities appear to warrant moderate concern for several reasons. The Kentucky cave shrimp is an endangered species with restricted distribution and several potential threats and stressors. Cave microorganisms, while critical to the cave ecosystem in nutrient cycling and as a food source, have the potential to negatively affect native cave biota creating moderate concern in relation to *P. destructans* and *B. amorpha* that can infect and cause death in bats and cave crickets respectively, both keystone species of the cave community. The woodrat is critical to the cave community and its decline or loss could be detrimental to other members of the cave ecosystem. There are serious potential threats to an already declining or small population. Though cricket populations appear to be stable to increasing, as a keystone species to the cave community, the cave cricket should remain a species of concern for resource managers. Though there has been extensive research conducted pertaining to the cave community at MACA and the specific indicators listed here, lack of current or long-term data across indicators makes assessment of trend unfeasible at this time.

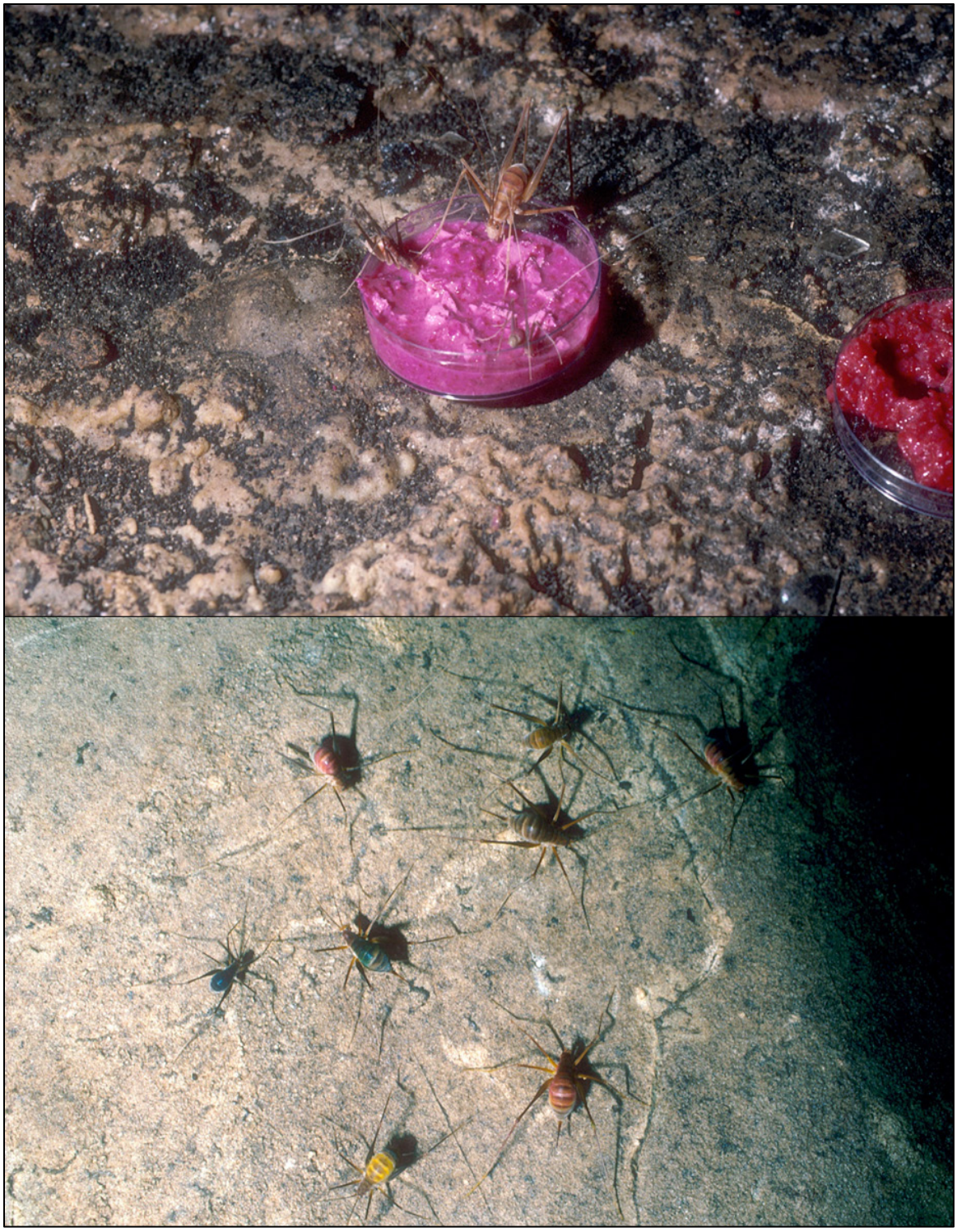


Figure 5.17. In an interesting experiment to track cave cricket (*Hadenoecus subterraneous*) movements, CUPN ecologist fed crickets different colors of dyed food (top image), and they were easily tracked later (bottom image) (NPS photos by Kurt Helf).

Table 5.15. Summary of overall cave community conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

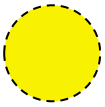
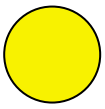
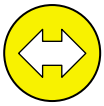
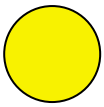
Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Cave communities	Kentucky cave shrimp		As an endangered species with restricted distribution and several potential threats and stressors, the Kentucky cave shrimp with a Recovery Priority rating of 5 warrants moderate concern. The 2015 USFWS 5-year review for *P. ganteri* states that recovery potential remains low, with a Recovery Priority rating of 5. The USFWS rating, 1 being the highest, 18 the lowest, is based on "degree of threat, recovery potential, taxonomic distinctiveness, and presence of an actual or imminent conflict between the species and development activities" (USFWS 2015). Reference conditions established between 1982 and 1998 show stable population estimates. Subsequent surveys by Pearson (2009) show slightly lower total individual numbers at three of the five survey locations and stable to increasing numbers at the remaining two. However, differences in methodology and lack of current data prohibits analysis of trend and provides medium confidence in current condition assessment.
	Cave microorganisms		Cave microorganisms while critical to the cave ecosystem in nutrient cycling and as a food source, have the potential to negatively affect native cave biota creating moderate concern in status and future trends. Fungi such as *P. destructans* and *B. amorpha*, can infect and kill bats and cave crickets respectively, both keystone species of the cave community. Lampenflora not only reduce the quality of the visitor experience but are also out-competing and/or excluding native biota in electrically lit passages. Bacteria and protozoa populations are assumed stable with no data to indicate improving or deteriorating conditions. However, identified stressors to cave conditions (changes in air/water quality, nutrient input, and human use) may pose threats to microorganism populations which form the food base for the cave community. Confidence in assessment is considered medium, and data for trend analysis are not available.

Table 5.15 (continued). Summary of overall cave community conditions, indicators and measures, and rationale for assigning condition assessments at MACA.

Indicators of Condition	Specific Measures	Condition Status/Trend	Rationale
Cave communities (continued)	Allegheny woodrats		A mean woodrat population estimate from 1997–2002 of 8.4 represents reference conditions for this indicator. A mean population estimate of 8.6 was calculated during subsequent monitoring from 2005–2007 so these numbers are considered stable. Concern for woodrat populations at MACA is moderate. The woodrat is critical to the cave community in the diversity and amount of organic matter it contributes to the trophic system. Its decline or loss could be detrimental to other members of the cave ecosystem, and so this population should continue to be of interest to resource managers. In other states woodrats have either experienced dramatic declines, are listed as endangered, or have been extirpated. As healthy populations appear to still exist in Kentucky, MACA could be an important center of distribution for this species. Confidence in this assessment is medium, as monitoring was temporarily suspended in 2008, creating uncertainty in current condition.
	Cave crickets		Population data collected for more than 20 years show stable to increasing numbers at all locations surveyed and therefore warrant a status rating of good. Lack of statistical trend analysis and further interpretation of source and sink population dynamics assign a moderate confidence level to this rating. Though this assessment appears to be favorable, as a keystone species to the cave community, the cave cricket should remain a species of concern for resource managers.
Cave Communities Overall			–

5.16.2. Management Considerations

Cave communities are being managed effectively with current practices. Bats, many species of which use the cave, are certainly threatened, and are discussed in their own sections. There are other rare and endangered species in the cave, and others that play key roles in the subsurface ecosystem, and MACA is working actively and effectively to understand and protect these. It is important to note that scientists with both the MACA Division of S&RM as well as CUPN, along with the various partners, understand well the interrelationships between cave ecological communities and other park resources, particularly water quality. Aside from WNS, the most significant potential threat to the subsurface ecosystem is water pollution, and continuing its efforts to study and protect water quality, is the single most effective strategy that the park can use to protect life in the cave.

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Appendix A. Species List for Mammoth Cave National Park

This appendix (Table A-1) has been drawn from the broader list of US national park species in NPSpecies (NPS 2018i). There is a total of 1,925 species known from the park, and the column headings are self-explanatory in describing the information provided. There are additional fields available in the original database (NPS 2018i), but the most relevant are provided here. For simplicity, since scientific names are provided, some obvious common names were left off. For the eastern screech owl, for example, the name eastern screech-owl was not included.

Table A-1. List of the known species from MACA (NPS 2018i).

Category	Scientific Name	Common Names	Occurrence
Mammal	*Odocoileus virginianus*	white-tailed deer	Present
Mammal	*Canis familiaris*	domestic dog	Present
Mammal	*Canis latrans*	coyote	Present
Mammal	*Urocyon cinereoargenteus*	gray fox	Present
Mammal	*Vulpes*	red fox	Present
Mammal	*Felis catus*	domestic cat	Present
Mammal	*Lynx rufus*	bobcat	Present
Mammal	*Mephitis mephitis*	striped skunk	Present
Mammal	*Lontra Canadensis*	river otter	Present
Mammal	*Mustela frenata*	long-tailed weasel	Present
Mammal	*Mustela vison*	mink	Present
Mammal	*Procyon lotor*	raccoon	Present
Mammal	*Corynorhinus rafinesquii*	Rafinesque's big-eared bat	Present
Mammal	*Eptesicus fuscus*	big brown bat	Present
Mammal	*Lasionycteris noctivagans*	silver-haired bat	Present
Mammal	*Lasiurus borealis*	eastern red bat	Present
Mammal	*Lasiurus cinereus*	hoary bat	Present
Mammal	*Lasiurus seminolus*	Seminole bat	Present
Mammal	*Myotis austroriparius*	southeastern bat	Probable
Mammal	*Myotis grisescens*	gray bat	Present
Mammal	*Myotis leibii*	eastern small-footed bat	Present
Mammal	*Myotis lucifugus*	little brown bat	Present
Mammal	*Myotis septentrionalis*	northern bat	Present
Mammal	*Myotis sodalis*	Indiana bat	Present
Mammal	*Nycticeius humeralis*	evening bat	Present
Mammal	*Perimyotis subflavus*	tri-colored bat	Present
Mammal	*Didelphis virginiana*	Virginia opossum	Present
Mammal	*Sylvilagus floridanus*	eastern cottontail	Present

Category	Scientific Name	Common Names	Occurrence
Mammal	*Castor canadensis*	American beaver	Present
Mammal	*Microtus ochrogaster*	prairie vole	Present
Mammal	*Microtus pinetorum*	woodland vole	Present
Mammal	*Neotoma magister*	Allegheny woodrat	Present
Mammal	*Ondatra zibethicus*	muskrat	Present
Mammal	*Peromyscus leucopus*	white-footed mouse	Present
Mammal	*Reithrodontomys humulis*	eastern harvest mouse	Present
Mammal	*Synaptomys cooperi*	southern bog lemming	Present
Mammal	*Zapus hudsonius*	meadow jumping mouse	Present
Mammal	*Rattus norvegicus*	Norway rat	Present
Mammal	*Glaucomys volans*	southern flying squirrel	Present
Mammal	*Marmota monax*	woodchuck	Present
Mammal	*Sciurus carolinensis*	eastern gray squirrel	Present
Mammal	*Sciurus niger*	eastern fox squirrel	Present
Mammal	*Tamias striatus*	eastern chipmunk	Present
Mammal	*Blarina brevicauda*	northern short-tailed shrew	Present
Mammal	*Cryptotis parva*	least shrew	Present
Mammal	*Sorex fumeus*	smoky shrew	Present
Mammal	*Sorex hoyi*	pygmy shrew	Present
Mammal	*Sorex longirostris*	southeastern shrew	Present
Mammal	*Scalopus aquaticus*	eastern mole	Present
Bird	*Accipiter cooperii*	Cooper’s hawk	Present
Bird	*Accipiter striatus*	sharp-shinned hawk	Present
Bird	*Buteo jamaicensis*	red-tailed hawk	Present
Bird	*Buteo lagopus*	roughleg, rough-legged buzzard	Present
Bird	*Buteo lineatus*	red-shouldered hawk	Present
Bird	*Buteo platypterus*	broad-winged hawk	Present
Bird	*Circus cyaneus*	northern harrier	Present
Bird	*Haliaeetus leucocephalus*	bald eagle	Present
Bird	*Cathartes aura*	turkey vulture	Present
Bird	*Coragyps atratus*	black vulture	Present
Bird	*Pandion haliaetus*	osprey, western osprey	Present
Bird	*Aix sponsa*	wood duck	Present
Bird	*Anas platyrhynchos*	mallard	Present
Bird	*Anas rubripes*	American black duck	Present
Bird	*Anas strepera*	gadwall	Present
Bird	*Branta canadensis*	Canada goose	Present
Bird	*Lophodytes cucullatus*	hooded merganser	Present

Category	Scientific Name	Common Names	Occurrence
Bird	*Chaetura pelagica*	chimney swift	Present
Bird	*Archilochus colubris*	ruby-throated hummingbird	Present
Bird	*Caprimulgus carolinensis*	Chuck-will's-widow	Present
Bird	*Caprimulgus vociferus*	whip-poor-will	Present
Bird	*Chordeiles minor*	common nighthawk	Probable
Bird	*Charadrius vociferus*	killdeer	Present
Bird	*Larus delawarensis*	ring-billed gull	Present
Bird	*Actitis macularius*	spotted sandpiper	Present
Bird	*Gallinago gallinago*	common snipe	Present
Bird	*Scolopax minor*	American woodcock	Present
Bird	*Columba livia*	rock pigeon	Present
Bird	*Zenaida macroura*	mourning dove	Present
Bird	*Ceryle alcyon*	belted lingfisher	Present
Bird	*Coccyzus americanus*	yellow-billed cuckoo	Present
Bird	*Coccyzus erythropthalmus*	black-billed cuckoo	Probable
Bird	*Falco columbarius*	Merlin	Present
Bird	*Falco sparverius*	American kestrel	Present
Bird	*Colinus virginianus*	northern bobwhite	Present
Bird	*Meleagris gallopavo*	wild turkey	Present
Bird	*Grus canadensis*	sandhill crane	Probable
Bird	*Fulica americana*	American coot	Present
Bird	*Eremophila alpestris*	horned lark	Present
Bird	*Bombycilla cedrorum*	cedar waxwing	Present
Bird	*Cardinalis cardinalis*	northern cardinal	Present
Bird	*Passerina caerulea*	blue grosbeak	Present
Bird	*Passerina cyanea*	indigo bunting	Present
Bird	*Pheucticus ludovicianus*	rose-breasted grosbeak	Present
Bird	*Piranga olivacea*	scarlet tanager	Present
Bird	*Piranga rubra*	summer tanager	Present
Bird	*Spiza americana*	dickcissel	Present
Bird	*Certhia americana*	brown creeper	Present
Bird	*Corvus brachyrhynchos*	American crow	Present
Bird	*Cyanocitta cristata*	blue jay	Present
Bird	*Junco hyemalis*	dark-eyed Junco	Present
Bird	*Melospiza georgiana*	swamp sparrow	Present
Bird	*Melospiza lincolnii*	Lincoln's sparrow	Present
Bird	*Melospiza melodia*	song sparrow	Present
Bird	*Passerculus sandwichensis*	Savannah sparrow	Present

Category	Scientific Name	Common Names	Occurrence
Bird	*Passerella iliaca*	fox sparrow, red fox sparrow	Present
Bird	*Pipilo erythrophthalmus*	eastern towhee, rufous-sided towhee	Present
Bird	*Spizella arborea*	American tree sparrow	Present
Bird	*Spizella passerina*	chipping sparrow	Present
Bird	*Spizella pusilla*	field sparrow	Present
Bird	*Zonotrichia albicollis*	white-throated sparrow	Present
Bird	*Zonotrichia leucophrys*	white-crowned sparrow	Present
Bird	*Carduelis pinus*	pine siskin	Present
Bird	*Carduelis tristis*	American goldfinch	Present
Bird	*Carpodacus mexicanus*	house finch	Present
Bird	*Carpodacus purpureus*	purple finch	Present
Bird	*Coccothraustes vespertinus*	evening grosbeak	Probable
Bird	*Hirundo rustica*	barn swallow	Present
Bird	*Progne subis*	purple martin	Present
Bird	*Stelgidopteryx serripennis*	northern rough-winged swallow	Present
Bird	*Tachycineta bicolor*	tree swallow	Present
Bird	*Agelaius phoeniceus*	red-winged blackbird	Present
Bird	*Euphagus carolinus*	rusty blackbird	Present
Bird	*Icterus galbula*	Baltimore oriole, northern oriole	Present
Bird	*Icterus spurius*	orchard oriole	Present
Bird	*Molothrus ater*	brown-headed cowbird	Present
Bird	*Quiscalus quiscula*	common grackle	Present
Bird	*Sturnella magna*	eastern meadowlark	Present
Bird	*Dumetella carolinensis*	gray catbird, grey catbird	Present
Bird	*Mimus polyglottos*	northern mockingbird	Present
Bird	*Toxostoma rufum*	brown thrasher	Present
Bird	*Anthus rubescens*	American pipit, buff-bellied pipit	Probable
Bird	*Baeolophus bicolor*	tufted titmouse	Present
Bird	*Poecile carolinensis*	Carolina chickadee	Present
Bird	*Dendroica caerulescens*	black-throated blue warbler	Present
Bird	*Dendroica castanea*	bay-breasted warbler	Present
Bird	*Dendroica cerulea*	cerulean warbler	Present
Bird	*Dendroica coronata*	yellow-rumped warbler	Present
Bird	*Dendroica discolor*	prairie warbler	Present
Bird	*Dendroica dominica*	yellow-throated warbler	Present
Bird	*Dendroica fusca*	blackburnian warbler	Present
Bird	*Dendroica magnolia*	magnolia warbler	Present
Bird	*Dendroica palmarum*	palm warbler	Present

Category	Scientific Name	Common Names	Occurrence
Bird	*Dendroica pensylvanica*	chestnut-sided warbler	Present
Bird	*Dendroica petechia*	American yellow warbler	Present
Bird	*Dendroica pinus*	pine warbler	Present
Bird	*Dendroica striata*	blackpoll warbler	Present
Bird	*Dendroica tigrina*	Cape May warbler	Present
Bird	*Dendroica virens*	black-throated green warbler	Present
Bird	*Geothlypis trichas*	common yellowthroat	Present
Bird	*Helmitheros vermivorum*	worm-eating warbler	Present
Bird	*Icteria virens*	yellow-breasted chat	Present
Bird	*Mniotilta varia*	black-and-white warbler	Present
Bird	*Oporornis agilis*	Connecticut warbler	Present
Bird	*Oporornis formosus*	Kentucky warbler	Present
Bird	*Oporornis philadelphia*	mourning warbler	Present
Bird	*Parula americana*	northern parula	Present
Bird	*Protonotaria citrea*	prothonotary warbler	Present
Bird	*Seiurus aurocapilla*	ovenbird	Present
Bird	*Seiurus motacilla*	Louisiana waterthrush	Present
Bird	*Seiurus noveboracensis*	northern waterthrush	Present
Bird	*Setophaga ruticilla*	American redstart	Present
Bird	*Vermivora celata*	orange-crowned warbler	Present
Bird	*Vermivora chrysoptera*	golden-winged warbler	Present
Bird	*Vermivora peregrina*	Tennessee warbler	Present
Bird	*Vermivora pinus*	blue-winged warbler	Present
Bird	*Vermivora ruficapilla*	Nashville warbler	Present
Bird	*Wilsonia canadensis*	Canada warbler	Present
Bird	*Wilsonia citrina*	hooded warbler	Present
Bird	*Wilsonia pusilla*	Wilson’s warbler	Present
Bird	*Passer domesticus*	house sparrow	Present
Bird	*Polioptila caerulea*	blue-gray gnatcatcher	Present
Bird	*Regulus calendula*	ruby-crowned kinglet	Present
Bird	*Regulus satrapa*	golden-crowned kinglet	Present
Bird	*Sitta canadensis*	red-breasted nuthatch	Present
Bird	*Sitta carolinensis*	white-breasted nuthatch	Present
Bird	*Sturnus vulgaris*	common starling, European s tarling	Present
Bird	*Cistothorus platensis*	sedge wren	Probable
Bird	*Thryomanes bewickii*	Bewick’s wren	Probable
Bird	*Thryothorus ludovicianus*	Carolina wren	Present

Category	Scientific Name	Common Names	Occurrence
Bird	*Troglodytes aedon*	house wren	Present
Bird	*Troglodytes troglodytes*	winter wren	Present
Bird	*Catharus fuscescens*	veery	Present
Bird	*Catharus guttatus*	hermit thrush	Present
Bird	*Catharus minimus*	gray-cheeked thrush	Present
Bird	*Catharus ustulatus*	Swainson’s thrush	Present
Bird	*Hylocichla mustelina*	wood thrush	Present
Bird	*Sialia sialis*	eastern bluebird	Present
Bird	*Turdus migratorius*	American robin	Present
Bird	*Contopus cooperi*	olive-sided flycatcher	Present
Bird	*Contopus virens*	eastern wood pewee	Present
Bird	*Empidonax flaviventris*	yellow-bellied flycatcher	Present
Bird	*Empidonax minimus*	least flycatcher	Present
Bird	*Empidonax virescens*	Acadian flycatcher	Present
Bird	*Myiarchus crinitus*	great crested flycatcher	Present
Bird	*Sayornis phoebe*	eastern phoebe	Present
Bird	*Tyrannus tyrannus*	eastern kingbird	Present
Bird	*Vireo flavifrons*	yellow-throated vireo	Present
Bird	*Vireo gilvus*	warbling vireo	Present
Bird	*Vireo griseus*	white-eyed vireo	Present
Bird	*Vireo olivaceus*	red-eyed vireo	Present
Bird	*Vireo philadelphicus*	Philadelphia vireo	Present
Bird	*Vireo solitarius*	blue-headed vireo, solitary vireo	Present
Bird	*Ardea herodias*	great blue heron	Present
Bird	*Butorides virescens*	green heron	Present
Bird	*Colaptes auratus*	northern flicker	Present
Bird	*Dryocopus pileatus*	pileated woodpecker	Present
Bird	*Melanerpes carolinus*	red-bellied woodpecker	Present
Bird	*Melanerpes erythrocephalus*	red-headed woodpecker	Present
Bird	*Picoides pubescens*	downy woodpecker	Present
Bird	*Picoides villosus*	hairy woodpecker	Present
Bird	*Sphyrapicus varius*	yellow-bellied sapsucker	Present
Bird	*Podilymbus podiceps*	pied-billed grebe	Present
Bird	*Aegolius acadicus*	northern saw-whet owl	Probable
Bird	*Bubo virginianus*	great horned owl	Present
Bird	*Megascops asio*	eastern screech owl	Present
Bird	*Strix varia*	barred owl	Present
Reptile	*Ophisaurus attenuatus*	eastern slender glass lizard	Present

Category	Scientific Name	Common Names	Occurrence
Reptile	*Carphophis amoenus*	worm snake	Present
Reptile	*Coluber constrictor*	black racer	Present
Reptile	*Diadophis punctatus*	ringneck snake	Present
Reptile	*Elaphe guttata*	corn snake	Present
Reptile	*Elaphe spiloides*	black rat snake	Present
Reptile	*Heterodon platirhinos*	eastern hognose snake	Present
Reptile	*Lampropeltis calligaster calligaster*	prairie kingsnake	Present
Reptile	*Lampropeltis getula nigra*	black kingsnake	Present
Reptile	*Lampropeltis triangulum*	eastern milk snake	Present
Reptile	*Nerodia sipedon*	northern water snake	Present
Reptile	*Opheodrys aestivus*	rough green snake	Present
Reptile	*Regina septemvittata*	queen snake	Present
Reptile	*Storeria dekayi*	brown snake	Present
Reptile	*Storeria occipitomaculata*	northern redbelly snake	Present
Reptile	*Thamnophis sirtalis*	eastern garter snake	Present
Reptile	*Virginia valeriae elegans*	western earth snake	Present
Reptile	*Sceloporus undulatus*	eastern fence lizard	Present
Reptile	*Eumeces anthracinus*	coal skink	Present
Reptile	*Eumeces fasciatus*	five-lined skink	Present
Reptile	*Eumeces laticeps*	broadhead skink	Present
Reptile	*Scincella lateralis*	ground skink	Present
Reptile	*Agkistrodon contortrix*	copperhead	Present
Reptile	*Crotalus horridus*	timber rattlesnake	Present
Reptile	*Chelydra serpentina*	common snapping turtle	Present
Reptile	*Chrysemys picta marginata*	midland painted turtle	Present
Reptile	*Graptemys geographica*	common map turtle	Present
Reptile	*Graptemys ouachitensis*	Ouachita map turtle	Present
Reptile	*Pseudemys concinna*	eastern river cooter	Present
Reptile	*Terrapene carolina*	eastern box turtle	Present
Reptile	*Trachemys scripta elegans*	red-eared slider	Present
Reptile	*Sternotherus odoratus*	common musk turtle	Probable
Reptile	*Apalone spinifera*	spiny softshell turtle	Present
Amphibian	*Bufo americanus*	American toad	Present
Amphibian	*Bufo fowleri*	Fowler’s toad	Present
Amphibian	*Acris crepitans*	northern cricket frog	Present
Amphibian	*Hyla chrysoscelis*	Cope’s gray treefrog	Present
Amphibian	*Pseudacris brachyphona*	mountain chorus frog	Present

Category	Scientific Name	Common Names	Occurrence
Amphibian	*Pseudacris crucifer*	spring peeper	Present
Amphibian	*Pseudacris feriarum*	upland chorus frog	Present
Amphibian	*Gastrophryne carolinensis*	eastern narrowmouth toad	Present
Amphibian	*Rana catesbeiana*	bullfrog	Present
Amphibian	*Rana clamitans*	green frog	Present
Amphibian	*Rana palustris*	pickerel frog	Present
Amphibian	*Rana sphenocephala*	southern leopard frog	Present
Amphibian	*Rana sylvatica*	wood frog	Present
Amphibian	*Scaphiopus holbrookii*	eastern spadefoot	Present
Amphibian	*Ambystoma jeffersonianum*	Jefferson salamander	Present
Amphibian	*Ambystoma maculatum*	spotted salamander	Present
Amphibian	*Ambystoma opacum*	marbled salamander	Present
Amphibian	*Desmognathus fuscus*	northern dusky salamander	Present
Amphibian	*Eurycea cirrigera*	southern two-lined salamander	Present
Amphibian	*Eurycea longicauda*	longtail salamander	Present
Amphibian	*Eurycea lucifuga*	cave salamander	Present
Amphibian	*Hemidactylium scutatum*	four-toed salamander	Present
Amphibian	*Plethodon dorsalis*	northern zigzag salamander	Present
Amphibian	*Plethodon glutinosus*	northern slimy salamander	Present
Amphibian	*Pseudotriton diastictus*	midland mud salamander	Present
Amphibian	*Pseudotriton ruber*	northern red salamander	Present
Amphibian	*Necturus maculosus*	common mudpuppy	Probable
Amphibian	*Notophthalmus viridescens*	red-spotted newt	Present
Fish	*Anguilla rostrata*	American eel	Present
Fish	*Labidesthes sicculus*	brook silverside	Present
Fish	*Alosa chrysochloris*	skipjack herring	Present
Fish	*Dorosoma cepedianum*	gizzard shad	Present
Fish	*Carpiodes carpio*	river carpsucker	Present
Fish	*Carpiodes cyprinus*	quillback	Present
Fish	*Catostomus commersonii*	white sucker	Present
Fish	*Hypentelium nigricans*	northern hog sucker	Present
Fish	*Ictiobus bubalus*	smallmouth buffalo	Present
Fish	*Minytrema melanops*	spotted sucker	Present
Fish	*Moxostoma anisurum*	silver redhorse	Present
Fish	*Moxostoma breviceps*	hookfin redhorse, smallmouth redhorse	Present
Fish	*Moxostoma carinatum*	river redhorse	Present
Fish	*Moxostoma duquesnei*	black redhorse	Present
Fish	*Moxostoma erythrurum*	golden redhorse	Present

Category	Scientific Name	Common Names	Occurrence
Fish	*Moxostoma macrolepidotum*	shorthead redhorse	Present
Fish	*Campostoma oligolepis*	largescale stoneroller	Present
Fish	*Carassius auratus*	goldfish	Present
Fish	*Cyprinella spiloptera*	spotfin shiner	Present
Fish	*Cyprinus carpio*	common carp	Present
Fish	*Erimystax dissimilis*	streamline chub	Present
Fish	*Hybopsis amblops*	bigeye chub	Present
Fish	*Luxilus chrysocephalus*	striped shiner	Present
Fish	*Lythrurus ardens*	rosefin shiner	Present
Fish	*Macrhybopsis aestivalis*	speckled chub	Present
Fish	*Notemigonus crysoleucas*	golden shiner	Present
Fish	*Notropis ariommus*	popeye shiner	Present
Fish	*Notropis atherinoides*	emerald shiner	Present
Fish	*Notropis buchanani*	ghost shiner	Present
Fish	*Notropis micropteryx*	highland shiner, redface shiner, southern rosyface shiner	Present
Fish	*Notropis photogenis*	silver shiner	Present
Fish	*Notropis rubellus*	rosyface shiner	Present
Fish	*Notropis volucellus*	mimic shiner	Present
Fish	*Opsopoeodus emiliae*	pugnose minnow	Present
Fish	*Phoxinus erythrogaster*	southern redbelly dace	Present
Fish	*Pimephales notatus*	bluntnose minnow	Present
Fish	*Pimephales vigilax*	bullhead minnow	Present
Fish	*Semotilus atromaculatus*	creek chub	Present
Fish	*Fundulus catenatus*	northern studfish	Present
Fish	*Fundulus notatus*	blackstripe topminnow	Present
Fish	*Gambusia affinis*	mosquitofish	Present
Fish	*Esox americanus*	grass pickerel	Present
Fish	*Esox masquinongy*	muskellunge	Present
Fish	*Lepisosteus osseus*	longnose gar	Present
Fish	*Hiodon tergisus*	mooneye	Present
Fish	*Ambloplites rupestris*	rock bass	Present
Fish	*Lepomis cyanellus*	green sunfish	Present
Fish	*Lepomis gulosus*	warmouth	Present
Fish	*Lepomis macrochirus*	bluegill	Present
Fish	*Lepomis megalotis*	longear sunfish	Present
Fish	*Lepomis microlophus*	redear sunfish	Present
Fish	*Micropterus dolomieu*	smallmouth bass	Present

Category	Scientific Name	Common Names	Occurrence
Fish	*Micropterus punctulatus*	spotted bass	Present
Fish	*Micropterus salmoides*	largemouth bass	Present
Fish	*Pomoxis annularis*	white crappie	Present
Fish	*Pomoxis nigromaculatus*	black crappie	Present
Fish	*Morone chrysops*	white bass	Present
Fish	*Morone saxatilis*	–	Present
Fish	*Ammocrypta clara*	western sand darter	Present
Fish	*Etheostoma bellum*	orangefin darter	Present
Fish	*Etheostoma blennioides*	greenside darter	Present
Fish	*Etheostoma caeruleum*	rainbow darter	Present
Fish	*Etheostoma flabellare*	fantail darter	Present
Fish	*Etheostoma maculatum*	spotted darter	Present
Fish	*Etheostoma nigrum*	Johnny darter	Present
Fish	*Etheostoma rafinesquei*	Kentucky snubnose darter	Present
Fish	*Etheostoma spectabile*	orangethroat darter	Present
Fish	*Etheostoma stigmaeum*	speckled darter	Present
Fish	*Etheostoma tippecanoe*	tippecanoe darter	Present
Fish	*Etheostoma zonale*	banded darter	Present
Fish	*Percina caprodes*	logperch	Present
Fish	*Percina copelandi*	channel darter	Present
Fish	*Percina evides*	gilt darter	Present
Fish	*Percina phoxocephala*	slenderhead darter	Present
Fish	*Percina sciera*	dusky darter	Present
Fish	*Sander vitreus*	walleye	Present
Fish	*Aplodinotus grunniens*	freshwater drum	Present
Fish	*Amblyopsis spelaea*	northern cavefish	Present
Fish	*Forbesichthys agassizii*	spring cavefish	Present
Fish	*Typhlichthys subterraneus*	southern cavefish	Present
Fish	*Oncorhynchus mykiss*	rainbow trout	Present
Fish	*Cottus carolinae*	banded sculpin	Present
Fish	*Ictalurus punctatus*	channel catfish	Present
Fish	*Noturus eleutherus*	mountain madtom	Present
Fish	*Noturus miurus*	brindled madtom	Present
Fish	*Noturus nocturnus*	freckled madtom	Present
Fish	*Pylodictis olivaris*	flathead catfish	Present
Vascular Plant	*Acorus calamus*	calamus, sweetflag, sweet-flag	Present
Vascular Plant	*Alisma subcordatum*	American water plantain, southern water plantain, waterplaintain	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Sagittaria brevirostra*	midwestern arrowhead, shortbeak arrowhead, short-beak arrowhead	Present
Vascular Plant	*Sagittaria graminea*	grassy arrowhead	Present
Vascular Plant	*Sagittaria latifolia*	broadleaf arrowhead, common arrowhead, duck-potato, wapato	Present
Vascular Plant	*Sagittaria platyphylla*	delta arrowhead	Present
Vascular Plant	*Sagittaria rigida*	sessilefruit arrowhead, sessile-fruited arrowhead	Present
Vascular Plant	*Arisaema dracontium*	green dragon, greendragon	Present
Vascular Plant	*Arisaema triphyllum*	Jack in the pulpit	Present
Vascular Plant	*Arisaema triphyllum* ssp. *triphyllum*	Jack in the pulpit	Present
Vascular Plant	*Lemna minor*	common duckweed	Present
Vascular Plant	*Spirodela polyrrhiza*	common duckmeat, common duckweed, greater duckweed	Present
Vascular Plant	*Wolffia*	watermeal	Present
Vascular Plant	*Potamogeton diversifolius*	waterthread, waterthread pondweed	Present
Vascular Plant	*Potamogeton pulcher*	heartleaf pondweed, spotted pondweed	Present
Vascular Plant	*Angelica venenosa*	hairy angelica, venous angelica	Present
Vascular Plant	*Chaerophyllum procumbens*	spreading chervil	Present
Vascular Plant	*Chaerophyllum tainturieri* var. *tainturieri*	hairyfruit chervil	Present
Vascular Plant	*Cicuta maculata* var. *maculata*	common water hemlock, poison parsnip, spotted cowbane	Present
Vascular Plant	*Conium maculatum*	cigue maculee, deadly hemlock, poison hemlock	Present
Vascular Plant	*Cryptotaenia canadensis*	Canadian honewort, honewort	Present
Vascular Plant	*Daucus carota*	bird’s nest, Queen Anne’s lace, wild carrot	Present
Vascular Plant	*Erigenia bulbosa*	harbinger of spring	Present
Vascular Plant	*Eryngium yuccifolium*	button eryngo, button snakeroot, Yuccaleaf eryngo	Present
Vascular Plant	*Ligusticum canadense*	Canadian licoriceroot	Present
Vascular Plant	*Osmorhiza claytonii*	Clayton’s sweetroot, hairy sweet-cicely	Present
Vascular Plant	*Osmorhiza longistylis*	aniseroot, longstyle sweetroot	Present
Vascular Plant	*Oxypolis rigidior*	stiff cowbane	Present
Vascular Plant	*Pastinaca sativa*	wild parsnip	Present
Vascular Plant	*Sanicula canadensis*	Canada sanicle, Canadian blacksnakeroot	Present
Vascular Plant	*Sanicula canadensis* var. *canadensis*	Canadian blacksnakeroot	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Sanicula marilandica*	black sanicle, Maryland black-snakeroot, Maryland sanicle	Present
Vascular Plant	*Sanicula odorata*	cluster sanicle, clustered blacksnakeroot	Present
Vascular Plant	*Sanicula smallii*	Small's blacksnakeroot	Present
Vascular Plant	*Sanicula trifoliata*	largefruit blacksnakeroot	Present
Vascular Plant	*Taenidia integerrima*	yellow pimpernel, yellow pimpernell	Present
Vascular Plant	*Thaspium barbinode*	hairyjoint meadowparsnip	Present
Vascular Plant	*Thaspium pinnatifidum*	cutleaf meadowparsnip	Present
Vascular Plant	*Thaspium trifoliatum*	purple meadowparsnip, purple thaspium	Present
Vascular Plant	*Zizia aptera*	heartleaf alexanders, heart-leaf alexanders, meadow zizia, meadowparsnip	Present
Vascular Plant	*Zizia aurea*	golden alexanders, golden zizia	Present
Vascular Plant	*Aralia racemosa*	American spikenard	Present
Vascular Plant	*Aralia spinosa*	angelicatree, devils walkingstick, devil's walkingstick	Present
Vascular Plant	*Hedera helix*	English ivy	Present
Vascular Plant	*Panax quinquefolius*	American ginseng	Present
Vascular Plant	*Ilex decidua*	possumhaw	Present
Vascular Plant	*Ilex opaca* var. *opaca*	American holly	Present
Vascular Plant	*Allium canadense*	Canada garlic, meadow garlic, meadow onion, wild onion	Present
Vascular Plant	*Allium cernuum*	nodding onion	Present
Vascular Plant	*Allium sativum*	cultivated garlic	Present
Vascular Plant	*Allium tricoccum*	ramp, small white leek, wild leek	Present
Vascular Plant	*Allium vineale* ssp. *vineale*	wild garlic	Present
Vascular Plant	*Hymenocallis caroliniana*	Carolina spiderlily	Present
Vascular Plant	*Narcissus poeticus*	poet's narcissus	Present
Vascular Plant	*Narcissus pseudonarcissus*	common daffodil, daffodil	Present
Vascular Plant	*Nothoscordum bivalve*	crowpoison	Present
Vascular Plant	*Asparagus officinalis*	asparagus, garden asparagus	Present
Vascular Plant	*Camassia scilloides*	Atlantic camas	Present
Vascular Plant	*Maianthemum racemosum* ssp. *racemosum*	feather Solomon's seal	Present
Vascular Plant	*Maianthemum stellatum*	false Solomon's seal, little false Solomon's-seal, star false Solomon's-seal, star-flower Solomon's-seal, starry false lily of the valley, starry false Solomon's seal, starry false Solomon's-seal, starry Solomon's-seal	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Manfreda virginica*	false aloe	Present
Vascular Plant	*Muscari botryoides*	common grape hyacinth	Present
Vascular Plant	*Polygonatum biflorum* var. *commutatum*	king Solomon's seal, King Solomon's-seal, smooth Solomon's seal	Present
Vascular Plant	*Polygonatum pubescens*	hairy Solomon's seal	Present
Vascular Plant	*Yucca filamentosa*	Adam's needle	Present
Vascular Plant	*Hypoxis hirsuta*	common goldstar	Present
Vascular Plant	*Belamcanda chinensis*	blackberry lily	Present
Vascular Plant	*Iris cristata*	crested iris, dwarf crested iris	Present
Vascular Plant	*Iris verna* var. *smalliana*	dwarf violet iris	Present
Vascular Plant	*Sisyrinchium albidum*	white blueeyed grass	Present
Vascular Plant	*Sisyrinchium angustifolium*	blueeyed grass, blue-eyed grass, common blue-eyed grass, common blue-eyedgrass, narrowleaf blue-eyed grass	Present
Vascular Plant	*Aplectrum hyemale*	Adam and Eve, puttyroot	Present
Vascular Plant	*Corallorrhiza odontorhiza*	autumn coralroot	Present
Vascular Plant	*Corallorrhiza wisteriana*	coralroot, spring coralroot	Present
Vascular Plant	*Cypripedium parviflorum*	greater yellow lady's slipper	Present
Vascular Plant	*Galearis spectabilis*	showy orchid	Present
Vascular Plant	*Goodyera pubescens*	downy rattlesnake-plantain	Present
Vascular Plant	*Hexalectris spicata*	crested coralroot, spiked crested coralroot, spiked crested-coralroot	Present
Vascular Plant	*Liparis liliifolia*	brown widelip orchid	Present
Vascular Plant	*Platanthera clavellata*	green woodland orchid, small green wood orchid	Present
Vascular Plant	*Platanthera lacera*	green fringed orchid	Present
Vascular Plant	*Spiranthes cernua*	common ladies' tresses, nodding ladiestresses, nodding ladies'-tresses, nodding lady's tresses, white nodding ladies'-tresses	Present
Vascular Plant	*Spiranthes lacera*	northern slender ladiestresses,	Present
Vascular Plant	*Spiranthes ovalis*	October ladiestresses, October ladies'-tresses, October lady's tresses	Present
Vascular Plant	*Spiranthes tuberosa*	little ladiestresses, little ladies'-tresses, little lady's tresses	Present
Vascular Plant	*Spiranthes vernalis*	spring ladies'-tresses, spring lady's tresses, upland ladiestresses	Present
Vascular Plant	*Tipularia discolor*	crippled cranefly	Present
Vascular Plant	*Triphora trianthophora*	three birds orchid, threebirds	Present
Vascular Plant	*Hemerocallis fulva*	orange daylily, tawny daylily	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Achillea millefolium*	bloodwort, carpenter's weed, common yarrow, hierba de las cortaduras, milenrama, milfoil, plumajillo, western yarrow, yarrow	Present
Vascular Plant	*Ageratina altissima*	white snakeroot	Present
Vascular Plant	*Ageratina altissima* var. *altissima*	white snakeroot	Present
Vascular Plant	*Ageratina aromatica* var. *aromatica*	lesser snakeroot	Present
Vascular Plant	*Ambrosia artemisiifolia*	annual ragweed, common ragweed, low ragweed, ragweed, Roman wormwood, short ragweed, small ragweed	Present
Vascular Plant	*Ambrosia artemisiifolia* var. *elatior*	annual ragweed	Present
Vascular Plant	*Ambrosia trifida* var. *trifida*	great ragweed	Present
Vascular Plant	*Antennaria neglecta*	field pussytoes	Present
Vascular Plant	*Antennaria plantaginifolia*	plantainleaf pussytoes, woman's tobacco	Present
Vascular Plant	*Antennaria solitaria*	singlehead pussytoes	Present
Vascular Plant	*Anthemis cotula*	chamomile, dog fennel, dogfennel, mayweed, mayweed chamomile, mayweed dogfennel, stinking chamomile, stinkweed	Present
Vascular Plant	*Arctium minus*	beggar's button, burdock, common burdock, lesser burdock, lesser burrdock, small burdock, smaller burdock, wild burdock, wild rhubarb	Present
Vascular Plant	*Arnoglossum atriplicifolium*	armoglossum	Present
Vascular Plant	*Arnoglossum muehlenbergii*	great Indian plaintain	Present
Vascular Plant	*Artemisia annua*	annual wormwood, sweet sagewort	Present
Vascular Plant	*Artemisia ludoviciana* ssp. *ludoviciana*	cudweed sagewort, foothill sagewort, Louisiana sagewort, white sagebrush	Present
Vascular Plant	*Astranthium integrifolium* ssp. *integrifolium*	entireleaf western daisy	Present
Vascular Plant	*Bidens aristosa*	bearded beggarticks, long-bracted beggar-ticks, tickseed sunflower	Present
Vascular Plant	*Bidens bipinnata*	Spanish needles, spanish-needles	Present
Vascular Plant	*Bidens discoidea*	discoid beggarticks, small beggarticks, swamp beggar-ticks	Present
Vascular Plant	*Bidens frondosa*	bur marigold, devil's beggartick, devil's beggarticks, devil's bootjack, devil's-pitchfork, pitchfork weed, sticktight, sticktights, tickseed sunflower	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Bidens tripartita*	threelobe beggarticks, three-lobe beggarticks	Present
Vascular Plant	*Brickellia eupatorioides* var. *eupatorioides*	false boneset	Present
Vascular Plant	*Carduus nutans*	chardon penche, musk thistle, nodding plumeless thistle, nodding plumeless-thistle, nodding thistle, plumeless thistle	Present
Vascular Plant	*Centaurea biebersteinii*	spotted knapweed	Present
Vascular Plant	*Cichorium intybus*	blue sailors, chickory, chicory, coffeeweed, common chicory, French endive, succory	Present
Vascular Plant	*Cirsium altissimum*	roadside thistle, tall thistle	Present
Vascular Plant	*Cirsium carolinianum*	Carolina thistle, soft thistle	Present
Vascular Plant	*Cirsium discolor*	field thistle	Present
Vascular Plant	*Cirsium virginianum*	Virginia thistle	Present
Vascular Plant	*Cirsium vulgare*	bull thistle, common thistle, spear thistle	Present
Vascular Plant	*Conoclinium coelestinum*	blue mistflower	Present
Vascular Plant	*Conyza canadensis*	Canadian horseweed	Present
Vascular Plant	*Conyza canadensis* var. *pusilla*	Canadian horseweed	Present
Vascular Plant	*Coreopsis auriculata*	lobed tickseed	Present
Vascular Plant	*Coreopsis lanceolata*	lance coreopsis, lanceleaf tickseed	Present
Vascular Plant	*Coreopsis major*	greater tickseed	Present
Vascular Plant	*Coreopsis tripteris*	Atlantic coreopsis, tall tickseed	Present
Vascular Plant	*Doellingeria infirma*	cornel-leaf whitetop	Present
Vascular Plant	*Doellingeria umbellata* var. *umbellata*	parasol whitetop	Present
Vascular Plant	*Echinacea pallida*	pale echinacea, pale purple coneflower, purple coneflower	Present
Vascular Plant	*Echinacea purpurea*	eastern purple coneflower, purple coneflower	Present
Vascular Plant	*Eclipta prostrata*	eclipta, false daisy, yerba de tago, yerba de tajo	Present
Vascular Plant	*Elephantopus carolinianus*	Carolina elephantsfoot, leafy elephantfoot	Present
Vascular Plant	*Erechtites hieraciifolia* var. *hieraciifolia*	American burnweed	Present
Vascular Plant	*Erigeron annuus*	annual fleabane, eastern daisy fleabane	Present
Vascular Plant	*Erigeron philadelphicus*	Philadelphia daisy, Philadelphia fleabane	Present
Vascular Plant	*Erigeron pulchellus*	poor robin fleabane, robin’s plantain	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Erigeron strigosus*	daisy fleabane, prairie fleabane, rough fleabane	Present
Vascular Plant	*Eupatorium album* var. *album*	white thoroughwort	Present
Vascular Plant	*Eupatorium album* var. *glandulosum*	white thoroughwort	Present
Vascular Plant	*Eupatorium altissimum*	tall joepyeweed, tall thoroughwort	Present
Vascular Plant	*Eupatorium dubium*	coastalplain joepyeweed	Present
Vascular Plant	*Eupatorium fistulosum*	joepyeweed, joe-pye-weed, trumpetweed	Present
Vascular Plant	*Eupatorium hyssopifolium*	hyssopleaf thoroughwort	Present
Vascular Plant	*Eupatorium hyssopifolium* var. *laciniatum*	hyssopleaf thoroughwort	Present
Vascular Plant	*Eupatorium perfoliatum* var. *perfoliatum*	common boneset	Present
Vascular Plant	*Eupatorium pilosum*	rough boneset	Present
Vascular Plant	*Eupatorium purpureum* var. *purpureum*	sweetscented joepyeweed	Present
Vascular Plant	*Eupatorium rotundifolium*	roundleaf eupatorium, roundleaf thoroughwort	Present
Vascular Plant	*Eupatorium rotundifolium* var. *ovatum*	roundleaf thoroughwort	Present
Vascular Plant	*Eupatorium rotundifolium* var. *rotundifolium*	roundleaf thoroughwort	Present
Vascular Plant	*Eupatorium serotinum*	late eupatorium, lateflowering thoroughwort	Present
Vascular Plant	*Eupatorium sessilifolium*	upland boneset	Present
Vascular Plant	*Eupatorium* X *truncatum*	eupatorium	Present
Vascular Plant	*Eurybia divaricata*	white wood aster	Present
Vascular Plant	*Eurybia macrophylla*	bigleaf aster	Present
Vascular Plant	*Euthamia graminifolia* var. *graminifolia*	flattop goldentop	Present
Vascular Plant	*Galinsoga quadriradiata*	fringed quickweed, hairy galinsoga, shaggy soldier, shaggy-soldier	Present
Vascular Plant	*Gamochaeta purpurea*	spoonleaf purple everlasting	Present
Vascular Plant	*Hasteola suaveolens*	–	Present
Vascular Plant	*Helenium autumnale* var. *autumnale*	common sneezeweed	Present
Vascular Plant	*Helenium flexuosum*	purplehead sneezeweed	Present
Vascular Plant	*Helianthus divaricatus*	woodland sunflower	Present
Vascular Plant	*Helianthus eggertii*	Eggert’s sunflower	Present
Vascular Plant	*Helianthus hirsutus*	hairy sunflower	Present
Vascular Plant	*Helianthus maximiliani*	Maximilian sunflower	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Helianthus microcephalus*	small woodland sunflower	Present
Vascular Plant	*Helianthus mollis*	ashy sunflower	Present
Vascular Plant	*Helianthus occidentalis* ssp. *occidentalis*	fewleaf sunflower	Present
Vascular Plant	*Helianthus strumosus*	paleleaf woodland sunflower	Present
Vascular Plant	*Helianthus tuberosus*	girasole, Jerusalem artichoke, Jerusalem sunflower, Jerusalem-artichoke	Present
Vascular Plant	*Heliopsis helianthoides*	heliopsis sunflower, oxeye, smooth oxeye, sunflower heliopsis	Present
Vascular Plant	*Heliopsis helianthoides* var. *scabra*	smooth oxeye	Present
Vascular Plant	*Heterotheca camporum* var. *glandulissimum*	lemonyellow falsegoldenaster	Present
Vascular Plant	*Hieracium aurantiacum*	orange hawkweed	Present
Vascular Plant	*Hieracium gronovii*	Gronovis hawkweed, queendevil	Present
Vascular Plant	*Hieracium marianum*	–	Present
Vascular Plant	*Hieracium pilosella*	mouseear hawkweed	Present
Vascular Plant	*Hieracium scabrum*	rough hawkweed	Present
Vascular Plant	*Hieracium venosum*	rattlesnakeweed	Present
Vascular Plant	*Ionactis linariifolius*	flaxleaf whitetop aster, savoryleaf aster	Present
Vascular Plant	*Krigia biflora*	tall dwarfdandelion, twoflower dwarfdandelion, two-flower dwarf-dandelion	Present
Vascular Plant	*Krigia caespitosa*	weedy dwarfdandelion	Present
Vascular Plant	*Krigia dandelion*	potato dwarfdandelion, tuber dandelion, tuber dwarfdandelion	Present
Vascular Plant	*Krigia occidentalis*	western dwarfdandelion	Present
Vascular Plant	*Krigia virginica*	Virginia dwarfdandelion	Present
Vascular Plant	*Lactuca canadensis*	Canada lettuce, Florida blue lettuce, wild lettuce	Present
Vascular Plant	*Lactuca floridana*	Florida lettuce, woodland lettuce	Present
Vascular Plant	*Lactuca saligna*	willowleaf lettuce, willow-leaf lettuce	Present
Vascular Plant	*Leucanthemum vulgare*	oxeyedaisy	Present
Vascular Plant	*Liatris aspera*	rough gayfeather, tall blazing star, tall gayfeather	Present
Vascular Plant	*Liatris scariosa*	devil’s bite	Probable
Vascular Plant	*Liatris spicata*	dense blazing star	Present
Vascular Plant	*Liatris squarrosa*	scaly blazing star, scaly gayfeather	Present
Vascular Plant	*Liatris squarrulosa*	Appalachian blazing star, Appalachian gayfeather, tall gayfeather	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Oligoneuron rigidum*	stiff goldenrod	Present
Vascular Plant	*Oligoneuron rigidum* var. *glabratum*	stiff goldenrod	Present
Vascular Plant	*Oligoneuron rigidum* var. *rigidum*	stiff goldenrod	Present
Vascular Plant	*Packera anonyma*	Small's ragwort	Present
Vascular Plant	*Packera aurea*	golden ragwort	Present
Vascular Plant	*Packera glabella*	butterweed	Present
Vascular Plant	*Packera obovata*	roundleaf ragwort	Present
Vascular Plant	*Packera paupercula*	balsam groundsel	Present
Vascular Plant	*Parthenium integrifolium* var. *integrifolium*	wild quinine	Present
Vascular Plant	*Pluchea camphorata*	camphor pluchea, camphor weed	Present
Vascular Plant	*Polymnia canadensis*	rayless leafcup, whiteflower leafcup	Present
Vascular Plant	*Prenanthes altissima*	rattlesnakeroot, tall rattlesnakeroot	Present
Vascular Plant	*Prenanthes racemosa*	purple rattlesnakeroot, purple rattlesnake-root	Present
Vascular Plant	*Prenanthes serpentaria*	cankerweed	Present
Vascular Plant	*Prenanthes trifoliolata*	dwarf rattlesnakeroot, gall of the earth	Present
Vascular Plant	*Pseudognaphalium obtusifolium* ssp. *obtusifolium*	rabbittobacco	Present
Vascular Plant	*Pyrrhopappus carolinianus*	Carolina desert chicory, Carolina desert-chicory, Carolina false dandelion, Carolina false-dandelion	Present
Vascular Plant	*Ratibida pinnata*	grayhead prairieconeflower, pinnate prairie coneflower	Present
Vascular Plant	*Rudbeckia fulgida*	orange coneflower	Present
Vascular Plant	*Rudbeckia fulgida* var. *fulgida*	orange coneflower	Present
Vascular Plant	*Rudbeckia fulgida* var. *spathulata*	orange coneflower	Present
Vascular Plant	*Rudbeckia fulgida* var. *umbrosa*	orange coneflower	Present
Vascular Plant	*Rudbeckia hirta*	blackeyed Susan, black-eyed Susan	Present
Vascular Plant	*Rudbeckia laciniata*	cutleaf coneflower, green-head coneflower	Present
Vascular Plant	*Rudbeckia triloba*	browneyed Susan	Present
Vascular Plant	*Sericocarpus linifolius*	narrowleaf whitetop aster	Present
Vascular Plant	*Silphium integrifolium*	wholeleaf rosinweed	Present
Vascular Plant	*Silphium perfoliatum* var. *perfoliatum*	cup plant	Present
Vascular Plant	*Silphium pinnatifidum*	tansy rosinweed	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Silphium terebinthinaceum*	prairie rosinweed	Probable
Vascular Plant	*Silphium trifoliatum*	whorled rosinweed	Present
Vascular Plant	*Smallanthus uvedalius*	hairy leafcup	Present
Vascular Plant	*Solidago arguta*	Atlantic goldenrod	Present
Vascular Plant	*Solidago arguta* var. *caroliniana*	Atlantic goldenrod	Present
Vascular Plant	*Solidago bicolor*	white goldenrod	Present
Vascular Plant	*Solidago caesia*	wreath goldenrod	Present
Vascular Plant	*Solidago canadensis*	Canada goldenrod, Canadian goldenrod, common goldenrod	Present
Vascular Plant	*Solidago canadensis* var. *scabra*	Canada goldenrod, Canadian goldenrod	Present
Vascular Plant	*Solidago flexicaulis*	zigzag goldenrod	Present
Vascular Plant	*Solidago gigantea*	giant goldenrod	Present
Vascular Plant	*Solidago hispida*	hairy goldenrod	Present
Vascular Plant	*Solidago juncea*	early goldenrod	Present
Vascular Plant	*Solidago missouriensis* var. *fasciculata*	Missouri goldenrod	Present
Vascular Plant	*Solidago nemoralis* var. *nemoralis*	gray goldenrod	Present
Vascular Plant	*Solidago odora* var. *odora*	anisescented goldenrod	Present
Vascular Plant	*Solidago patula* var. *patula*	roundleaf goldenrod	Present
Vascular Plant	*Solidago puberula* var. *puberula*	downy goldenrod	Present
Vascular Plant	*Solidago rugosa*	wrinkleleaf goldenrod	Present
Vascular Plant	*Solidago rugosa* ssp. *aspera*	wrinkleleaf goldenrod	Present
Vascular Plant	*Solidago rugosa* ssp. *rugosa*	wrinkleleaf goldenrod	Present
Vascular Plant	*Solidago rupestris*	rock goldenrod	Present
Vascular Plant	*Solidago speciosa*	noble goldenrod, showy goldenrod	Present
Vascular Plant	*Solidago speciosa* var. *erecta*	showy goldenrod	Present
Vascular Plant	*Solidago speciosa* var. *rigidiuscula*	showy goldenrod	Present
Vascular Plant	*Solidago sphacelata*	autumn goldenrod	Present
Vascular Plant	*Solidago ulmifolia* var. *ulmifolia*	elmleaf goldenrod	Present
Vascular Plant	*Sonchus asper*	perennial sowthistle, prickly sow thistle, prickly sowthistle, spiny sowthistle, spiny-leaf sow-thistle	Present
Vascular Plant	*Symphyotrichum cordifolium*	common blue wood aster	Present
Vascular Plant	*Symphyotrichum dumosum*	rice button aster	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Symphyotrichum dumosum* var. *dumosum*	rice button aster	Present
Vascular Plant	*Symphyotrichum laeve* var. *laeve*	smooth blue aster	Present
Vascular Plant	*Symphyotrichum lanceolatum* ssp. *lanceolatum var. lanceolatum*	–	Present
Vascular Plant	*Symphyotrichum lateriflorum*	calico aster	Present
Vascular Plant	*Symphyotrichum lateriflorum* var. *lateriflorum*	calico aster	Present
Vascular Plant	*Symphyotrichum lowrieanum*	Lowrie's blue wood aster	Present
Vascular Plant	*Symphyotrichum novae-angliae*	New England aster	Present
Vascular Plant	*Symphyotrichum ontarione*	bottomland aster	Present
Vascular Plant	*Symphyotrichum patens* var. *patens*	late purple aster	Present
Vascular Plant	*Symphyotrichum patens* var. *patentissimum*	late purple aster	Present
Vascular Plant	*Symphyotrichum pilosum*	hairy white oldfield aster	Present
Vascular Plant	*Symphyotrichum pilosum* var. *pilosum*	hairy white oldfield aster	Present
Vascular Plant	*Symphyotrichum pratense*	barrens silky aster	Present
Vascular Plant	*Symphyotrichum prenanthoides*	crookedstem aster	Present
Vascular Plant	*Symphyotrichum racemosum*	smooth white oldfield aster	Present
Vascular Plant	*Symphyotrichum sericeum*	western silver aster	Present
Vascular Plant	*Symphyotrichum shortii*	Short's aster	Present
Vascular Plant	*Symphyotrichum undulatum*	waxylear aster	Present
Vascular Plant	*Taraxacum laevigatum*	red-seed dandelion, rock dandelion	Present
Vascular Plant	*Taraxacum officinale* ssp. *officinale*	wandering dandelion	Present
Vascular Plant	*Tragopogon dubius*	yellow salsify	Present
Vascular Plant	*Verbesina alternifolia*	wingstem	Present
Vascular Plant	*Verbesina helianthoides*	gravelweed, gravelweed crownbeard	Present
Vascular Plant	*Verbesina occidentalis*	yellow crownbeard	Present
Vascular Plant	*Verbesina virginica* var. *virginica*	maritime groundcherry	Present
Vascular Plant	*Vernonia gigantea* ssp. *gigantea*	giant ironweed	Present
Vascular Plant	*Vernonia noveboracensis*	New York ironweed	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Xanthium strumarium*	Canada cocklebur, cocklebur, cockleburr, common cocklebur, rough cocklebur, rough cockleburr	Present
Vascular Plant	*Xanthium strumarium* var. *canadense*	Canada cocklebur, Canada cockleburr, cocklebur, common cocklebur, rough cocklebur, rough cockleburr	Present
Vascular Plant	*Campanula divaricata*	small bonny bellflower	Present
Vascular Plant	*Campanulastrum americanum*	American bellflower	Present
Vascular Plant	*Lobelia cardinalis*	cardinalflower	Present
Vascular Plant	*Lobelia inflata*	Indian tobacco, Indian-tobacco	Present
Vascular Plant	*Lobelia puberula*	downy lobelia	Present
Vascular Plant	*Lobelia siphilitica* var. *siphilitica*	great blue lobelia	Present
Vascular Plant	*Lobelia spicata*	palespike lobelia, pale-spike lobelia, pale-spiked lobelia	Present
Vascular Plant	*Lobelia spicata* var. *leptostachys*	palespike lobelia	Present
Vascular Plant	*Triodanis perfoliata*	clasping Venus' lookingglass	Present
Vascular Plant	*Triodanis perfoliata* var. *perfoliata*	clasping Venus' lookingglass, clasping Venus' looking-glass, clasping-leaf Venus' looking-glass	Present
Vascular Plant	*Buglossoides arvensis*	corn gromwell	Present
Vascular Plant	*Cynoglossum virginianum* var. *virginianum*	wild comfrey	Present
Vascular Plant	*Hackelia virginiana*	beggar's-lice, sticktight, virginia stickseed	Present
Vascular Plant	*Lithospermum canescens*	hoary gromwell, hoary puccoon	Present
Vascular Plant	*Lithospermum latifolium*	American stoneseed	Present
Vascular Plant	*Lithospermum officinale*	European stoneseed	Present
Vascular Plant	*Mertensia virginica*	Virginia bluebells	Present
Vascular Plant	*Myosotis arvensis*	field forget-me-not	Present
Vascular Plant	*Myosotis macrosperma*	southern forget me not	Present
Vascular Plant	*Myosotis verna*	spring forget-me-not	Present
Vascular Plant	*Heliotropium tenellum*	pasture heliotrope	Present
Vascular Plant	*Hydrophyllum appendiculatum*	great waterleaf	Present
Vascular Plant	*Hydrophyllum canadense*	bluntleaf waterleaf, blunt-leaf waterleaf	Present
Vascular Plant	*Hydrophyllum macrophyllum*	largeleaf waterleaf	Present
Vascular Plant	*Phacelia bipinnatifida*	fernleaf phacelia	Present
Vascular Plant	*Phacelia purshii*	Miami mist	Present
Vascular Plant	*Alliaria petiolata*	garlic mustard, garlic-mustard	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Arabidopsis thaliana*	mouseear cress, mouse-ear cress	Present
Vascular Plant	*Arabis canadensis*	sicklepod, sicklepod rockcress	Present
Vascular Plant	*Arabis laevigata*	smooth rockcress, smooth rock-cress	Present
Vascular Plant	*Arabis laevigata* var. *laevigata*	smooth rockcress	Present
Vascular Plant	*Barbarea vulgaris*	garden yellow rocket, garden yellowrocket, winter cress, yellow rocket	Present
Vascular Plant	*Brassica nigra*	black mustard, shortpod mustard	Present
Vascular Plant	*Brassica rapa*	field mustard	Present
Vascular Plant	*Capsella bursa-pastoris*	shepherdspurse, shepherd's-purse	Present
Vascular Plant	*Cardamine angustata*	slender toothwort	Present
Vascular Plant	*Cardamine bulbosa*	bulb bittercress, bulbous bittercress, bulbous bitter-cress	Present
Vascular Plant	*Cardamine concatenata*	cutleaf toothwort	Present
Vascular Plant	*Cardamine diphylla*	crinkleroot	Present
Vascular Plant	*Cardamine dissecta*	forkleaf toothwort	Present
Vascular Plant	*Cardamine douglassii*	limestone bittercress	Present
Vascular Plant	*Cardamine hirsuta*	hairy bittercress	Present
Vascular Plant	*Cardamine parviflora* var. *arenicola*	sand bittercress	Present
Vascular Plant	*Cardamine pensylvanica*	Pennsylvania bittercress, Quaker bittercress	Present
Vascular Plant	*Cardamine rotundifolia*	American bittercress	Present
Vascular Plant	*Diplotaxis tenuifolia*	perennial wallrocket	Present
Vascular Plant	*Draba brachycarpa*	shortfruited draba, shortpod draba, short-pod whitlowgrass	Present
Vascular Plant	*Draba verna*	spring draba, spring whitlowgrass	Present
Vascular Plant	*Iodanthus pinnatifidus*	purple rocket, purplerocket	Present
Vascular Plant	*Lepidium campestre*	cream-anther field pepperwort, field pepperweed	Present
Vascular Plant	*Lepidium densiflorum*	common pepperweed, greenflower pepperweed, miners' pepperweed, miner's pepperwort, peppergrass, prairie pepperweed	Present
Vascular Plant	*Lepidium ruderale*	roadside pepperweed	Present
Vascular Plant	*Lepidium virginicum* var. *virginicum*	Virginia pepperweed	Present
Vascular Plant	*Rorippa palustris* ssp. *fernaldiana*	Fernald's yellowcress	Present
Vascular Plant	*Rorippa sylvestris*	creeping yellow cress, creeping yellowcress, keek, yellow fieldcress	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Sibara virginica*	Virginia sibara, Virginia winged rockcress	Present
Vascular Plant	*Sisymbrium officinale*	hairypod hedgemustard, hedge mustard, hedge tumblemustard, hedgemustard, hedge-mustard, hedgeweed, wild mustard	Present
Vascular Plant	*Thlaspi arvense*	fanweed, field pennycress, Frenchweed, pennycress, stinkweed	Present
Vascular Plant	*Cleome hassleriana*	pink queen, pinkqueen, spider-flower, spiderplant	Present
Vascular Plant	*Amaranthus albus*	pigweed, pigweed amaranth, prostrate pigweed, tumble pigweed, tumbleweed, white pigweed	Present
Vascular Plant	*Amaranthus retroflexus*	careless weed, redroot amaranth, red-root amaranth, redroot pigweed, rough pigweed	Present
Vascular Plant	*Amaranthus spinosus*	pigweed, spiny amaranth	Present
Vascular Plant	*Chenopodium album*	common lambsquarters, lambsquarters, lambsquarters goosefoot, white goosefoot	Present
Vascular Plant	*Chenopodium ambrosioides* var. *ambrosioides*	Mexican tea	Present
Vascular Plant	*Iresine rhizomatosa*	Juda's bush, rootstock bloodleaf	Present
Vascular Plant	*Opuntia humifusa*	devil's-tongue, pricklypear	Present
Vascular Plant	*Opuntia humifusa* var. *humifusa*	pricklypear	Present
Vascular Plant	*Cerastium fontanum* ssp. *vulgare*	big chickweed	Present
Vascular Plant	*Cerastium glomeratum*	sticky chickweed	Present
Vascular Plant	*Cerastium nutans* var. *nutans*	nodding chickweed	Present
Vascular Plant	*Dianthus armeria*	Deptford pink	Present
Vascular Plant	*Holosteum umbellatum*	jagged chickweed	Present
Vascular Plant	*Minuartia patula*	pitcher's stitchwort	Present
Vascular Plant	*Paronychia canadensis*	smooth forked nailwort	Present
Vascular Plant	*Paronychia fastigiata*	clusterstem nailwort, hairy forked nailwort	Present
Vascular Plant	*Saponaria officinalis*	bouncing bet, bouncingbet, bouncingbet soapweed, soapwort, sweet Betty	Present
Vascular Plant	*Silene rotundifolia*	roundleaf catchfly	Present
Vascular Plant	*Silene stellata*	whorled catchfly, widowsfrill	Present
Vascular Plant	*Silene virginica*	fire pink, firepink	Present
Vascular Plant	*Stellaria media*	chickweed, common chickweed, nodding chickweed	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Stellaria pubera*	star chickweed	Present
Vascular Plant	*Mollugo verticillata*	carpetweed, carpet-weed, green carpetweed, green carpet-weed, Indian chickweed	Present
Vascular Plant	*Claytonia virginica*	narrow-leaved spring beauty, Spring beauty, Virginia springbeauty	Present
Vascular Plant	*Phytolacca americana* var. *americana*	American pokeweed	Present
Vascular Plant	*Polygonum amphibium*	water knotweed	Present
Vascular Plant	*Polygonum arifolium*	halberdleaf tearthumb	Present
Vascular Plant	*Polygonum caespitosum* var. *longisetum*	oriental lady's thumb, oriental ladysthumb	Present
Vascular Plant	*Polygonum convolvulus*	black bindweed, black-bindweed, climbing buckwheat, climbing knotweed, cornbind, dullseed cornbind, pink smartweed, wild buckwheat	Present
Vascular Plant	*Polygonum hydropiper*	annual smartweed, marshpepper knotweed, mild water-pepper	Present
Vascular Plant	*Polygonum hydropiperoides*	swamp smartweed	Present
Vascular Plant	*Polygonum pensylvanicum*	Pennsylvania knotweed, Pennsylvania smartweed, pinkweed, pinweed	Present
Vascular Plant	*Polygonum persicaria*	ladysthumb, lady's-thumb, ladysthumb smartweed, spotted knotweed, spotted ladysthumb, spotted smartweed	Present
Vascular Plant	*Polygonum punctatum*	dotted smartweed	Present
Vascular Plant	*Polygonum sagittatum*	arrowleaf knotweed, arrowleaf tearthumb, arrow-leaf tearthumb, arrowvine	Present
Vascular Plant	*Polygonum scandens*	climbing false buckwheat, climbing knotweed	Present
Vascular Plant	*Polygonum scandens* var. *cristatum*	climbing false buckwheat	Present
Vascular Plant	*Polygonum setaceum*	bog smartweed	Present
Vascular Plant	*Polygonum virginianum*	jumpseed	Present
Vascular Plant	*Rumex acetosella*	common sheep sorrel, field sorrel, red sorrel, sheep sorrel	Present
Vascular Plant	*Rumex crispus*	curly dock, narrowleaf dock, sour dock, yellow dock	Present
Vascular Plant	*Rumex obtusifolius*	bitter dock, bluntleaf dock	Present
Vascular Plant	*Rumex pulcher*	fiddle dock	Present
Vascular Plant	*Rumex salicifolius*	willow dock	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Portulaca oleracea*	akulikuli-kula, common purslane, duckweed, garden purslane, little hogweed, little-hogweed, purslane, pursley, wild portulaca	Present
Vascular Plant	*Celastrus scandens*	American bittersweet, staffvine, waxwork	Present
Vascular Plant	*Euonymus americana*	strawberry bush, strawberrybush	Present
Vascular Plant	*Euonymus atropurpurea*	eastern wahoo, wahoo	Present
Vascular Plant	*Commelina communis*	Asiatic dayflower, common dayflower	Present
Vascular Plant	*Commelina virginica*	Virginia dayflower	Present
Vascular Plant	*Tradescantia subaspera*	zigzag spiderwort	Present
Vascular Plant	*Tradescantia virginiana*	Virginia spiderwort	Present
Vascular Plant	*Cornus alternifolia*	alternateleaf dogwood, alternate-leaf dogwood	Present
Vascular Plant	*Cornus amomum*	silky dogwood	Present
Vascular Plant	*Cornus drummondii*	roughleaf dogwood	Present
Vascular Plant	*Cornus florida*	flowering dogwood	Present
Vascular Plant	*Cornus foemina*	–	Present
Vascular Plant	*Hydrangea arborescens*	smooth hydrangea, wild hydrangea	Present
Vascular Plant	*Nyssa sylvatica*	black gum, black tupelo, blackgum	Present
Vascular Plant	*Staphylea trifolia*	American bladdernut	Present
Vascular Plant	*Sicyos angulatus*	bur cucumber, oneseed bur cucumber, oneseed burr cucumber, wall bur cucumber	Present
Vascular Plant	*Dioscorea oppositifolia*	–	Present
Vascular Plant	*Dioscorea quaternata*	fourleaf yam	Present
Vascular Plant	*Dioscorea villosa*	wild yam	Present
Vascular Plant	*Sambucus nigra* ssp. *canadensis*	American black elderberry, blue elder, common elderberry, elder, elderberry, Mexican elderberry	Present
Vascular Plant	*Viburnum acerifolium*	mapleleaf viburnum	Present
Vascular Plant	*Viburnum prunifolium*	blackhaw	Present
Vascular Plant	*Viburnum rufidulum*	rusty blackhaw, rusty viburnum	Present
Vascular Plant	*Lonicera japonica*	Chinese honeysuckle, Japanese honeysuckle	Present
Vascular Plant	*Lonicera maackii*	Amur honeysuckle, Amur honeysuckle bush	Present
Vascular Plant	*Lonicera sempervirens*	trumpet honeysuckle	Present
Vascular Plant	*Symphoricarpos orbiculatus*	buck brush, coralberry, Indiancurrant coralberry	Present
Vascular Plant	*Triosteum angustifolium*	yellowfruit horsegentian, yellowfruit horse-gentian	Present

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Vascular Plant	*Triosteum aurantiacum*	orangefruit horse-gentian	Present
Vascular Plant	*Triosteum perfoliatum*	common horsegentian, feverwort	Present
Vascular Plant	*Dipsacus fullonum*	common teasel, Fuller's teasel, teasel, venuscup teasle	Present
Vascular Plant	*Dipsacus fullonum* ssp. *sylvestris*	common teasel, Fuller's teasel, teasel	Present
Vascular Plant	*Valeriana pauciflora*	largeflower valerian	Present
Vascular Plant	*Equisetum arvense*	common horsetail, field horsetail, scouringrush, western horsetail	Present
Vascular Plant	*Equisetum hyemale* var. *affine*	scouringrush horsetail, stout scouringrush, tall scouring-rush	Present
Vascular Plant	*Impatiens capensis*	jewelweed, spotted touch-me-not	Present
Vascular Plant	*Impatiens pallida*	pale snapweed, pale touch-me-not	Present
Vascular Plant	*Diospyros virginiana*	common persimmon, eastern persimmon	Present
Vascular Plant	*Chimaphila maculata*	striped prince's pine	Present
Vascular Plant	*Gaultheria procumbens*	checkerberry, eastern teaberry, eastern wintergreen	Present
Vascular Plant	*Gaylussacia baccata*	black huckleberry	Present
Vascular Plant	*Kalmia latifolia*	mountain laurel	Present
Vascular Plant	*Leucothoe recurva*	redtwig doghobble	Present
Vascular Plant	*Monotropa hypopithys*	pinesap	Present
Vascular Plant	*Monotropa uniflora*	ghost plant, Indian pipe, Indianpipe	Present
Vascular Plant	*Oxydendrum arboreum*	lily-of-the-valley tree, sorrel tree, sourwood	Present
Vascular Plant	*Vaccinium arboreum*	farkleberry, sparkleberry, tree sparkleberry, tree-huckleberry	Present
Vascular Plant	*Vaccinium corymbosum*	highbush blueberry, New Jersey blueberry, smallflower blueberry, Southern blueberry	Present
Vascular Plant	*Vaccinium pallidum*	Blue Ridge blueberry	Present
Vascular Plant	*Vaccinium stamineum*	deerberry	Present
Vascular Plant	*Phlox amoena* ssp. *amoena*	hairy phlox	Present
Vascular Plant	*Phlox bifida*	cleft phlox	Present
Vascular Plant	*Phlox carolina*	thickleaf phlox	Present
Vascular Plant	*Phlox divaricata*	wild blue phlox	Present
Vascular Plant	*Phlox glaberrima*	smooth phlox	Present
Vascular Plant	*Phlox glaberrima* ssp. *triflora*	smooth phlox	Present
Vascular Plant	*Phlox maculata*	wild sweetwilliam	Present
Vascular Plant	*Phlox paniculata*	fall phlox	Present
Vascular Plant	*Phlox subulata*	moss phlox	Present

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Vascular Plant	*Polemonium reptans*	creeping polemonium, Greek valerian	Present
Vascular Plant	*Anagallis arvensis*	pimpernel, scarlet pimpernel	Present
Vascular Plant	*Dodecatheon frenchii*	French's shootingstar	Present
Vascular Plant	*Dodecatheon meadia*	common shootingstar, pride of Ohio	Present
Vascular Plant	*Lysimachia ciliata*	fringed loosestrife, fringed yellow-loosestrife	Present
Vascular Plant	*Lysimachia lanceolata*	lanceleaf loosestrife	Present
Vascular Plant	*Lysimachia nummularia*	creeping jenny, moneywort	Present
Vascular Plant	*Lysimachia quadrifolia*	crosswort, whorled loosestrife, whorled yellow loosestrife	Present
Vascular Plant	*Samolus valerandi* ssp. *parviflorus*	seaside brookweed	Present
Vascular Plant	*Sideroxylon lycioides*	buckthorn bully	Present
Vascular Plant	*Albizia julibrissin*	mimosa, powderpuff tree, silk tree, silktree	Present
Vascular Plant	*Amphicarpaea bracteata*	American hogpeanut, hog-peanut	Present
Vascular Plant	*Apios americana*	groundnut, potatobean	Present
Vascular Plant	*Cercis canadensis* var. *canadensis*	redbud	Present
Vascular Plant	*Chamaecrista fasciculata* var. *fasciculata*	partridge pea, sleepingplant	Present
Vascular Plant	*Chamaecrista nictitans* ssp. *nictitans var. nictitans*	partridge pea	Present
Vascular Plant	*Clitoria mariana*	Atlantic pigeonwings, butterfly-pea, pigeonwings	Present
Vascular Plant	*Coronilla varia*	crownvetch, purple crownvetch, purple crown-vetch, Varia crownvetch	Present
Vascular Plant	*Desmodium canadense*	Canada tickclover, showy ticktrefoil, showy tick-trefoil	Probable
Vascular Plant	*Desmodium canescens*	hoary tickclover, hoary ticktrefoil	Present
Vascular Plant	*Desmodium ciliare*	hairy small-leaf ticktrefoil, littleleaf tickclover	Present
Vascular Plant	*Desmodium cuspidatum*	largebract ticktrefoil	Present
Vascular Plant	*Desmodium glabellum*	Dillenius' ticktrefoil	Present
Vascular Plant	*Desmodium glutinosum*	largeflower tickclover, pointedleaf ticktrefoil, trefoil tickclover	Present
Vascular Plant	*Desmodium laevigatum*	smooth tickclover, smooth ticktrefoil	Present
Vascular Plant	*Desmodium marilandicum*	Maryland tickclover, smooth small-leaf ticktrefoil	Present
Vascular Plant	*Desmodium nudiflorum*	barestem tickclover, bare-stemmed tick-treefoil, nakedflower ticktrefoil	Present
Vascular Plant	*Desmodium obtusum*	stiff tickclover, stiff ticktrefoil	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Desmodium ochroleucum*	cream ticktrefoil	Present
Vascular Plant	*Desmodium paniculatum* var. *paniculatum*	panicledleaf ticktrefoil	Present
Vascular Plant	*Desmodium pauciflorum*	fewflower ticktrefoil, fewflowered tickclover	Present
Vascular Plant	*Desmodium perplexum*	perplexed ticktrefoil	Present
Vascular Plant	*Desmodium rotundifolium*	prostrate ticktrefoil, roundhead tickclover	Present
Vascular Plant	*Desmodium sessilifolium*	sessile tickclover, sessileleaf tickclover, sessileleaf ticktrefoil	Present
Vascular Plant	*Desmodium viridiflorum*	velvetleaf tickclover, velvetleaf ticktrefoil	Present
Vascular Plant	*Galactia volubilis*	downy milkpea	Present
Vascular Plant	*Gleditsia triacanthos*	common honeylocust, honey locust, honeylocust, honey-locust	Present
Vascular Plant	*Gymnocladus dioicus*	Kentucky coffeetree	Present
Vascular Plant	*Kummerowia stipulacea*	Korean clover	Present
Vascular Plant	*Kummerowia striata*	Japanese clover	Present
Vascular Plant	*Lespedeza capitata*	roundhead lespedeza	Present
Vascular Plant	*Lespedeza cuneata*	Chinese lespedeza, sericea lespedeza	Present
Vascular Plant	*Lespedeza hirta* ssp. *hirta*	hairy lespedeza	Present
Vascular Plant	*Lespedeza procumbens*	trailing lespedeza	Present
Vascular Plant	*Lespedeza stuevei*	Stueve’s lespedeza, tall lespedeza	Present
Vascular Plant	*Lespedeza violacea*	violet lespedeza	Present
Vascular Plant	*Lespedeza virginica*	slender lespedeza	Present
Vascular Plant	*Medicago lupulina*	black medic, black medic clover, black medick, hop clover, hop medic, nonesuch, yellow trefoil	Present
Vascular Plant	*Medicago sativa* ssp. *sativa*	alfalfa	Present
Vascular Plant	*Melilotus albus*	Bokhara-clover, honey-clover, white melilot, white sweet-clover	Present
Vascular Plant	*Melilotus officinalis*	cornilla real, field melilot, ribbed melilot, yellow sweetclover, yellow sweet-clover	Present
Vascular Plant	*Orbexilum pedunculatum*	Sampson’s snakeroot	Present
Vascular Plant	*Orbexilum pedunculatum* var. *pedunculatum*	Sampson’s snakeroot	Present
Vascular Plant	*Orbexilum pedunculatum* var. *psoralioides*	Sampson’s snakeroot	Present
Vascular Plant	*Phaseolus polystachios*	slimleaf bean, thicket bean	Present
Vascular Plant	*Pueraria montana* var. *lobata*	kudzu	Present
Vascular Plant	*Rhynchosia tomentosa*	twining snoutbean	Present
Vascular Plant	*Robinia hispida*	bristly locust, rose acacia	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Robinia pseudoacacia*	black locust, false acacia, yellow locust	Present
Vascular Plant	*Senna hebecarpa*	American wild sensitive plant	Present
Vascular Plant	*Senna marilandica*	Maryland wild sensitive plant	Present
Vascular Plant	*Strophostyles helvula*	trailing fuzzybean, trailing wild-bean, Trailing wildbean	Present
Vascular Plant	*Strophostyles umbellata*	perennial wildbean, pink fuzzybean	Present
Vascular Plant	*Stylosanthes biflora*	endbeak pencilflower, sidebeak pencilflower	Present
Vascular Plant	*Tephrosia virginiana*	Virginia tephrosia	Present
Vascular Plant	*Trifolium arvense*	hairy clover, hare's foot clover, oldfield clover, rabbitfoot clover, rabbit-foot clover, stone clover	Present
Vascular Plant	*Trifolium aureum*	golden clover	Present
Vascular Plant	*Trifolium campestre*	field clover	Present
Vascular Plant	*Trifolium hybridum*	alsike clover	Present
Vascular Plant	*Trifolium pratense*	red clover	Present
Vascular Plant	*Trifolium reflexum*	buffalo clover	Present
Vascular Plant	*Trifolium repens*	Dutch clover, ladino clover, white clover, white Dutch clover	Present
Vascular Plant	*Vicia caroliniana*	Carolina vetch	Present
Vascular Plant	*Vicia sativa*	common vetch, garden vetch, narrowleaf vetch, tare	Present
Vascular Plant	*Wisteria frutescens*	American wisteria	Present
Vascular Plant	*Wisteria sinensis*	Chinese wisteria	Present
Vascular Plant	*Polygala ambigua*	whorled milkwort	Present
Vascular Plant	*Polygala incarnata*	procession flower	Present
Vascular Plant	*Polygala sanguinea*	blood milkwort, purple milkwort	Present
Vascular Plant	*Polygala verticillata*	whorled milkwort	Present
Vascular Plant	*Alnus glutinosa*	black alder, European alder, European black alder	Probable
Vascular Plant	*Betula alleghaniensis*	yellow birch	Present
Vascular Plant	*Betula alleghaniensis* var. *alleghaniensis*	yellow birch	Present
Vascular Plant	*Betula lenta*	sweet birch	Present
Vascular Plant	*Betula nigra*	river birch	Present
Vascular Plant	*Carpinus caroliniana*	American hornbeam	Present
Vascular Plant	*Carpinus caroliniana* ssp. *virginiana*	American hornbeam	Present
Vascular Plant	*Corylus americana*	American hazelnut, hazel, hazelnut	Present
Vascular Plant	*Ostrya virginiana*	eastern hophornbeam, hophornbeam	Present
Vascular Plant	*Castanea dentata*	American chestnut	Present

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Vascular Plant	*Fagus grandifolia*	American beech	Present
Vascular Plant	*Quercus alba*	white oak	Present
Vascular Plant	*Quercus bicolor*	swamp white oak	Present
Vascular Plant	*Quercus coccinea* var. *coccinea*	scarlet oak	Present
Vascular Plant	*Quercus falcata*	southern red oak	Present
Vascular Plant	*Quercus imbricaria*	shingle oak	Present
Vascular Plant	*Quercus macrocarpa*	bur oak	Present
Vascular Plant	*Quercus marilandica*	blackjack oak	Present
Vascular Plant	*Quercus michauxii*	swamp chestnut oak	Present
Vascular Plant	*Quercus muehlenbergii*	chinkapin oak	Present
Vascular Plant	*Quercus nigra*	water oak	Present
Vascular Plant	*Quercus pagoda*	cherrybark oak, Texas oak	Present
Vascular Plant	*Quercus palustris*	pin oak	Present
Vascular Plant	*Quercus phellos*	willow oak	Present
Vascular Plant	*Quercus prinus*	chestnut oak	Present
Vascular Plant	*Quercus rubra* var. *rubra*	northern red oak	Present
Vascular Plant	*Quercus shumardii*	shumard oak	Present
Vascular Plant	*Quercus stellata*	post oak	Present
Vascular Plant	*Quercus velutina*	black oak	Present
Vascular Plant	*Carya alba*	mockernut hickory	Present
Vascular Plant	*Carya cordiformis*	bitternut hickory, noyer amer, pignut	Present
Vascular Plant	*Carya glabra*	pignut hickory, sweet pignut	Present
Vascular Plant	*Carya illinoinensis*	nogal morado, nuez encarcelada, pecan, pecanier	Present
Vascular Plant	*Carya laciniosa*	kingnut, shellbark hickory	Present
Vascular Plant	*Carya ovalis*	pignut hickory, red hickory	Present
Vascular Plant	*Carya ovata*	–	Present
Vascular Plant	*Carya pallida*	sand hickory	Present
Vascular Plant	*Juglans cinerea*	butternut, white walnut	Present
Vascular Plant	*Juglans nigra*	black walnut, noyer noir	Present
Vascular Plant	*Apocynum cannabinum*	common dogbane, dogbane, hemp dogbane, Indian hemp, Indian-hemp, prairie dogbane	Present
Vascular Plant	*Asclepias amplexicaulis*	bluntleaf milkweed, blunt-leaved milkweed, clasping milkweed, sand milkweed	Present
Vascular Plant	*Asclepias exaltata*	poke milkweed	Present
Vascular Plant	*Asclepias incarnata*	rose milkweed, swamp milkweed	Present
Vascular Plant	*Asclepias purpurascens*	purple milkweed	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Asclepias quadrifolia*	fourleaf milkweed	Present
Vascular Plant	*Asclepias syriaca*	broadleaf milkweed, common milkweed	Present
Vascular Plant	*Asclepias tuberosa*	butterfly milkweed, butterflyweed	Present
Vascular Plant	*Asclepias variegata*	redring milkweed, white milkweed	Present
Vascular Plant	*Asclepias verticillata*	eastern whorled milkweed, whorled milkweed	Present
Vascular Plant	*Asclepias viridiflora*	green antelopehorn milkweed, green comet milkweed, green milkweed	Present
Vascular Plant	*Cynanchum laeve*	honeyvine	Present
Vascular Plant	*Matelea carolinensis*	maroon Carolina milkvine	Present
Vascular Plant	*Matelea gonocarpos*	angularfruit milkvine	Present
Vascular Plant	*Matelea obliqua*	climbing milkvine	Present
Vascular Plant	*Trachelospermum difforme*	climbing dogbane	Present
Vascular Plant	*Vinca minor*	common periwinkle, lesser periwinkle, myrtle	Present
Vascular Plant	*Bartonia paniculata* ssp. *paniculata*	twining screwstem	Present
Vascular Plant	*Bartonia virginica*	yellow screwstem	Present
Vascular Plant	*Centaurium pulchellum*	branched centaury	Present
Vascular Plant	*Frasera caroliniensis*	American columbo	Present
Vascular Plant	*Gentiana andrewsii*	closed bottle gentian	Present
Vascular Plant	*Gentiana puberulenta*	downy gentian	Present
Vascular Plant	*Gentiana saponaria* var. *saponaria*	harvestbells	Present
Vascular Plant	*Gentiana villosa*	striped gentian	Present
Vascular Plant	*Obolaria virginica*	Virginia pennywort	Present
Vascular Plant	*Sabatia angularis*	rosepink, squarestem rosegentian	Present
Vascular Plant	*Cephalanthus occidentalis*	buttonbush, common buttonbush	Present
Vascular Plant	*Diodia teres* var. *teres*	poorjoe	Present
Vascular Plant	*Diodia virginiana*	Virginia buttonweed	Present
Vascular Plant	*Galium aparine*	bedstraw, catchweed bedstraw, cleavers, cleaverwort, goose grass, scarthgrass, stickywilly, sticky-willy, white hedge	Present
Vascular Plant	*Galium asprellum*	rough bedstraw	Probable
Vascular Plant	*Galium circaezans*	licorice bedstraw, wild licorice, woods bedstraw	Present
Vascular Plant	*Galium concinnum*	shining bedstraw	Present
Vascular Plant	*Galium obtusum* ssp. *obtusum*	bluntleaf bedstraw	Present
Vascular Plant	*Galium pilosum*	hairy bedstraw	Present

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Vascular Plant	*Galium tinctorium*	dye bedstraw, stiff marsh bedstraw	Present
Vascular Plant	*Galium triflorum*	fragrant bedstraw, sweet bedstraw, sweetscented bedstraw	Present
Vascular Plant	*Houstonia caerulea*	azure bluet	Present
Vascular Plant	*Houstonia canadensis*	Canadian summer bluet	Present
Vascular Plant	*Houstonia longifolia*	longleaf bluet, longleaf summer bluet, long-leaf summer bluet	Present
Vascular Plant	*Houstonia purpurea*	purple bluets, Venus' pride	Present
Vascular Plant	*Houstonia purpurea* var. *calycosa*	Venus' pride	Present
Vascular Plant	*Houstonia purpurea* var. *purpurea*	Venus' pride	Present
Vascular Plant	*Houstonia pusilla*	tiny bluet	Present
Vascular Plant	*Mitchella repens*	partridgeberry	Present
Vascular Plant	*Sherardia arvensis*	blue fieldmadder, blue field-madder, field madder	Present
Vascular Plant	*Geranium carolinianum* var. *carolinianum*	Carolina geranium	Present
Vascular Plant	*Geranium dissectum*	cutleaf geranium	Present
Vascular Plant	*Geranium maculatum*	spotted crane's-bill, spotted geranium, wild crane's-bill	Present
Vascular Plant	*Geranium molle*	awnless geranium, dovefoot geranium	Present
Vascular Plant	*Trichomanes boschianum*	Appalachian bristle fern	Present
Vascular Plant	*Justicia americana*	American water-willow, common water-willow, spike justica	Present
Vascular Plant	*Ruellia caroliniensis* ssp. *caroliniensis var. caroliniensis*	Carolina wild petunia	Present
Vascular Plant	*Ruellia humilis*	fringeleaf wild petunia, low ruellia, wild petunia	Present
Vascular Plant	*Ruellia strepens*	limestone wild petunia	Present
Vascular Plant	*Bignonia capreolata*	cross vine, crossvine	Present
Vascular Plant	*Campsis radicans*	common trumpetcreeper, cow-itch, trumpet creeper	Present
Vascular Plant	*Catalpa speciosa*	northern catalpa	Present
Vascular Plant	*Agastache nepetoides*	catnip giant hyssop, yellow giant hyssop	Present
Vascular Plant	*Blephilia ciliata*	downy blephilia, downy pagoda-plant	Present
Vascular Plant	*Blephilia hirsuta* var. *hirsuta*	hairy pagodaplant	Present
Vascular Plant	*Clinopodium vulgare*	wild basil	Present
Vascular Plant	*Collinsonia canadensis*	richweed	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Glechoma hederacea*	creeping charlie, gill-over-the-ground, ground ivy, groundivy, haymaids	Present
Vascular Plant	*Hedeoma pulegioides*	American false pennyroyal	Present
Vascular Plant	*Isanthus brachiatus*	false pennyroyal, fluxweed	Present
Vascular Plant	*Lamium amplexicaule*	common henbit, giraffehead, henbit, henbit deadnettle	Present
Vascular Plant	*Lamium purpureum*	purple deadnettle, red deadnettle	Present
Vascular Plant	*Lycopus americanus*	American bugleweed, American water horehound, American waterhorehound, cut-leaf water-horehound, water horehound, waterhorehound	Present
Vascular Plant	*Lycopus rubellus*	taperleaf bugleweed, taperleaf water horehound	Present
Vascular Plant	*Lycopus uniflorus*	bugleweed, northern bugleweed, northern water-horehound, oneflower bugleweed	Present
Vascular Plant	*Lycopus virginicus*	Virginia bugleweed, Virginia water horehound	Present
Vascular Plant	*Melissa officinalis*	common balm	Present
Vascular Plant	*Mentha* X *piperita*	peppermint	Present
Vascular Plant	*Monarda clinopodia*	white bergamot	Present
Vascular Plant	*Monarda fistulosa*	mintleaf beebalm, Oswego-tea, wild bergamot, wildbergamot beebalm, wildbergamot horsemint	Present
Vascular Plant	*Monarda russeliana*	redpurple beebalm, Russell's henbit	Present
Vascular Plant	*Mosla dianthera*	miniature beefsteak, miniature beefsteakplant	Present
Vascular Plant	*Perilla frutescens*	beefsteak mint, beefsteak plant, purple mint	Present
Vascular Plant	*Perilla frutescens* var. *crispa*	beefsteakplant	Present
Vascular Plant	*Physostegia virginiana*	obedient plant, obedient-plant	Present
Vascular Plant	*Physostegia virginiana* ssp. *praemorsa*	obedient plant	Present
Vascular Plant	*Physostegia virginiana* ssp. *virginiana*	obedient plant	Present
Vascular Plant	*Prunella vulgaris*	common selfheal, heal all, healall, selfheal	Present
Vascular Plant	*Pycnanthemum incanum* var. *incanum*	hoary mountainmint	Present
Vascular Plant	*Pycnanthemum loomisii*	Loomis' mountainmint	Present
Vascular Plant	*Pycnanthemum pycnanthemoides* var. *pycnanthemoides*	southern mountainmint	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Pycnanthemum tenuifolium*	narrowleaf mountainmint	Present
Vascular Plant	*Pycnanthemum verticillatum* var. *pilosum*	whorled mountainmint	Present
Vascular Plant	*Salvia lyrata*	lyreleaf sage	Present
Vascular Plant	*Scutellaria elliptica*	hairy skullcap	Present
Vascular Plant	*Scutellaria incana*	hoary skullcap	Present
Vascular Plant	*Scutellaria lateriflora*	blue skullcap, mad dog skullcap	Present
Vascular Plant	*Scutellaria nervosa*	veiny skullcap	Present
Vascular Plant	*Scutellaria ovata*	eggleaf skullcap, heartleaf skullcap	Present
Vascular Plant	*Scutellaria parvula*	small skullcap	Present
Vascular Plant	*Scutellaria parvula* var. *missouriensis*	Leonard's skullcap	Present
Vascular Plant	*Stachys tenuifolia*	slender betony, smooth hedgenettle, smooth hedge-nettle	Present
Vascular Plant	*Synandra hispidula*	Guyandotte beauty	Present
Vascular Plant	*Teucrium canadense* var. *canadense*	Canada germander	Present
Vascular Plant	*Trichostema dichotomum*	blue curls, forked bluecurls	Present
Vascular Plant	*Trichostema setaceum*	narrowleaf bluecurls	Present
Vascular Plant	*Utricularia gibba*	conespur bladderpod, humped bladderwort	Present
Vascular Plant	*Lindernia dubia*	moistbank pimpernel, shortstalk lindernia, yellowseed false pimpernel, yellow-seed false pimpernel	Present
Vascular Plant	*Lindernia dubia* var. *anagallidea*	yellowseed false pimpernel	Present
Vascular Plant	*Chionanthus virginicus*	white fringetree	Present
Vascular Plant	*Fraxinus americana*	white ash	Present
Vascular Plant	*Fraxinus nigra*	black ash	Present
Vascular Plant	*Fraxinus pennsylvanica*	green ash	Present
Vascular Plant	*Fraxinus quadrangulata*	blue ash	Present
Vascular Plant	*Ligustrum sinense*	Chinese privet, common Chinese privet	Present
Vascular Plant	*Agalinis tenuifolia*	slenderleaf false foxglove	Present
Vascular Plant	*Aureolaria flava*	smooth yellow false foxglove	Present
Vascular Plant	*Aureolaria patula*	spreading yellow false foxglove	Present
Vascular Plant	*Aureolaria virginica*	downy yellow false foxglove	Present
Vascular Plant	*Buchnera americana*	American bluehearts, bupleurum	Present
Vascular Plant	*Conopholis americana*	American cancer-root, American squawroot, squaw-root	Present
Vascular Plant	*Dasistoma macrophylla*	mullein foxglove	Present
Vascular Plant	*Epifagus virginiana*	beechdrops	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Pedicularis canadensis* ssp. *canadensis*	Canadian lousewort	Present
Vascular Plant	*Paulownia tomentosa*	princess tree, royal paulownia	Present
Vascular Plant	*Mimulus alatus*	sharpwing monkeyflower	Present
Vascular Plant	*Phryma leptostachya*	American lopseed, lopseed	Present
Vascular Plant	*Bacopa rotundifolia*	disc waterhyssop, disk waterhyssop, disk water-hyssop, wet waterhyssop	Present
Vascular Plant	*Chelone glabra*	white turtlehead	Present
Vascular Plant	*Chelone obliqua*	red turtlehead	Present
Vascular Plant	*Gratiola neglecta*	clammy hedgehyssop, clammy hedge-hyssop, drug hedgehyssop, hedge hyssop, neglected hedgehyssop	Present
Vascular Plant	*Gratiola virginiana* var. *virginiana*	roundfruit hedgehyssop	Present
Vascular Plant	*Leucospora multifida*	narrowleaf paleseed	Present
Vascular Plant	*Linaria vulgaris*	butter and eggs, flaxweed, greater butter-and-eggs, Jacob's ladder, ramsted, wild snapdragon, yellow toadflax	Present
Vascular Plant	*Penstemon calycosus*	longsepal beardtongue	Present
Vascular Plant	*Penstemon canescens*	eastern gray beardtongue	Present
Vascular Plant	*Penstemon digitalis*	talus slope penstemon	Present
Vascular Plant	*Penstemon hirsutus*	hairy beardtongue	Present
Vascular Plant	*Penstemon pallidus*	pale beardtongue	Present
Vascular Plant	*Penstemon tenuiflorus*	eastern whiteflower beardtongue	Present
Vascular Plant	*Plantago aristata*	bottlebrush Indianwheat, largebracted plantain	Present
Vascular Plant	*Plantago lanceolata*	buckhorn plantain, English plantain, lanceleaf Indianwheat, lanceleaf plantain, narrowleaf plantain, ribgrass, ribwort	Present
Vascular Plant	*Plantago rugelii*	blackseed plantain, black-seed plantain, Rugel's plantain	Present
Vascular Plant	*Plantago virginica*	paleseed Indianwheat, Virginia plantain	Present
Vascular Plant	*Veronica arvensis*	common speedwell, corn speedwell, rock speedwell, wall speedwell	Present
Vascular Plant	*Veronica peregrina*	neckweed, purslane speedwell	Present
Vascular Plant	*Veronica serpyllifolia* ssp. *serpyllifolia*	thymeleaf speedwell	Present
Vascular Plant	*Veronicastrum virginicum*	Culver's root	Present
Vascular Plant	*Scrophularia marilandica*	carpenter's square, Maryland figwort	Present
Vascular Plant	*Verbascum blattaria*	moth mullein, white moth mullein	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Verbascum thapsus*	big taper, common mullein, flannel mullein, flannel plant, great mullein, mullein, velvet dock, velvet plant, woolly mullein	Present
Vascular Plant	*Glandularia canadensis*	rose mock vervain	Present
Vascular Plant	*Phyla lanceolata*	lanceleaf fogfruit	Present
Vascular Plant	*Verbena hastata* var. *hastata*	swamp verbena	Present
Vascular Plant	*Verbena simplex*	narrowleaf vervain, narrow-leaved vervain, simple verbena	Present
Vascular Plant	*Verbena stricta*	hoary verbena, hoary vervain, tall vervain, woolly verbena	Present
Vascular Plant	*Verbena urticifolia*	white verbena, white vervain	Present
Vascular Plant	*Calycanthus floridus* var. *glaucus*	eastern sweetshrub	Present
Vascular Plant	*Lindera benzoin*	northern spicebush, spicebush	Present
Vascular Plant	*Lindera benzoin* var. *pubescens*	northern spicebush	Present
Vascular Plant	*Sassafras albidum*	sassafras	Present
Vascular Plant	*Uvularia grandiflora*	largeflower bellwort, large-flower bellwort	Present
Vascular Plant	*Uvularia perfoliata*	perfoliate bellwort	Present
Vascular Plant	*Uvularia sessilifolia*	sessileleaf bellwort, sessile-leaf bellwort	Present
Vascular Plant	*Erythronium albidum*	small white fawnlily, white fawnlily	Present
Vascular Plant	*Erythronium americanum* ssp. *americanum*	American troutlily	Present
Vascular Plant	*Lilium canadense*	Canada lily	Present
Vascular Plant	*Lilium michiganense*	Michigan lily	Present
Vascular Plant	*Lilium philadelphicum*	wood lily	Present
Vascular Plant	*Medeola virginiana*	Indian cucumber	Present
Vascular Plant	*Ornithogalum umbellatum*	Pyrenees Star of Bethlehem, sleepydick, Star-of-Bethlehem	Present
Vascular Plant	*Chamaelirium luteum*	fairywand	Present
Vascular Plant	*Melanthium woodii*	Wood’s bunchflower	Present
Vascular Plant	*Trillium flexipes*	nodding wakerobin	Present
Vascular Plant	*Trillium sessile*	toadshade	Present
Vascular Plant	*Smilax bona-nox*	saw greenbrier	Present
Vascular Plant	*Smilax ecirrata*	greenbriar, upright carrionflower, upright carrion-flower	Present
Vascular Plant	*Smilax glauca*	cat greenbrier, sawbrier, wild sarsaparilla	Present
Vascular Plant	*Smilax herbacea*	herbaceous greenbriar, Jacob’s lader, smooth carrionflower	Present

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Vascular Plant	*Smilax hugeri*	Huger's carrionflower	Present
Vascular Plant	*Smilax rotundifolia*	bullbriar, common catbriar, common greenbrier, greenbrier, horsebriar, roundleaf greenbriar, roundleaf greenbrier	Present
Vascular Plant	*Smilax tamnoides*	bristly greenbrier	Present
Vascular Plant	*Huperzia lucidula*	shining clubmoss	Present
Vascular Plant	*Huperzia porophila*	rock clubmoss	Present
Vascular Plant	*Lycopodium digitatum*	fan clubmoss	Present
Vascular Plant	*Asimina triloba*	pawpaw	Present
Vascular Plant	*Liriodendron tulipifera*	bois-jaune, tulip poplar, tulip-poplar, tuliptree, yellow poplar, yellow-poplar	Present
Vascular Plant	*Magnolia acuminata*	cucumbertree, cucumber-tree	Present
Vascular Plant	*Magnolia macrophylla*	bigleaf magnolia	Present
Vascular Plant	*Magnolia tripetala*	umbrella magnolia, umbrella-tree	Present
Vascular Plant	*Acalypha gracilens*	slender copperleaf, slender threeseed mercury	Present
Vascular Plant	*Acalypha rhomboidea*	common threeseed mercury, Virginia threeseed mercury	Present
Vascular Plant	*Acalypha virginica*	mercuryweed, threeseeded mercury, Virginia copperleaf, Virginia threeseed mercury, wax balls	Present
Vascular Plant	*Chamaesyce humistrata*	spreading sandmat	Present
Vascular Plant	*Chamaesyce maculata*	spotted spurge	Present
Vascular Plant	*Chamaesyce nutans*	eyebane	Present
Vascular Plant	*Croton capitatus*	capitate croton, doveweed, hogweed, hogwort, woolly croton	Present
Vascular Plant	*Croton monanthogynus*	oneseeded croton, prairie tea, prairie-tea	Present
Vascular Plant	*Croton willdenowii*	Willdenow's croton	Present
Vascular Plant	*Euphorbia commutata*	tinted euphorbia, tinted woodland spurge	Present
Vascular Plant	*Euphorbia corollata*	flowering spurge, floweringspurge euphorbia	Present
Vascular Plant	*Euphorbia dentata* var. *dentata*	toothed spurge, toothedleaf poinsettia	Present
Vascular Plant	*Euphorbia heterophylla*	Mexican fireplant, painted euphorbia	Present
Vascular Plant	*Tragia cordata*	heartleaf noseburn	Present
Vascular Plant	*Hypericum denticulatum*	coppery St. Johnswort	Present
Vascular Plant	*Hypericum dolabriforme*	straggling St. Johnswort	Present
Vascular Plant	*Hypericum drummondii*	Drummond's St. Johnswort, nits and lice	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Hypericum formosum*	–	Present
Vascular Plant	*Hypericum frondosum*	cedarglade St. Johnswort	Present
Vascular Plant	*Hypericum gentianoides*	orangegrass, pinweed St. Johnswort	Present
Vascular Plant	*Hypericum hypericoides*	St. Andrew's cross	Present
Vascular Plant	*Hypericum hypericoides* ssp. *hypericoides*	St. Andrew's cross	Present
Vascular Plant	*Hypericum hypericoides* ssp. *multicaule*	St. Andrew's cross	Present
Vascular Plant	*Hypericum lobocarpum*	fivelobe St. Johnswort	Present
Vascular Plant	*Hypericum mutilum*	dwarf St. Johnswort	Present
Vascular Plant	*Hypericum perforatum*	common St. John's wort, common St. Johnswort, Klamath weed, Klamathweed, St. John's wort, St. Johnswort	Present
Vascular Plant	*Hypericum prolificum*	shrubby St. Johnswort	Present
Vascular Plant	*Hypericum punctatum*	spotted St. Johnswort	Present
Vascular Plant	*Hypericum sphaerocarpum*	roundseed St. Johnswort	Present
Vascular Plant	*Triadenum walteri*	greater marsh St. Johnswort	Present
Vascular Plant	*Linum medium* var. *texanum*	stiff yellow flax	Present
Vascular Plant	*Linum striatum*	ridged yellow flax, rigid flax	Present
Vascular Plant	*Linum virginianum*	woodland flax	Present
Vascular Plant	*Passiflora incarnata*	purple passionflower	Present
Vascular Plant	*Passiflora lutea*	passionflower, yellow passionflower	Present
Vascular Plant	*Populus alba*	white poplar	Present
Vascular Plant	*Populus deltoides* ssp. *deltoides*	eastern cottonwood	Present
Vascular Plant	*Salix exigua*	coyote willow, desert willow, narrowleaf willow, sandbar willow	Present
Vascular Plant	*Salix humilis*	prairie willow	Present
Vascular Plant	*Salix humilis* var. *tristis*	prairie willow	Present
Vascular Plant	*Salix interior*	sandbar willow	Present
Vascular Plant	*Salix nigra*	black willow	Present
Vascular Plant	*Salix sericea*	silky willow	Present
Vascular Plant	*Salix* X *sepulcralis*	weeping willow	Present
Vascular Plant	*Hybanthus concolor*	eastern greenviolet, nodding violet	Present
Vascular Plant	*Viola affinis*	sand violet	Present
Vascular Plant	*Viola bicolor*	field pansy	Present
Vascular Plant	*Viola blanda*	sweet white violet	Present
Vascular Plant	*Viola canadensis* var. *canadensis*	Canadian white violet	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Viola conspersa*	American dog violet	Present
Vascular Plant	*Viola cucullata*	marsh blue violet	Present
Vascular Plant	*Viola hirsutula*	southern woodland violet	Present
Vascular Plant	*Viola lanceolata* ssp. *lanceolata*	bog white violet	Present
Vascular Plant	*Viola palmata* var. *palmata*	violet	Present
Vascular Plant	*Viola pedata*	birdfoot violet	Present
Vascular Plant	*Viola pedatifida*	crow-foot violet	Present
Vascular Plant	*Viola pubescens*	downy yellow violet	Present
Vascular Plant	*Viola pubescens* var. *pubescens*	smooth yellow violet	Present
Vascular Plant	*Viola pubescens* var. *scabriuscula*	downy yellow violet	Present
Vascular Plant	*Viola rostrata*	longspur violet, long-spur violet	Present
Vascular Plant	*Viola rotundifolia*	roundleaf violet, roundleaf yellow violet	Present
Vascular Plant	*Viola sagittata*	arrowleaf violet, arrow-leaved violet	Present
Vascular Plant	*Viola sororia*	common blue violet	Present
Vascular Plant	*Viola striata*	striped cream violet	Present
Vascular Plant	*Viola walteri*	prostrate blue violet	Present
Vascular Plant	*Viola* X *primulifolia*	–	Present
Vascular Plant	*Lechea racemulosa*	Illinois pinweed	Present
Vascular Plant	*Abutilon theophrasti*	butterprint, buttonweed, Indian mallow, velvetleaf, velvetleaf Indian mallow	Present
Vascular Plant	*Hibiscus laevis*	halberdleaf rosemallow	Present
Vascular Plant	*Hibiscus moscheutos*	crimsoneyed rosemallow, swamp rosemallow	Present
Vascular Plant	*Hibiscus syriacus*	althea, rose of Sharon, shrub althea	Present
Vascular Plant	*Sida spinosa*	prickly fanpetals, prickly sida	Present
Vascular Plant	*Tilia americana*	American basswood	Present
Vascular Plant	*Dirca palustris*	eastern leatherwood, moosewood	Present
Vascular Plant	*Ammannia coccinea*	purple ammannia, valley redstem	Present
Vascular Plant	*Cuphea viscosissima*	blue waxweed	Present
Vascular Plant	*Rotala ramosior*	lowland rotala, lowland toothcup, rotala	Present
Vascular Plant	*Rhexia mariana*	Maryland meadowbeauty	Present
Vascular Plant	*Rhexia virginica*	common meadowbeauty, handsome Harry	Present
Vascular Plant	*Circaea lutetiana* ssp. *canadensis*	broadleaf enchanter’s nightshade	Present
Vascular Plant	*Gaura filipes*	slenderstalk beeblossom	Present
Vascular Plant	*Ludwigia alternifolia*	bushy seedbox, seedbox	Present

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Vascular Plant	*Ludwigia decurrens*	wingleaf primrose-willow, wingleaf waterprimrose	Present
Vascular Plant	*Ludwigia palustris*	marsh primrose-willow, marsh seedbox	Present
Vascular Plant	*Oenothera biennis*	common evening primrose, common evening-primrose, hoary eveningprimrose, king's-cureall	Present
Vascular Plant	*Oenothera clelandii*	Cleland's evening primrose, Cleland's evening-primrose	Present
Vascular Plant	*Oenothera fruticosa*	narrowleaf evening primrose, narrowleaf evening-primrose	Present
Vascular Plant	*Oenothera fruticosa* ssp. *glauca*	narrowleaf eveningprimrose	Present
Vascular Plant	*Oenothera perennis*	little evening primrose, little evening-primrose	Present
Vascular Plant	*Brasenia schreberi*	Schreber's watershield, watershield	Present
Vascular Plant	*Botrychium biternatum*	sparselobe grapefern	Present
Vascular Plant	*Botrychium dissectum*	cutleaf grapefern, cut-leaf grape-fern, dissected grapefern	Present
Vascular Plant	*Botrychium virginianum*	rattlesnake fern	Present
Vascular Plant	*Ophioglossum engelmannii*	adderstongue, limestone adderstongue, limestone adder's-tongue	Present
Vascular Plant	*Ophioglossum vulgatum*	southern adderstongue, southern adder's-tongue	Present
Vascular Plant	*Osmunda cinnamomea* var. *cinnamomea*	cinnamon fern	Present
Vascular Plant	*Osmunda claytoniana*	interrupted fern	Present
Vascular Plant	*Osmunda regalis* var. *spectabilis*	royal fern	Present
Vascular Plant	*Oxalis grandis*	great yellow woodsorrel	Present
Vascular Plant	*Oxalis stricta*	common yellow oxalis, erect woodsorrel, sheep sorrel, sourgrass, toad sorrel, upright yellow woodsorrel, upright yellow wood-sorrel, yellow woodsorrel	Present
Vascular Plant	*Oxalis violacea*	purple woodsorrel, violet woodsorrel, violet wood-sorrel	Present
Vascular Plant	*Juniperus virginiana* var. *virginiana*	eastern redcedar	Present
Vascular Plant	*Pinus echinata*	Arkansas pine, shortleaf pine, shortleaf yellow pine, shortstraw pine, southern yellow pine, yellow pine	Present
Vascular Plant	*Pinus strobus*	eastern white pine, northern white pine, soft pine, Weymouth pine, white pine	Present
Vascular Plant	*Pinus taeda*	loblolly pine	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Pinus virginiana*	Jersey pine, scrub pine, Virginia pine	Present
Vascular Plant	*Tsuga canadensis*	Canada hemlock, eastern hemlock, hemlock spruce	Present
Vascular Plant	*Aristolochia macrophylla*	pipevine	Present
Vascular Plant	*Aristolochia serpentaria*	Virginia dutchman's pipe, Virginia snakeroot	Present
Vascular Plant	*Aristolochia tomentosa*	common dutchman's pipe, woolly dutchman's pipe	Present
Vascular Plant	*Asarum canadense*	Canadian wild ginger, Canadian wildginger	Present
Vascular Plant	*Saururus cernuus*	lizard's tail	Present
Vascular Plant	*Carex albicans* var. *albicans*	whitetinge sedge	Present
Vascular Plant	*Carex albicans* var. *australis*	stellate sedge	Present
Vascular Plant	*Carex albicans* var. *emmonsii*	Emmons' sedge	Present
Vascular Plant	*Carex albursina*	white bear sedge	Present
Vascular Plant	*Carex amphibola*	amphibious sedge, eastern narrowleaf sedge	Present
Vascular Plant	*Carex blanda*	bland sedge, eastern woodland sedge, woodland sedge	Present
Vascular Plant	*Carex brevior*	brevior sedge, fescue sedge, shortbeak sedge	Present
Vascular Plant	*Carex careyana*	Carey's sedge	Present
Vascular Plant	*Carex cephalophora*	ovalleaf sedge, oval-leaf sedge, oval-leaved sedge	Present
Vascular Plant	*Carex communis*	fibrousroot sedge	Present
Vascular Plant	*Carex comosa*	longhair sedge	Present
Vascular Plant	*Carex complanata*	blue sedge, hirsute sedge	Present
Vascular Plant	*Carex crinita*	fringed sedge	Present
Vascular Plant	*Carex crinita* var. *crinita*	fringed sedge	Present
Vascular Plant	*Carex decomposita*	cypressknee sedge	Present
Vascular Plant	*Carex digitalis*	slender wood sedge, slender woodland sedge	Present
Vascular Plant	*Carex eburnea*	bristleleaf sedge, bristle-leaf sedge	Present
Vascular Plant	*Carex flaccosperma*	thinfruit sedge	Present
Vascular Plant	*Carex frankii*	Frank's sedge	Present
Vascular Plant	*Carex gigantea*	giant sedge	Present
Vascular Plant	*Carex glaucodea*	blue sedge	Present
Vascular Plant	*Carex gracilescens*	slender looseflower sedge	Present
Vascular Plant	*Carex grayi*	Gray's sedge	Present
Vascular Plant	*Carex gynandra*	nodding sedge	Present
Vascular Plant	*Carex hirsutella*	fuzzy wuzzy sedge, hirsute sedge	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Carex hirtifolia*	pubescent sedge	Present
Vascular Plant	*Carex jamesii*	James' sedge	Present
Vascular Plant	*Carex laevivaginata*	smoothsheath sedge, woolly sedge	Present
Vascular Plant	*Carex laxiculmis*	spreading sedge	Present
Vascular Plant	*Carex laxiflora*	broad looseflower sedge	Present
Vascular Plant	*Carex louisianica*	Louisiana sedge	Present
Vascular Plant	*Carex lupuliformis*	false hop sedge	Present
Vascular Plant	*Carex lupulina*	hop sedge	Present
Vascular Plant	*Carex lurida*	shallow sedge	Present
Vascular Plant	*Carex meadii*	Mead's sedge	Present
Vascular Plant	*Carex muehlenbergii* var. *enervis*	Muhlenberg's sedge	Present
Vascular Plant	*Carex nigromarginata*	black edge sedge	Present
Vascular Plant	*Carex oligocarpa*	eastern few-fruit sedge, richwoods sedge	Present
Vascular Plant	*Carex pensylvanica*	Penn sedge, Pennsylvania sedge	Present
Vascular Plant	*Carex picta*	Boott's sedge	Present
Vascular Plant	*Carex plantaginea*	plantainleaf sedge	Present
Vascular Plant	*Carex platyphylla*	broadleaf sedge, broad-leaved sedge	Present
Vascular Plant	*Carex retroflexa*	reflexed sedge	Present
Vascular Plant	*Carex rosea*	rosy sedge	Present
Vascular Plant	*Carex squarrosa*	squarrose sedge	Present
Vascular Plant	*Carex striatula*	lined sedge	Present
Vascular Plant	*Carex stricta*	upright sedge, uptight sedge	Present
Vascular Plant	*Carex styloflexa*	bent sedge	Present
Vascular Plant	*Carex swanii*	swan sedge, Swan's sedge	Present
Vascular Plant	*Carex texensis*	Texas sedge	Present
Vascular Plant	*Carex tribuloides*	blunt broom sedge	Present
Vascular Plant	*Carex tribuloides* var. *sangamonensis*	blunt broom sedge	Present
Vascular Plant	*Carex typhina*	cattail sedge, cat-tail sedge	Present
Vascular Plant	*Carex virescens*	ribbed sedge	Present
Vascular Plant	*Carex vulpinoidea*	common fox sedge	Present
Vascular Plant	*Carex willdenowii*	Willdenow's sedge	Present
Vascular Plant	*Cyperus echinatus*	globe flatsedge	Present
Vascular Plant	*Cyperus erythrorhizos*	redroot flatsedge	Present
Vascular Plant	*Cyperus flavescens*	pale flatsedge, yellow flatsedge	Present
Vascular Plant	*Cyperus odoratus*	fragrant flatsedge, rusty flat sedge	Present
Vascular Plant	*Cyperus pseudovegetus*	marsh flatsedge	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Cyperus retrofractus*	rough flatsedge	Present
Vascular Plant	*Cyperus retrorsus* var. *retrorsus*	pine barren flatsedge	Present
Vascular Plant	*Cyperus squarrosus*	awned flat sedge, bearded flatsedge, bearded nutgrass	Present
Vascular Plant	*Cyperus strigosus*	stawcolored flatsedge, strawcolor flatsedge, strawcolor nutgrass, strawcolored flatsedge, strawcolored nutgrass	Present
Vascular Plant	*Dulichium arundinaceum*	threeway sedge	Present
Vascular Plant	*Eleocharis engelmannii*	Engelmann's spikerush, Engelmann's spike-rush	Present
Vascular Plant	*Eleocharis erythropoda*	bald spikerush	Present
Vascular Plant	*Eleocharis obtusa*	blunt spikerush, blunt spikesedge	Present
Vascular Plant	*Eleocharis ovata*	ovate spikerush, ovoid spikerush, ovoid spike-rush	Present
Vascular Plant	*Eleocharis palustris*	common spikerush, creeping spikerush, creeping spike-rush, marsh spike-rush, spikesedge	Present
Vascular Plant	*Eleocharis quadrangulata*	squarestem spikerush, squarestem spikesedge	Present
Vascular Plant	*Eleocharis tenuis*	slender spikerush	Present
Vascular Plant	*Fimbristylis autumnalis*	slender fimbry	Present
Vascular Plant	*Rhynchospora capitellata*	brownish beaksedge	Present
Vascular Plant	*Rhynchospora corniculata*	shortbristle horned beaksedge	Present
Vascular Plant	*Schoenoplectus tabernaemontani*	great bulrush, softstem bulrush, soft-stem bulrush	Present
Vascular Plant	*Scirpus atrovirens*	dark-green bulrush, green bulrush	Present
Vascular Plant	*Scirpus cyperinus*	bulrush, woolgrass	Present
Vascular Plant	*Scirpus georgianus*	Georgia bulrush	Present
Vascular Plant	*Scirpus pendulus*	rufous bulrush	Present
Vascular Plant	*Scirpus polyphyllus*	leafy bulrush	Present
Vascular Plant	*Scleria ciliata*	fringed nutrush	Present
Vascular Plant	*Scleria triglomerata*	whip nutrush	Present
Vascular Plant	*Juncus acuminatus*	sharp-fruit rush, tapertip rush	Present
Vascular Plant	*Juncus brachycarpus*	whiteroot rush	Present
Vascular Plant	*Juncus coriaceus*	leathery rush	Present
Vascular Plant	*Juncus effusus*	common rush, lamp rush	Present
Vascular Plant	*Juncus effusus* var. *solutus*	lamp rush	Present
Vascular Plant	*Juncus secundus*	lopsided rush	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Juncus tenuis*	field rush, path rush, poverty rush, slender rush, slender yard rush, wiregrass	Present
Vascular Plant	*Luzula echinata*	hedgehog woodrush	Present
Vascular Plant	*Luzula multiflora*	common woodrush	Present
Vascular Plant	*Agrostis elliottiana*	Elliot bentgrass, Elliott bentgrass, Elliott's bentgrass	Present
Vascular Plant	*Agrostis gigantea*	redtop	Present
Vascular Plant	*Agrostis hyemalis*	winter bentgrass	Present
Vascular Plant	*Agrostis perennans*	autumm bentgrass, upland bent, upland bentgrass	Present
Vascular Plant	*Andropogon gerardii*	big bluestem, bluejoint, turkeyfoot	Present
Vascular Plant	*Andropogon gyrans* var. *gyrans*	Elliott bluestem, Elliott's bluestem	Present
Vascular Plant	*Andropogon ternarius*	splitbeard bluestem	Present
Vascular Plant	*Andropogon virginicus* var. *virginicus*	broomsedge bluestem	Present
Vascular Plant	*Anthoxanthum odoratum*	sweet vernalgrass	Present
Vascular Plant	*Aristida dichotoma*	churchmouse threeawn	Present
Vascular Plant	*Aristida oligantha*	Oldfield (Prairie) 3-awn, oldfield threeawn, prairie threeawn	Present
Vascular Plant	*Aristida purpurascens* var. *purpurascens*	longleaf threeawn	Present
Vascular Plant	*Arundinaria gigantea* ssp. *gigantea*	giant cane	Present
Vascular Plant	*Arundo donax*	giant reed, giantreed	Present
Vascular Plant	*Brachyelytrum erectum*	bearded shorthusk	Present
Vascular Plant	*Bromus commutatus*	hairy brome, hairy chess, meadow brome	Present
Vascular Plant	*Bromus japonicus*	Japanese brome, Japanese bromegrass, Japanese chess	Present
Vascular Plant	*Bromus nottowayanus*	Nottoway Valley brome	Present
Vascular Plant	*Bromus pubescens*	common eastern brome	Present
Vascular Plant	*Bromus racemosus*	bald brome	Present
Vascular Plant	*Bromus sterilis*	barren bromegrass, poverty brome, sterile brome	Present
Vascular Plant	*Bromus tectorum*	cheat grass, cheatgrass, downy brome, early chess, military grass, wild oats	Present
Vascular Plant	*Chasmanthium latifolium*	Indian woodoats	Present
Vascular Plant	*Chasmanthium laxum*	slender woodoats, spike uniola	Present
Vascular Plant	*Cinna arundinacea*	stout wood reed-grass, stout woodreed, sweet woodreed, sweet wood-reed	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Cynodon dactylon*	Bermudagrass, chiendent pied-de-poule, common bermudagrass, devilgrass, grama-seda, manienie, motie molulu	Present
Vascular Plant	*Dactylis glomerata* ssp. *glomerata*	orchardgrass	Present
Vascular Plant	*Danthonia compressa*	flattened oatgrass	Present
Vascular Plant	*Danthonia spicata*	poverty danthonia, poverty oatgrass, poverty wild oat grass	Present
Vascular Plant	*Diarrhena americana*	American beakgrain	Present
Vascular Plant	*Dichanthelium aciculare*	needleleaf rosette grass	Present
Vascular Plant	*Dichanthelium acuminatum* var. *acuminatum*	tapered tosette grass	Present
Vascular Plant	*Dichanthelium acuminatum* var. *fasciculatum*	western panicgrass	Present
Vascular Plant	*Dichanthelium boscii*	Bosc's panicgrass	Present
Vascular Plant	*Dichanthelium clandestinum*	deertongue	Present
Vascular Plant	*Dichanthelium commutatum*	variable panicgrass	Present
Vascular Plant	*Dichanthelium depauperatum*	starved panicgrass	Present
Vascular Plant	*Dichanthelium dichotomum*	cypress panicgrass	Present
Vascular Plant	*Dichanthelium dichotomum* var. *dichotomum*	cypress panicgrass	Present
Vascular Plant	*Dichanthelium dichotomum* var. *ramulosum*	a panic grass	Present
Vascular Plant	*Dichanthelium latifolium*	broadleaf rosette grass	Present
Vascular Plant	*Dichanthelium laxiflorum*	openflower rosette grass	Present
Vascular Plant	*Dichanthelium oligosanthes* var. *oligosanthes*	Heller's rosette grass	Present
Vascular Plant	*Dichanthelium oligosanthes* var. *scribnerianum*	Heller's rosette grass, Scribner panic, Scribner panicum, Scribners panicum, Scribner's panicum, Scribner's rosette grass	Present
Vascular Plant	*Dichanthelium ravenelii*	Ravenel's rosette grass	Present
Vascular Plant	*Dichanthelium scoparium*	velvet panicum	Present
Vascular Plant	*Dichanthelium sphaerocarpon*	roundseed panicgrass, roundseed panicum	Present
Vascular Plant	*Dichanthelium sphaerocarpon* var. *isophyllum*	roundseed panicgrass, roundseed panicum	Present
Vascular Plant	*Dichanthelium sphaerocarpon* var. *sphaerocarpon*	roundseed panicgrass, roundseed panicum	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Dichanthelium villosissimum* var. *villosissimum*	whitehair rosette grass	Present
Vascular Plant	*Digitaria filiformis*	slender crabgrass	Present
Vascular Plant	*Digitaria ischaemum*	small crabgrass, smooth crab grass, smooth crabgrass	Present
Vascular Plant	*Digitaria sanguinalis*	crabgrass, hairy crab grass, hairy crabgrass, large crabgrass, purple crabgrass, redhair crabgrass	Present
Vascular Plant	*Echinochloa crus-galli*	barnyard grass, barnyardgrass, cockspur, Japanese millet, large barnyard grass, watergrass	Present
Vascular Plant	*Echinochloa muricata*	rough barnyard grass, rough barnyardgrass	Present
Vascular Plant	*Echinochloa muricata* var. *microstachya*	rough barnyard grass, rough barnyardgrass	Present
Vascular Plant	*Eleusine indica*	crowsfoot grass, goose grass, goosegrass, Indian goose grass, Indian goosegrass, manienie ali'I, silver crabgrass, wiregrass	Present
Vascular Plant	*Elymus hystrix*	eastern bottlebrush grass, eastern bottle-brush grass	Present
Vascular Plant	*Elymus hystrix* var. *hystrix*	eastern bottlebrush grass	Present
Vascular Plant	*Elymus villosus*	hairy wild rye, hairy wildrye, slender wild-rye	Present
Vascular Plant	*Elymus virginicus* var. *virginicus*	Virginia wildrye	Present
Vascular Plant	*Eragrostis cilianensis*	candy grass, lovegrass, stink grass, stinkgrass, strongscented lovegrass	Present
Vascular Plant	*Eragrostis frankii*	sandbar lovegrass	Present
Vascular Plant	*Eragrostis hypnoides*	creeping lovegrass, teal love grass, teal lovegrass	Present
Vascular Plant	*Eragrostis pectinacea* var. *pectinacea*	purple love grass, Purple lovegrass, spreading lovegrass, tufted lovegrass	Present
Vascular Plant	*Eragrostis spectabilis*	petticoat-climber, purple lovegrass	Present
Vascular Plant	*Festuca rubra*	ravine fescue, red fescue	Present
Vascular Plant	*Festuca subverticillata*	nodding fescue	Present
Vascular Plant	*Glyceria acutiflora*	creeping mannagrass	Present
Vascular Plant	*Glyceria striata*	fowl manna grass, fowl mannagrass	Present
Vascular Plant	*Gymnopogon ambiguus*	bearded skeletongrass	Present
Vascular Plant	*Holcus lanatus*	common velvetgrass, velvetgrass, Yorkshire fog	Present
Vascular Plant	*Hordeum pusillum*	little barley, little wildbarley	Present
Vascular Plant	*Leersia oryzoides*	rice cut grass, rice cutgrass	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Leersia virginica*	white grass, whitegrass	Present
Vascular Plant	*Leptochloa panicea* ssp. *brachiata*	mucronate sprangeltop	Present
Vascular Plant	*Leptochloa panicea* ssp. *mucronata*	mucronate sprangletop	Present
Vascular Plant	*Lolium arundinaceum*	tall fescue	Present
Vascular Plant	*Lolium perenne*	perennial ryegrass	Present
Vascular Plant	*Lolium pratense*	meadow fescue, meadow ryegrass	Present
Vascular Plant	*Melica mutica*	oniongrass, twoflower melic, twoflower melicgrass	Present
Vascular Plant	*Microstegium vimineum*	Japanese stiltgrass, Nepalese browntop	Present
Vascular Plant	*Miscanthus sinensis*	Chinese silvergrass	Present
Vascular Plant	*Muhlenbergia capillaris*	hairawn muhly	Present
Vascular Plant	*Muhlenbergia frondosa*	wirestem muhly, wire-stem muhly	Present
Vascular Plant	*Muhlenbergia mexicana*	Mexican muhly	Present
Vascular Plant	*Muhlenbergia schreberi*	nimblewill, nimblewill muhly	Present
Vascular Plant	*Muhlenbergia sobolifera*	rock muhly	Present
Vascular Plant	*Muhlenbergia tenuiflora*	slender muhly	Present
Vascular Plant	*Panicum anceps*	beaked panicgrass, beaked panicum	Present
Vascular Plant	*Panicum capillare*	annual witchgrass, common panic grass, common witchgrass, panicgrass, ticklegrass, tumble panic, tumbleweed grass, witches hair, witchgrass	Present
Vascular Plant	*Panicum dichotomiflorum* var. *dichotomiflorum*	fall panicgrass	Present
Vascular Plant	*Panicum flexile*	wiry panic grass, wiry panicgrass, wiry witch grass	Present
Vascular Plant	*Panicum gattingeri*	Gattinger’s panicgrass	Present
Vascular Plant	*Panicum rigidulum*	redtop panicgrass	Present
Vascular Plant	*Panicum rigidulum* var. *elongatum*	redtop panicgrass	Present
Vascular Plant	*Panicum rigidulum* var. *rigidulum*	redtop panicum	Present
Vascular Plant	*Panicum verrucosum*	warty panicgrass	Present
Vascular Plant	*Panicum virgatum* var. *virgatum*	switchgrass	Present
Vascular Plant	*Paspalum dilatatum*	dallas grass, dallis grass, dallisgrass, herbe de miel, herbe sirop, hiku nua, palpalum dilate, water grass	Present
Vascular Plant	*Paspalum fluitans*	horsetail paspalum	Present
Vascular Plant	*Paspalum laeve*	field paspalum	Present
Vascular Plant	*Paspalum pubiflorum*	hairyseed paspalum	Present

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Vascular Plant	*Paspalum setaceum*	thin paspalum	Present
Vascular Plant	*Pennisetum glaucum*	pearl millet, pearl-millet, yellow bristlegrass	Present
Vascular Plant	*Phleum pratense*	common timothy, timothy	Present
Vascular Plant	*Poa annua*	annual bluegrass	Present
Vascular Plant	*Poa autumnalis*	autumn bluegrass	Present
Vascular Plant	*Poa chapmaniana*	Chapman's bluegrass	Present
Vascular Plant	*Poa compressa*	Canada bluegrass, flat-stem blue grass	Present
Vascular Plant	*Poa cuspidata*	early bluegrass	Present
Vascular Plant	*Poa pratensis*	Kentucky bluegrass	Present
Vascular Plant	*Poa sylvestris*	woodland bluegrass	Present
Vascular Plant	*Saccharum alopecuroidum*	silver plumegrass	Present
Vascular Plant	*Schizachyrium scoparium*	little bluestem	Present
Vascular Plant	*Schizachyrium scoparium* var. *scoparium*	little bluestem	Present
Vascular Plant	*Secale cereale*	cereal rye, common rye, cultivated annual rye, cultivated rye, rye	Present
Vascular Plant	*Setaria faberi*	Chinese foxtail, Chinese millet, giant bristlegrass, giant foxtail, Japanese bristlegrass, nodding foxtail, tall green bristlegrass	Present
Vascular Plant	*Setaria parviflora*	yellow bristlegrass	Present
Vascular Plant	*Sorghastrum nutans*	Indiangrass, yellow indian-grass	Present
Vascular Plant	*Sorghum halepense*	aleppo milletgrass, herbe de Cuba, Johnson grass, Johnsongrass, sorgho d'Alep, sorgo de alepo, zacate Johnson	Present
Vascular Plant	*Sphenopholis intermedia*	slender wedgegrass, slender wedgescale	Present
Vascular Plant	*Sphenopholis nitida*	shiny wedgescale	Present
Vascular Plant	*Sphenopholis obtusata*	prairie wedgescale	Present
Vascular Plant	*Sporobolus clandestinus*	rough dropseed	Present
Vascular Plant	*Sporobolus compositus* var. *compositus*	dropseed	Present
Vascular Plant	*Sporobolus neglectus*	puffsheath dropseed, small dropseed	Present
Vascular Plant	*Sporobolus vaginiflorus*	poverty dropseed, poverty grass	Present
Vascular Plant	*Tridens flavus* var. *flavus*	purpletop tridens	Present
Vascular Plant	*Vulpia octoflora*	eight-flower six-weeks grass, pullout grass, sixweeks fescue, sixweeks grass	Present
Vascular Plant	*Sparganium androcladum*	branched burreed, branched bur-reed, branching bur-reed	Present
Vascular Plant	*Typha angustifolia*	narrowleaf cattail, narrow-leaf cat-tail	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Typha latifolia*	broadleaf cattail, cattail, common cattail	Present
Vascular Plant	*Asplenium montanum*	mountain spleenwort	Present
Vascular Plant	*Asplenium pinnatifidum*	lobed spleenwort	Present
Vascular Plant	*Asplenium platyneuron*	ebony spleenwort	Present
Vascular Plant	*Asplenium resiliens*	blackstem spleenwort	Present
Vascular Plant	*Asplenium rhizophyllum*	walking fern	Present
Vascular Plant	*Asplenium trichomanes*	maidenhair spleenwort	Present
Vascular Plant	*Asplenium* X *trudellii*	Trudell's spleenwort	Present
Vascular Plant	*Woodwardia areolata*	chainfern, netted chainfern	Present
Vascular Plant	*Dennstaedtia punctilobula*	eastern hayscented fern	Present
Vascular Plant	*Pteridium aquilinum*	western brackenfern	Present
Vascular Plant	*Pteridium aquilinum* var. *latiusculum*	eastern bracken, northern bracken fern, western brackenfern	Present
Vascular Plant	*Dryopteris carthusiana*	spinulose woodfern	Present
Vascular Plant	*Dryopteris goldiana*	Goldie's woodfern	Present
Vascular Plant	*Dryopteris intermedia*	intermediate woodfern	Present
Vascular Plant	*Dryopteris marginalis*	marginal woodfern, woodfern	Present
Vascular Plant	*Polystichum acrostichoides* var. *acrostichoides*	Christmas fern	Present
Vascular Plant	*Onoclea sensibilis*	sensitive fern	Present
Vascular Plant	*Pleopeltis polypodioides* ssp. *michauxiana*	resurrection fern	Present
Vascular Plant	*Polypodium virginianum*	rock polypody	Present
Vascular Plant	*Adiantum pedatum*	maidenfern, maidenhair, maidenhair fern, northern maidenhair	Present
Vascular Plant	*Cheilanthes lanosa*	hairy lipfern	Present
Vascular Plant	*Pellaea atropurpurea*	purple cliffbrake, purple-stem cliffbrake, purple-stem cliff-brake	Present
Vascular Plant	*Phegopteris hexagonoptera*	broad beechfern	Present
Vascular Plant	*Thelypteris noveboracensis*	New York fern	Present
Vascular Plant	*Athyrium filix-femina*	common ladyfern	Present
Vascular Plant	*Athyrium filix-femina* ssp. *asplenioides*	asplenium ladyfern	Present
Vascular Plant	*Cystopteris bulbifera*	bulb bladderfern, bulblet bladderfern	Present
Vascular Plant	*Cystopteris fragilis*	brittle bladder fern, brittle bladderfern, fragile fern	Present
Vascular Plant	*Cystopteris protrusa*	lowland bladderfern	Present
Vascular Plant	*Cystopteris tennesseensis*	Tennessee bladderfern	Present
Vascular Plant	*Cystopteris tenuis*	brittle bladderfern, upland brittle bladderfern	Present

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Vascular Plant	*Deparia acrostichoides*	silver false spleenwort	Present
Vascular Plant	*Diplazium pycnocarpon*	glade fern	Present
Vascular Plant	*Woodsia obtusa*	bluntlobe cliff fern, blunt-lobe woodsia	Present
Vascular Plant	*Platanus occidentalis*	American sycamore, sycamore	Present
Vascular Plant	*Berberis thunbergii*	Japanese barberry	Present
Vascular Plant	*Caulophyllum thalictroides*	blue cohosh, caulophylle faux-pigamon, papoose-root, squaw-root	Present
Vascular Plant	*Jeffersonia diphylla*	rheumatism-root, twinleaf	Present
Vascular Plant	*Podophyllum peltatum*	Indian-apple, May apple, mayapple, pomme de mai, wild-mandrake	Present
Vascular Plant	*Menispermum canadense*	Canadian moonseed, common moonseed	Present
Vascular Plant	*Corydalis flavula*	yellow fumewort	Present
Vascular Plant	*Dicentra canadensis*	squirrel corn	Present
Vascular Plant	*Dicentra cucullaria*	Dutchman’s breeches	Present
Vascular Plant	*Sanguinaria canadensis*	bloodroot	Present
Vascular Plant	*Stylophorum diphyllum*	celandine poppy	Present
Vascular Plant	*Actaea pachypoda*	baneberry, white baneberry	Present
Vascular Plant	*Actaea racemosa* var. *racemosa*	–	Present
Vascular Plant	*Anemone quinquefolia*	nightcaps, wood anemone	Present
Vascular Plant	*Anemone virginiana* var. *virginiana*	tall thimbleweed	Present
Vascular Plant	*Aquilegia canadensis*	American columbine, Colorado columbine, honeysuckle, meeting-houses, red columbine, wild columbine	Present
Vascular Plant	*Clematis glaucophylla*	whiteleaf leather flower	Present
Vascular Plant	*Clematis terniflora*	leatherleaf clematis, sweet autumn virginsbower, yam-leaved clematis	Present
Vascular Plant	*Clematis versicolor*	manycolored virginsbower, pale leather flower	Present
Vascular Plant	*Clematis viorna*	vasevine	Present
Vascular Plant	*Clematis virginiana*	devil’s darning needles, devil’s-darning-needles, Virginia bower, virgin’s bower	Present
Vascular Plant	*Delphinium tricorne*	dwarf larkspur, rock larkspur	Present
Vascular Plant	*Enemion biternatum*	eastern false rue anemone	Present
Vascular Plant	*Hepatica nobilis* var. *acuta*	sharplobe hepatica	Present
Vascular Plant	*Hepatica nobilis* var. *obtusa*	roundlobe hepatica	Present
Vascular Plant	*Hydrastis canadensis*	goldenseal	Present

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Vascular Plant	*Ranunculus abortivus*	early woodbuttercup, kidney-leaf buttercup, littleleaf buttercup, smallflower buttercup, smallflower crowfoot	Present
Vascular Plant	*Ranunculus bulbosus*	blister flower, bulbous buttercup, bulbous crowfoot, gowan, St. Anthony's turnip, yellow weed	Present
Vascular Plant	*Ranunculus fascicularis*	early buttercup, prairie buttercup, tufted buttercup	Present
Vascular Plant	*Ranunculus hispidus*	bristly buttercup	Present
Vascular Plant	*Ranunculus hispidus* var. *nitidus*	bristly buttercup, swamp buttercup	Present
Vascular Plant	*Ranunculus micranthus*	rock buttercup	Present
Vascular Plant	*Ranunculus recurvatus*	blisterwort, littleleaf buttercup	Present
Vascular Plant	*Ranunculus sardous*	hairy buttercup	Present
Vascular Plant	*Thalictrum clavatum*	mountain meadow-rue	Present
Vascular Plant	*Thalictrum dioicum*	early meadow-rue	Present
Vascular Plant	*Thalictrum pubescens*	king of the meadow	Present
Vascular Plant	*Thalictrum revolutum*	waxyleaf meadowrue, waxyleaf meadow-rue	Present
Vascular Plant	*Thalictrum thalictroides*	rue anemone	Present
Vascular Plant	*Celtis laevigata*	sugar hackberry	Present
Vascular Plant	*Celtis occidentalis*	common hackberry, hackberry, western hackberry	Present
Vascular Plant	*Celtis tenuifolia*	dwarf hackberry, Georgia hackberry	Present
Vascular Plant	*Elaeagnus umbellata* var. *parvifolia*	autumn olive, oleaster	Present
Vascular Plant	*Maclura pomifera*	osage orange, osage-orange	Present
Vascular Plant	*Morus rubra* var. *rubra*	red mulberry	Present
Vascular Plant	*Ceanothus americanus*	Jersey tea, New Jersey tea	Present
Vascular Plant	*Frangula caroliniana*	Carolina buckthorn	Present
Vascular Plant	*Agrimonia gryposepala*	agrimony, tall hairy agrimony, tall hairy groovebur	Present
Vascular Plant	*Agrimonia parviflora*	harvestlice, manyflowered groovebur	Present
Vascular Plant	*Agrimonia pubescens*	groovebur, roadside agrimony, soft agrimony, soft groovebur	Present
Vascular Plant	*Agrimonia rostellata*	beaked agrimony, woodland groovebur	Present
Vascular Plant	*Amelanchier arborea* var. *arborea*	common serviceberry	Present
Vascular Plant	*Amelanchier canadensis*	Canadian serviceberry	Probable
Vascular Plant	*Aruncus dioicus*	bride's feathers, goatsbeard	Present
Vascular Plant	*Crataegus marshallii*	parsley hawthorn	Present

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Vascular Plant	*Duchesnea indica*	India mockstrawberry, Indian strawberry	Present
Vascular Plant	*Fragaria virginiana*	thickleaved wild strawberry, Virginia strawberry, wild strawberry	Present
Vascular Plant	*Fragaria virginiana* ssp. *grayana*	Virginia strawberry	Present
Vascular Plant	*Geum canadense* var. *canadense*	Canada avens	Present
Vascular Plant	*Geum vernum*	heartleaf avens, spring avens	Present
Vascular Plant	*Geum virginianum*	cream avens	Present
Vascular Plant	*Photinia melanocarpa*	black chokeberry	Present
Vascular Plant	*Photinia pyrifolia*	red chokeberry	Present
Vascular Plant	*Physocarpus opulifolius* var. *opulifolius*	common ninebark	Present
Vascular Plant	*Porteranthus stipulatus*	Indian physic	Present
Vascular Plant	*Potentilla recta*	erect cinquefoil, roughfruit cinquefoil, sulphur cinquefoil	Present
Vascular Plant	*Potentilla simplex*	common cinquefoil, oldfield cinquefoil, oldfield fivefingers, spreading cinquefoil	Present
Vascular Plant	*Prunus americana*	American plum	Present
Vascular Plant	*Prunus angustifolia* var. *angustifolia*	Chickasaw plum	Present
Vascular Plant	*Prunus avium*	sweet cherry	Present
Vascular Plant	*Prunus persica*	peach	Present
Vascular Plant	*Prunus serotina* var. *serotina*	black cherry	Present
Vascular Plant	*Prunus virginiana*	chokecherry, common chokecherry, Virginia chokecherry	Present
Vascular Plant	*Rosa carolina* var. *carolina*	Carolina rose	Present
Vascular Plant	*Rosa multiflora*	multiflora rose	Present
Vascular Plant	*Rosa palustris*	swamp rose	Present
Vascular Plant	*Rosa setigera*	climbing rose, Prairie rose	Present
Vascular Plant	*Rosa virginiana*	Virginia rose	Present
Vascular Plant	*Rubus allegheniensis*	Allegheny blackberry	Present
Vascular Plant	*Rubus argutus*	prickly Florida blackberry, sawtooth blackberry	Present
Vascular Plant	*Rubus bifrons*	Himalayan berry	Present
Vascular Plant	*Rubus flagellaris*	northern dewberry, whiplash dewberry	Present
Vascular Plant	*Rubus frondosus*	yankee blackberry	Present
Vascular Plant	*Rubus occidentalis*	black raspberry	Present
Vascular Plant	*Rubus pensilvanicus*	Pennsylvania blackberry	Present
Vascular Plant	*Rubus trivialis*	southern dewberry	Present
Vascular Plant	*Spiraea prunifolia*	bridalwreath spirea	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Spiraea tomentosa*	steeplebush	Present
Vascular Plant	*Spiraea tomentosa* var. *rosea*	steeplebush	Present
Vascular Plant	*Spiraea tomentosa* var. *tomentosa*	steeplebush	Present
Vascular Plant	*Waldsteinia fragarioides*	Appalachian barren strawberry	Present
Vascular Plant	*Waldsteinia fragarioides* ssp. *doniana*	Appalachian barren strawberry	Present
Vascular Plant	*Planera aquatica*	planertree, water elm, water-elm	Present
Vascular Plant	*Ulmus alata*	winged elm	Present
Vascular Plant	*Ulmus americana*	American elm	Present
Vascular Plant	*Ulmus rubra*	slippery elm	Present
Vascular Plant	*Ulmus serotina*	September elm	Present
Vascular Plant	*Ulmus thomasii*	–	Present
Vascular Plant	*Boehmeria cylindrica*	smallspike false nettle, small-spike false nettle	Present
Vascular Plant	*Laportea canadensis*	Canada lettuce, Canada woodnettle, Canadian woodnettle, Canadian wood-nettle	Present
Vascular Plant	*Parietaria pensylvanica*	Pennsylvania pellitory	Present
Vascular Plant	*Pilea pumila*	Canada clearweed, Canadian clearweed	Present
Vascular Plant	*Comandra umbellata* ssp. *umbellata*	bastard toadflax	Present
Vascular Plant	*Phoradendron leucarpum*	oak mistletoe	Present
Vascular Plant	*Rhus aromatica* var. *aromatica*	fragrant sumac	Present
Vascular Plant	*Rhus copallinum* var. *latifolia*	winged sumac	Present
Vascular Plant	*Rhus glabra*	smooth sumac	Present
Vascular Plant	*Rhus hirta*	staghorn sumac	Present
Vascular Plant	*Toxicodendron radicans*	eastern poison ivy, poison ivy	Present
Vascular Plant	*Ptelea trifoliata*	common hoptree, hoptree	Present
Vascular Plant	*Acer negundo*	ashleaf maple, ash-leaf maple, box elder, boxelder, boxelder maple, California boxelder, Manitoba maple, three-leaf maple, western boxelder	Present
Vascular Plant	*Acer nigrum*	black maple, black sugar maple, hard maple, rock maple, sugar maple	Present
Vascular Plant	*Acer rubrum*	red maple	Present
Vascular Plant	*Acer rubrum* var. *trilobum*	red maple	Present
Vascular Plant	*Acer saccharinum*	silver maple	Present
Vascular Plant	*Acer saccharum*	sugar maple	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Aesculus flava*	yellow buckeye	Present
Vascular Plant	*Aesculus glabra* var. *glabra*	Ohio buckeye	Present
Vascular Plant	*Ailanthus altissima*	copal tree, tree of heaven, tree-of-heaven	Present
Vascular Plant	*Liquidambar styraciflua*	sweetgum	Present
Vascular Plant	*Sedum pulchellum*	widowscross	Present
Vascular Plant	*Sedum ternatum*	woodland stonecrop	Present
Vascular Plant	*Ribes missouriense*	Missouri gooseberry	Present
Vascular Plant	*Proserpinaca palustris*	marsh mermaidweed, marsh mermaid-weed	Present
Vascular Plant	*Proserpinaca palustris* var. *crebra*	marsh mermaidweed	Present
Vascular Plant	*Hamamelis virginiana*	American witchhazel, witchhazel, witch-hazel	Present
Vascular Plant	*Penthorum sedoides*	ditch stonecrop, Virginia penthorum	Present
Vascular Plant	*Astilbe biternata*	Appalachian false goat's beard	Present
Vascular Plant	*Boykinia aconitifolia*	Allegheny brookfoam, brook saxifrage	Present
Vascular Plant	*Heuchera americana* var. *americana*	American alumroot	Present
Vascular Plant	*Heuchera americana* var. *hirsuticaulis*	American alumroot	Present
Vascular Plant	*Heuchera parviflora*	littleflower alumroot	Present
Vascular Plant	*Heuchera parviflora* var. *parviflora*	littleflower alumroot	Present
Vascular Plant	*Heuchera parviflora* var. *puberula*	littleflower alumroot	Present
Vascular Plant	*Heuchera villosa* var. *villosa*	hairy alumroot	Present
Vascular Plant	*Mitella diphylla*	twoleaf miterwort	Present
Vascular Plant	*Saxifraga virginiensis*	early saxifrage	Present
Vascular Plant	*Tiarella cordifolia*	heartleaf foamflower	Present
Vascular Plant	*Calystegia sepium*	bearbind, devil's guts, hedge bindweed, hedge false bindweed, hedgebell, large bindweed, old man's night cap, wild morningglory	Present
Vascular Plant	*Calystegia sepium* ssp. *angulata*	hedge false bindweed	Present
Vascular Plant	*Calystegia sepium* ssp. *sepium*	hedge false bindweed	Present
Vascular Plant	*Calystegia spithamaea* ssp. *spithamaea*	low false bindweed	Present

Category	Scientific Name	Common Names	Occurrence
Vascular Plant	*Convolvulus arvensis*	creeping jenny, European bindweed, field bindweed, perennial morningglory, smallflowered morningglory	Present
Vascular Plant	*Cuscuta gronovii*	scaldweed	Present
Vascular Plant	*Ipomoea coccinea*	Mexican morningglory, red morningglory, redstar, scarlet morningglory, starglory, woolly tidestromia	Present
Vascular Plant	*Ipomoea hederacea*	entireleaf morningglory, ivyleaf morningglory, ivyleaf morning-glory, Mexican morningglory	Present
Vascular Plant	*Ipomoea lacunosa*	pitted morningglory, white morningglory, whitestar	Present
Vascular Plant	*Ipomoea pandurata*	bigroot morningglory, man of the earth, man-of-the-earth	Present
Vascular Plant	*Ipomoea purpurea*	common morningglory, common morning-glory, tall morningglory, tall morning-glory	Present
Vascular Plant	*Datura stramonium*	Jamestown weed, jimsonweed, mad apple, moonflower, stinkwort, thorn apple	Present
Vascular Plant	*Physalis cordata*	heartleaf groundcherry	Present
Vascular Plant	*Physalis heterophylla* var. *heterophylla*	clammy groundcherry	Present
Vascular Plant	*Physalis longifolia*	common groundcherry, longleaf groundcherry, long-leaf ground-cherry	Present
Vascular Plant	*Physalis longifolia* var. *subglabrata*	longleaf groundcherry	Present
Vascular Plant	*Physalis virginiana* var. *virginiana*	Virginia groundcherry	Present
Vascular Plant	*Solanum carolinense* var. *carolinense*	Carolina horsenettle	Present
Vascular Plant	*Solanum ptychanthum*	–	Present
Vascular Plant	*Ampelopsis arborea*	peppervine	Present
Vascular Plant	*Parthenocissus quinquefolia*	American ivy, fiveleaved ivy, Virginia creeper, woodbine	Present
Vascular Plant	*Vitis aestivalis*	summer grape	Present
Vascular Plant	*Vitis cinerea*	graybark grape, sweet grape	Present
Vascular Plant	*Vitis labrusca*	fox grape	Present
Vascular Plant	*Vitis palmata*	catbird grape	Present
Vascular Plant	*Vitis rotundifolia*	muscadine	Present
Vascular Plant	*Vitis vulpina*	fox grape, frost grape, wild grape	Present
Non-vascular Plant	*Conocephalum conicum*	–	Present

Category	Scientific Name	Common Names	Occurrence
Crab/Lobster/Shrimp	*Gammaridae*	–	Present
Crab/Lobster/Shrimp	*Pontoporeiidae*	–	Present
Crab/Lobster/Shrimp	*Cambaridae*	crayfishes	Present
Crab/Lobster/Shrimp	*Palaemonetes kadiakensis*	Mississippi grass shrimp	Present
Crab/Lobster/Shrimp	*Lirceus*	–	Present
Slug/Snail	*Ancylidae*	–	Present
Slug/Snail	*Physidae*	–	Present
Slug/Snail	*Planorbidae*	–	Present
Slug/Snail	*Hydrobiidae*	–	Present
Slug/Snail	*Pleuroceridae*	–	Present
Spider/Scorpion	*Hydracarina*	water mites	Present
Insect	*Parcoblatta pensylvanica*	Pennsylvania wood cockroach	Present
Insect	*Parcoblatta virginica*	Virginia wood cockroach	Present
Insect	*Dryopidae*	long-toe water beetles	Present
Insect	*Copelatus chevrolati renovatus*	–	Present
Insect	*Copelatus glyphicus*	–	Present
Insect	*Ilybius biguttulus*	–	Present
Insect	*Thermonectus basillaris*	–	Present
Insect	*Elmidae*	riffle beetles	Present
Insect	*Gyrinidae*	whirligig beetles	Present
Insect	*Haliplidae*	crawling water beetles	Present
Insect	*Tropicus pusillus*	–	Present
Insect	*Hydrophilidae*	water scavenger beetles	Present
Insect	*Ectopria*	–	Present
Insect	*Psephenus herricki*	–	Present
Insect	*Aphodius*	–	Present
Insect	*Phyllophaga ilicis*	–	Present
Insect	*Phyllophaga obsoleta*	–	Present
Insect	*Phyllophaga quercus*	–	Present
Insect	*Scirtidae*	marsh beetles	Present
Insect	*Ceratopogonidae*	biting midges, no-see-ums, punkies	Present
Insect	*Chironomidae*	midges	Present
Insect	*Empididae*	balloon flies, dance flies	Present
Insect	*Simuliidae*	black flies, buffalo gnats	Present
Insect	*Euparyphus*	–	Present
Insect	*Tabanus fulvulus*	–	Present
Insect	*Tabanus longus*	–	Present

Category	Scientific Name	Common Names	Occurrence
Insect	*Tabanus turbidus*	–	Present
Insect	*Tipulidae*	crane flies	Present
Insect	*Ameletus lineatus*	–	Present
Insect	*Baetidae*	–	Present
Insect	*Caenis*	–	Present
Insect	*Ephemerella*	–	Present
Insect	*Eurylophella funeralis*	–	Present
Insect	*Ephemera guttulata*	–	Present
Insect	*Hexagenia limbata*	–	Present
Insect	*Maccaffertium*	–	Present
Insect	*Stenacron interpunctatum*	–	Present
Insect	*Stenonema femoratum*	–	Present
Insect	*Isonychia*	–	Present
Insect	*Tricorythodes*	–	Present
Insect	*Habrophlebiodes americana*	–	Present
Insect	*Leptophlebia*	–	Present
Insect	*Paraleptophlebia*	–	Present
Insect	*Paraleptophlebia debilis*	–	Present
Insect	*Anthopotamus*	–	Present
Insect	*Corixidae*	water boatman	Present
Insect	*Gerridae*	pond skaters, water striders	Present
Insect	*Ranatra australis*	–	Present
Insect	*Microvelia americana*	–	Present
Insect	*Bittacus*	–	Present
Insect	*Chauliodes pectinicornis*	–	Present
Insect	*Chauliodes rastricornis*	–	Present
Insect	*Nigronia fasciatus*	–	Present
Insect	*Anax junius*	Common Green Darner	Present
Insect	*Epiaeschna heros*	Swamp Darner	Present
Insect	*Calopteryx*	–	Present
Insect	*Calopteryx maculata*	ebony jewelwing, Ebony Jewelwing	Present
Insect	*Argia moesta*	Powdered Dancer	Present
Insect	*Argia tibialis*	Blue-tipped Dancer	Present
Insect	*Chromagrion conditum*	Aurora Damsel	Present
Insect	*Enallagma aspersum*	Azure Bluet	Present
Insect	*Enallagma exsulans*	Stream Bluet	Present
Insect	*Ischnura posita*	Fragile Forktail	Present
Insect	*Cordulegaster erronea*	Tiger Spiketail	Present

Category	Scientific Name	Common Names	Occurrence
Insect	*Epitheca cynosura*	Common Baskettail	Present
Insect	*Neurocordulia obsoleta*	Umber Shadowdragon	Present
Insect	*Neurocordulia virginiensis*	Cinnamon Shadowdragon	Present
Insect	*Hagenius brevistylus*	Dragonhunter	Present
Insect	*Lestes dryas*	Emerald Spreadwing	Present
Insect	*Lestes eurinus*	Amber-winged Spreadwing	Present
Insect	*Erythemis simplicicollis*	Eastern Pondhawk, Green Clearwing	Present
Insect	*Libellula cyanea*	Spangled Skimmer	Present
Insect	*Libellula incesta*	Slaty Skimmer	Present
Insect	*Libellula pulchella*	Twelve-spotted Skimmer	Present
Insect	*Libellula vibrans*	Great Blue Skimmer	Present
Insect	*Pachydiplax longipennis*	Blue Dasher	Present
Insect	*Plathemis lydia*	Common Whitetail	Present
Insect	*Tramea carolina*	Carolina Saddlebags	Present
Insect	*Macromiidae*	belted skimmers, Cruisers, river skimmers	Present
Insect	*Tachopteryx thoreyi*	Gray Petaltail	Present
Insect	*Camptonotus carolinensis*	–	Present
Insect	*Gryllus rubens*	–	Present
Insect	*Velarifictorus micado*	–	Present
Insect	*Neoxabea bipunctata*	–	Present
Insect	*Atlanticus*	–	Present
Insect	*Microcentrum retinerve*	angularwinged katydid	Present
Insect	*Neoconocephalus triops*	–	Present
Insect	*Scudderia furcata furcata*	–	Present
Insect	*Allonemobius socius*	–	Present
Insect	*Eunemobius carolinus*	Carolina ground cricket	Present
Insect	*Neonemobius cubensis*	Cuban ground cricket	Present
Insect	*Sweltsa*	–	Present
Insect	*Leuctra alta*	–	Present
Insect	*Leuctra grandis*	–	Present
Insect	*Leuctra schusteri*	karst needlefly	Present
Insect	*Leuctra sibleyi*	–	Present
Insect	*Amphinemura nigritta*	–	Present
Insect	*Soyedina vallicularia*	–	Present
Insect	*Acroneuria frisoni*	–	Present
Insect	*Neoperla stewarti*	–	Present
Insect	*Perlesta*	–	Present

Category	Scientific Name	Common Names	Occurrence
Insect	*Perlinella drymo*	–	Present
Insect	*Perlinella ephyre*	–	Present
Insect	*Diploperla robusta*	–	Present
Insect	*Pteronarcyidae*	giant stoneflies	Present
Insect	*Taeniopterygidae*	winter stoneflies	Present
Insect	*Micrasema bennetti*	–	Present
Insect	*Anisocentropus pyraloides*	–	Present
Insect	*Phylocentropus lucidus*	–	Present
Insect	*Agapetus minutus*	–	Present
Insect	*Glossosoma nigrior*	–	Present
Insect	*Protoptila palina*	–	Present
Insect	*Goera fuscula*	–	Present
Insect	*Goera stylata*	–	Present
Insect	*Goerita betteni*	–	Present
Insect	*Helicopsyche borealis*	–	Present
Insect	*Cheumatopsyche analis*	–	Present
Insect	*Cheumatopsyche campyla*	–	Present
Insect	*Cheumatopsyche harwoodi*	–	Present
Insect	*Cheumatopsyche oxa*	–	Present
Insect	*Cheumatopsyche pasella*	–	Present
Insect	*Diplectrona metaqui*	–	Present
Insect	*Diplectrona modesta*	–	Present
Insect	*Hydropsyche betteni*	–	Present
Insect	*Hydropsyche cheilonis*	–	Present
Insect	*Hydropsyche orris*	–	Present
Insect	*Hydropsyche phalerata*	–	Present
Insect	*Hydropsyche scalaris*	–	Present
Insect	*Hydropsyche simulans*	–	Present
Insect	*Hydropsyche sparna*	–	Present
Insect	*Agraylea multipunctata*	–	Present
Insect	*Hydroptila armata*	–	Present
Insect	*Hydroptila consimilis*	–	Present
Insect	*Hydroptila coweetensis*	–	Present
Insect	*Hydroptila delineata*	–	Present
Insect	*Hydroptila gunda*	–	Present
Insect	*Hydroptila kuehnei*	–	Present
Insect	*Hydroptila remita*	–	Present
Insect	*Hydroptila spatulata*	–	Present

Category	Scientific Name	Common Names	Occurrence
Insect	*Hydroptila vala*	–	Present
Insect	*Ochrotrichia eliaga*	–	Present
Insect	*Ochrotrichia riesi*	–	Present
Insect	*Ochrotrichia tarsalis*	–	Present
Insect	*Orthotrichia aegerfasciella*	–	Present
Insect	*Orthotrichia cristata*	–	Present
Insect	*Oxyethira pallida*	–	Present
Insect	*Lepidostoma sackeni*	–	Present
Insect	*Ceraclea cancellata*	–	Present
Insect	*Ceraclea enodis*	–	Present
Insect	*Ceraclea flava*	–	Present
Insect	*Ceraclea maculata*	–	Present
Insect	*Ceraclea tarsipunctata*	–	Present
Insect	*Leptocerus americanus*	–	Present
Insect	*Nectopsyche candida*	–	Present
Insect	*Nectopsyche exquisita*	–	Present
Insect	*Nectopsyche pavida*	–	Present
Insect	*Oecetis avara*	–	Present
Insect	*Oecetis cinerascens*	–	Present
Insect	*Oecetis ditissa*	–	Present
Insect	*Oecetis inconspicua*	–	Present
Insect	*Oecetis nocturna*	–	Present
Insect	*Oecetis persimilis*	–	Present
Insect	*Setodes incertus*	–	Present
Insect	*Triaenodes injustus*	–	Present
Insect	*Triaenodes tardus*	–	Present
Insect	*Ironoquia punctatissima*	–	Present
Insect	*Pseudostenophylax uniformis*	–	Present
Insect	*Pycnopsyche antica*	–	Present
Insect	*Pycnopsyche gentilis*	–	Present
Insect	*Pycnopsyche guttifer*	–	Present
Insect	*Pycnopsyche luculenta*	–	Present
Insect	*Molanna blenda*	–	Present
Insect	*Psilotreta rufa*	–	Present
Insect	*Chimarra aterrima*	–	Present
Insect	*Chimarra obscura*	–	Present
Insect	*Dolophilodes distinctus*	–	Present
Insect	*Wormaldia moesta*	–	Present

Category	Scientific Name	Common Names	Occurrence
Insect	*Oligostomis ocelligera*	–	Present
Insect	*Phryganea cinerea*	–	Present
Insect	*Phryganea sayi*	–	Present
Insect	*Ptilostomis ocellifera*	–	Present
Insect	*Cyrnellus fraternus*	–	Present
Insect	*Neureclipsis crepuscularis*	–	Present
Insect	*Nyctiophylax moestus*	–	Present
Insect	*Plectrocnemia cinerea*	–	Present
Insect	*Polycentropus carolinensis*	–	Present
Insect	*Polycentropus centralis*	–	Present
Insect	*Polycentropus confusus*	–	Present
Insect	*Polycentropus elarus*	–	Present
Insect	*Lype diversa*	–	Present
Insect	*Psychomyia flavida*	–	Present
Insect	*Rhyacophila acutiloba*	–	Present
Insect	*Rhyacophila banksi*	–	Present
Insect	*Rhyacophila carolina*	–	Present
Insect	*Rhyacophila fenestra*	–	Present
Insect	*Rhyacophila glaberrima*	–	Present
Insect	*Rhyacophila invaria*	–	Present
Insect	*Rhyacophila ledra*	–	Present
Insect	*Rhyacophila parantra*	–	Present
Insect	*Rhyacophila torva*	–	Present
Insect	*Neophylax concinnus*	–	Present
Insect	*Neophylax fuscus*	–	Present
Insect	*Neophylax wigginsi*	–	Present
Other Non-vertebrates	*Eurynia dilatata*	–	Present
Other Non-vertebrates	*Nematoda*	–	Present
Other Non-vertebrates	*Turbellaria*	planarians, turbellarians	Present
Other Non-vertebrates	*Lumbriculidae*	aquatic oligochaete worm	Present
Other Non-vertebrates	*Tubificidae*	–	Present
Other Non-vertebrates	*Margaritifera monodonta*	spectaclecase	Present
Other Non-vertebrates	*Actinonaias ligamentina*	mucket	Present
Other Non-vertebrates	*Alasmidonta marginata*	elktoe	Present
Other Non-vertebrates	*Amblema plicata*	threeridge, three-ridge	Present
Other Non-vertebrates	*Anodonta suborbiculata*	flat floater	Present
Other Non-vertebrates	*Arcidens confragosus*	rock pocketbook	Present
Other Non-vertebrates	*Cyclonaias nodulata*	–	Present

Category	Scientific Name	Common Names	Occurrence
Other Non-vertebrates	*Cyclonaias pustulosa*	–	Present
Other Non-vertebrates	*Cyclonaias tuberculata*	purple wartyback	Present
Other Non-vertebrates	*Cyprogenia stegaria*	fanshell	Present
Other Non-vertebrates	*Ellipsaria lineolata*	butterfly	Present
Other Non-vertebrates	*Elliptio crassidens*	elephantear	Present
Other Non-vertebrates	*Epioblasma obliquata*	catspaw, purple cat's paw pearlymussel	Present
Other Non-vertebrates	*Epioblasma triquetra*	snuffbox	Present
Other Non-vertebrates	*Fusconaia flava*	Wabash pigtoe	Present
Other Non-vertebrates	*Fusconaia subrotunda*	longsolid, long-solid	Present
Other Non-vertebrates	*Lampsilis abrupta*	pink mucket	Present
Other Non-vertebrates	*Lampsilis cardium*	plain pocketbook	Present
Other Non-vertebrates	*Lampsilis fasciola*	wavyrayed lampmussel	Present
Other Non-vertebrates	*Lampsilis ovata*	pocketbook	Present
Other Non-vertebrates	*Lampsilis siliquoidea*	fatmucket	Present
Other Non-vertebrates	*Lampsilis teres*	yellow sandshell	Present
Other Non-vertebrates	*Lasmigona complanata*	white heelsplitter	Present
Other Non-vertebrates	*Lasmigona costata*	flutedshell, fluted-shell	Present
Other Non-vertebrates	*Leptodea fragilis*	fragile papershell	Present
Other Non-vertebrates	*Leptodea leptodon*	scaleshell	Present
Other Non-vertebrates	*Ligumia recta*	black sandshell	Present
Other Non-vertebrates	*Megalonaias nervosa*	washboard	Present
Other Non-vertebrates	*Obliquaria reflexa*	threehorn wartyback	Present
Other Non-vertebrates	*Obovaria retusa*	ring pink	Present
Other Non-vertebrates	*Obovaria subrotunda*	round hickorynut	Present
Other Non-vertebrates	*Plethobasus cyphyus*	sheepnose	Present
Other Non-vertebrates	*Pleurobema cordatum*	Ohio pigtoe	Present
Other Non-vertebrates	*Pleurobema plenum*	rough pigtoe	Present
Other Non-vertebrates	*Pleurobema rubrum*	pyramid pigtoe	Present
Other Non-vertebrates	*Pleurobema sintoxia*	round pigtoe	Present
Other Non-vertebrates	*Potamilus alatus*	pink heelsplitter	Present
Other Non-vertebrates	*Ptychobranchus fasciolaris*	kidneyshell	Present
Other Non-vertebrates	*Pyganodon grandis*	giant floater	Present
Other Non-vertebrates	*Quadrula quadrula*	mapleleaf	Present
Other Non-vertebrates	*Strophitus undulatus*	creeper	Present
Other Non-vertebrates	*Theliderma cylindrica*	rabbitsfoot	Present
Other Non-vertebrates	*Theliderma metanevra*	monkeyface	Present
Other Non-vertebrates	*Toxolasma lividum*	purple lilliput	Present
Other Non-vertebrates	*Toxolasma parvum*	lilliput	Present

Category	Scientific Name	Common Names	Occurrence
Other Non-vertebrates	*Tritogonia verrucosa*	pistolgrip	Present
Other Non-vertebrates	*Truncilla donaciformis*	fawnsfoot	Present
Other Non-vertebrates	*Truncilla truncata*	deertoe	Present
Other Non-vertebrates	*Utterbackia imbecillis*	paper pondshell	Present
Other Non-vertebrates	*Villosa ortmanni*	Kentucky creekshell	Present
Other Non-vertebrates	*Corbicula fluminea*	Asian clam	Present
Other Non-vertebrates	*Sphaeriidae*	–	Present

Appendix B. Confirmed Non-Native Plant Species List for Mammoth Cave National Park

This appendix lists the confirmed invasive species currently in MACA (Table B-1) based on data from the Kentucky Invasive Plant Council (KY-IPC 2019) which is a chapter of the Southeast Exotic Pest Plant Council (SE-EPPC 2019). These include the scientific and common names of the plants as well as a listing of the current severity of the distribution of these species in the state. A description of these listings is given in Table B-2.

Table B-1. Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Severe	*Conuim*	*maculatum*	cigue maculee, cigue tachetee, deadly hamlock, poison hemlock, poison parsley, poison-hemlock
Severe	*Carduus*	*nutans*	chardon penche, musk thistle, nodding plumeless thistle, nodding plumeless-thistle, nodding thistle, plumeless thistle
Severe	*Alliaria*	*petiolata*	garlic mustard, garlic-mustard
Severe	*Stellaria*	*media*	chickweed, common chickweed, nodding chickweed
Severe	*Polygonum (Fallopia)*	*cuspidatum*	Japanese knotweed
Severe	*Celastrus*	*orbiculatus*	oriental bittersweet
Severe	*Euonymus*	*alatus*	burning bush
Severe	*Euonymus*	*fortunei*	wintercreeper
Severe	*Arthraxon*	*hispidus*	hairy jointgrass
Severe	*Dioscorea*	*oppositifolia*	Chinese yam
Severe	*Lonicera*	*japonica*	Chinese honeysuckle, Japanese honeysuckle
Severe	*Lonicera*	*maackii*	bush honeysuckle
Severe	*Lysimachia*	*nummularia*	creeping jenny, moneywort
Severe	*Coronilla*	*varia*	crownvetch, purple crownvetch, purple crown-vetch, Varia crownvetch
Severe	*Kummerowia*	*stipulacea*	Korean clover
Severe	*Lespedeza*	*cuneata*	Chinese lespedeza, sericea lespedeza
Severe	*Melilotus*	*albus*	Bokhara-clover, honey-clover, white melilot, white sweet-clover

* Because common names are listed, to keep the table simpler we have not listed some subspecies or variety names.

Table B-1 (continued). Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Severe	*Melilotus*	*officinalis*	cornilla real, field melilot, ribbed melilot, yellow sweetclover, yellow sweet-clover
Severe	*Pueraria*	*montana*	kudzu
Severe	*Glechoma*	*hederacea*	creeping charlie, gill-over-the-ground, ground ivy, groundivy, haymaids
Severe	*Ligustrum*	*sinense*	Chinese privet, common Chinese privet
Severe	*Paulownia*	*tomentosa*	princess tree, royal paulownia
Severe	*Lolium (Festuca)*	*arundinaceum*	tall fescue, Kentucky 31 fescue
Severe	*Microstegium*	*vimineum*	Japanese stiltgrass, Nepalese browntop
Severe	*Miscanthus*	*sinensis*	Chinese silvergrass
Severe	*Phragmites*	*australis*	common reed
Severe	*Sorghum*	*halepense*	aleppo milletgrass, herbe de Cuba, Johnson grass, Johnsongrass, sorgho d'Alep, sorgo de alepo, zacate Johnson
Severe	*Clematis*	*terniflora*	leatherleaf clematis, sweet autumn virginsbower, yam-leaved clematis
Severe	*Elaeagnus*	*umbellata*	autumn olive, oleaster
Severe	*Rosa*	*multiflora*	multiflora rose
Severe	*Ailanthus*	*altissima*	copal tree, tree of heaven, tree-of-heaven
Severe	*Pyrus*	*calleryana*	Bradford pear, Callery pear
Signficiant	*Daucus*	*carota*	bird's nest, queen anne's lace, wild carrot
Significant	*Pastinaca*	*sativa*	wild parsnip
Significant	*Hedera*	*helix*	English Ivy
Significant	*Hemerocallis*	*fulva*	orange daylily, tawny daylily
Significant	*Centaurea*	*biebersteinii*	spotted knapweed
Significant	*Cirsium*	*vulgare*	bull thistle, common thistle, spear thistle
Significant	*Leucanthemum*	*vulgare*	oxeyedaisy
Significant	*Polygonum*	*cespitosum*	bunchy knotweed
Significant	*Polygonum*	*persicaria*	ladysthumb, lady's-thumb, ladysthumb smartweed, spotted knotweed, spotted ladysthumb, spotted smartweed
Significant	*Dipsacus*	*fullonum*	common teasel, Fuller's teasel, teasel, venuscup teasle
Significant	*Dipsacus*	*fullonum*	common teasel, Fuller's teasel, teasel
Significant	*Albizia*	*julibrissin*	mimosa, powderpuff tree, silk tree, silktree

* Because common names are listed, to keep the table simpler we have not listed some subspecies or variety names.

Table B-1 (continued). Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Significant	*Kummerowia*	*striata*	Japanese clover
Significant	*Medicago*	*lupulina*	black medic, black medic clover, black medick, hop clover, hop medic, nonesuch, yellow trefoil
Significant	*Vinca*	*minor*	common periwinkle, lesser periwinkle, myrtle
Significant	*Mentha*	*piperita*	peppermint
Significant	*Mosla*	*dianthera*	miniature beefsteak, miniature beefsteakplant
Significant	*Perilla*	*frutescens*	beefsteak mint, beefsteak plant, purple mint
Significant	*Verbascum*	*thapsus*	big taper, common mullein, flannel mullein, flannel plant, great mullein, mullein, velvet dock, velvet plant, woolly mullein
Significant	*Ornithogalum*	*umbellatum*	Pyrenees Star of Bethlehem, sleepydick, Star-of-Bethlehem
Significant	*Populus*	*alba*	white poplar
Significant	*Bromus*	*japonicus*	Japanese brome, Japanese bromegrass, Japanese chess
Significant	*Bromus*	*tectorum*	cheat grass, cheatgrass, downy brome, early chess, military grass, wild oats
Significant	*Echinochloa*	*crus-galli*	barnyard grass, barnyardgrass, cockspur, Japanese millet, large barnyard grass, watergrass
Significant	*Eleusine*	*indica*	crowsfoot grass, goose grass, goosegrass, Indian goose grass, Indian goosegrass, manienie ali'I, silver crabgrass, wiregrass
Significant	*Poa*	*compressa*	Canada bluegrass, flat-stem blue grass
Significant	*Poa*	*pratensis*	Kentucky bluegrass
Significant	*Setaria*	*faberi*	Chinese foxtail, Chinese millet, giant bristlegrass, giant foxtail, Japanese bristlegrass, nodding foxtail, tall green bristlegrass
Significant	*Typha*	*angustifolia*	narrowleaf cattail, narrow-leaf cat-tail
Significant	*Berberis*	*thunbergii*	Japanese barberry
Moderate	*Allium*	*vineale*	wild garlic
Moderate	*Arctium*	*minus*	beggare's button, burdock, small burdock, wild burdock, wild rhubarb

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Table B-1 (continued). Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Moderate	*Cichorium*	*intybus*	blue sailors, chickory, chicory, coffeeweed, common chicory, French endive, succory
Moderate	*Barbarea*	*vulgaris*	garden yellow rocket, garden yellowrocket, winter cress, yellow rocket
Moderate	*Chenopodium*	*album*	common lambsquarters, lambsquarters, lambsquarters goosefoot, white goosefoot
Moderate	*Rumex*	*acetosella*	common sheep sorrel, field sorrel, red sorrel, sheep sorrel
Moderate	*Commelina*	*communis*	Asiatic dayflower, common dayflower
Moderate	*Wisteria*	*sinensis*	Chinese wisteria
Moderate	*Lamium*	*amplexicaule*	common henbit, giraffehead, henbit, henbit deadnettle
Moderate	*Lamium*	*purpureum*	purple deadnettle, red deadnettle
Moderate	*Hypericum*	*perforatum*	common St. John's wort, common St. Johnswort, Klamath weed, Klamathweed, St. John's wort, St. Johnswort
Moderate	*Bromus*	*racemosus*	bald brome
Moderate	*Holcus*	*lanatus*	common velvetgrass, velvetgrass, Yorkshire fog
Moderate	*Paspalum*	*dilatatum*	dallas grass, dallis grass, dallisgrass, herbe de miel, herbe sirop, hiku nua, palpalum dilate, water grass
Moderate	*Ranunculus*	*bulbosus*	blister flower, bulbous buttercup, bulbous crowfoot, gowan, St. Anthony's turnip, yellow weed
Moderate	*Duchesnea*	*indica*	India mockstrawberry, Indian strawberry
Moderate	*Potentilla*	*recta*	erect cinquefoil, roughfruit cinquefoil, sulphur cinquefoil
Moderate	*Convolvulus*	*arvensis*	creeping jenny, European bindweed, field bindweed, perennial morningglory, smallflowered morningglory
Moderate	*Ipomoea*	*hederacea*	entireleaf morningglory, ivyleaf morningglory, ivyleaf morning-glory, Mexican morningglory
Moderate	*Ipomoea*	*purpurea*	common morningglory, common morning-glory, tall morningglory, tall morning-glory

* Because common names are listed, to keep the table simpler we have not listed some subspecies or variety names.

Table B-1 (continued). Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Watch List	*Allium*	*sativum*	cultivated garlic
Watch List	*Lactuca*	*saligna*	willowleaf lettuce, willow-leaf lettuce
Watch List	*Sonchus*	*asper*	perennial sowthistle, prickly sow thistle, prickly sowthistle, spiny sowthistle, spiny-leaf sow-thistle
Watch List	*Trifolium*	*campestre*	field clover
Watch List	*Trifolium*	*pratense*	red clover
Watch List	*Trifolium*	*repens*	Dutch clover, ladino clover, white clover, white Dutch clover
Watch List	*Vicia*	*sativa*	common vetch, garden vetch, narrowleaf vetch, tare
Watch List	*Arundo*	*donax*	giant reed, giantreed
Watch List	*Eragrostis*	*cilianensis*	candy grass, lovegrass, stink grass, stinkgrass, strongscented lovegrass
Watch List	*Rubus*	*bifrons*	Himalayan berry
Not Listed	*Narcissus*	*poeticus*	poet's narcissus
Not Listed	*Narcissus*	*pseudonarcissus*	common daffodil, daffodil
Not Listed	*Asparagus*	*officinalis*	asparagus, garden asparagus
Not Listed	*Muscari*	*botryoides*	common grape hyacinth
Not Listed	*Belamcanda*	*chinensis*	blackberry lily
Not Listed	*Achillea*	*millefolium*	bloodwort, carpenter's weed, common yarrow, hierba de las cortaduras, milenrama, milfoil,plumajilo, western yarrow
Not Listed	*Anthemis*	*cotula*	chamomile, dog fennel, mayweed, mayweed chamomile, mayweed dogfennel, stinking chamomile, stinkweed
Not Listed	*Artemisia*	*annua*	annual wormwood, sweet sagewort
Not Listed	*Galinsoga*	*quadriradiata*	fringed quickweed, hairy galinsoga, shaggy soldier, shaggy-soldier
Not Listed	*Hieracium*	*aurantiacum*	orange hawkweed
Not Listed	*Hieracium*	*pilosella*	mouseear hawkweed
Not Listed	*Taraxacum*	*laevigatum*	red-seed dandelion, rock dandelion
Not Listed	*Taraxacum*	*officinale*	wandering dandelion
Not Listed	*Tragopogon*	*dubius*	yellow salsify
Not Listed	*Buglossoides*	*arvensis*	corn gromwell

* Because common names are listed, to keep the table simpler we have not listed some subspecies or variety names.

Table B-1 (continued). Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Not Listed	*Lithospermum*	*officinale*	European stoneseed
Not Listed	*Myosotis*	*arvensis*	field forget-me-not
Not Listed	*Arabidopsis*	*thaliana*	mouseear cress, mouse-ear cress
Not Listed	*Brassica*	*nigra*	black mustard, shortpod mustard
Not Listed	*Brassica*	*rapa*	field mustard
Not Listed	*Capsella*	*bursa-pastoris*	shepherdspurse, shepherd's-purse
Not Listed	*Cardamine*	*hirsuta*	hairy bittercress
Not Listed	*Diplotaxis*	*tenuifolia*	perennial wallrocket
Not Listed	*Draba*	*verna*	spring draba, spring whitlowgrass
Not Listed	*Lepidium*	*campestre*	cream-anther field pepperwort, field pepperweed
Not Listed	*Lepidium*	*ruderale*	roadside pepperweed
Not Listed	*Rorippa*	*sylvestris*	creeping yellow cress, creeping yellowcress, keek, yellow fieldcress
Not Listed	*Sisymbrium*	*officinale*	hairypod hedgemustard, hedge mustard, hedge tumblemustard, hedgemustard, hedge-mustard, hedgeweed, wild mustard
Not Listed	*Thlaspi*	*arvense*	fanweed, field pennycress, Frenchweed, pennycress, stinkweed
Not Listed	*Cleome*	*hassleriana*	pink queen, pinkqueen, spider-flower, spiderplant
Not Listed	*Chenopodium*	*ambrosioides*	Mexican tea
Not Listed	*Cerastium*	*Fontanum*	big chickweed
Not Listed	*Cerastium*	*glomeratum*	sticky chickweed
Not Listed	*Dianthus*	*armeria*	Deptford pink
Not Listed	*Holosteum*	*umbellatum*	jagged chickweed
Not Listed	*Saponaria*	*officinalis*	bouncing bet, bouncingbet, bouncingbet soapweed, soapwort, sweet Betty
Not Listed	*Polygonum*	*convolvulus*	black bindweed, black-bindweed, climbing buckwheat, climbing knotweed, cornbind, dullseed cornbind, pink smartweed, wild buckwheat
Not Listed	*Rumex*	*crispus*	curly dock, narrowleaf dock, sour dock, yellow dock
Not Listed	*Rumex*	*obtusifolius*	bitter dock, bluntleaf dock

* Because common names are listed, to keep the table simpler we have not listed some subspecies or variety names.

Table B-1 (continued). Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Not Listed	*Rumex*	*pulcher*	fiddle dock
Not Listed	*Portulaca*	*oleracea*	akulikuli-kula, common purslane, duckweed, garden purslane, little hogweed, little-hogweed, purslane, pursley, wild portulaca
Not Listed	*Anagallis*	*arvensis*	pimpernel, scarlet pimpernel
Not Listed	*Medicago*	*sativa*	alfalfa
Not Listed	*Trifolium*	*arvense*	hairy clover, hare's foot clover, oldfield clover, rabbitfoot clover, rabbit-foot clover, stone clover
Not Listed	*Trifolium*	*aureum*	golden clover
Not Listed	*Trifolium*	*hybridum*	alsike clover
Not Listed	*Centaurium*	*pulchellum*	branched centaury
Not Listed	*Sherardia*	*arvensis*	blue fieldmadder, blue field-madder, field madder
Not Listed	*Geranium*	*dissectum*	cutleaf geranium
Not Listed	*Geranium*	*molle*	awnless geranium, dovefoot geranium
Not Listed	*Melissa*	*officinalis*	common balm
Not Listed	*Linaria*	*vulgaris*	butter and eggs, flaxweed, greater butter-and-eggs, Jacob's ladder, ramsted, wild snapdragon, yellow toadflax
Not Listed	*Plantago*	*lanceolata*	buckhorn plantain, English plantain, lanceleaf Indianwheat, lanceleaf plantain, narrowleaf plantain, ribgrass, ribwort
Not Listed	*Veronica*	*arvensis*	common speedwell, corn speedwell, rock speedwell, wall speedwell
Not Listed	*Veronica*	*serpyllifolia* ssp. *serpyllifolia*	thymeleaf speedwell
Not Listed	*Verbascum*	*blattaria*	moth mullein, white moth mullein
Not Listed	*Hypericum*	*formosum*	–
Not Listed	*Salix*	*X sepulcralis*	weeping willow
Not Listed	*Abutilon*	*theophrasti*	butterprint, buttonweed, Indian mallow, velvetleaf, velvetleaf Indian mallow
Not Listed	*Agrostis*	*gigantea*	redtop
Not Listed	*Anthoxanthum*	*odoratum*	sweet vernalgrass
Not Listed	*Bromus*	*commutatus*	hairy brome, hairy chess, meadow brome

* Because common names are listed, to keep the table simpler we have not listed some subspecies or variety names.

Table B-1 (continued). Confirmed irma.nps.gov Non-Native Plants & Kentucky Environmental and Public Protection Cabinet (KyEPPC) Listing 2013 for MACA with additions from CUPN vegetation monitoring (Bledsoe 2017). Compiled by Brice Leech, Resource Management Specialist, MACA Division of Science and Resource Management.

KyEPPC Listing	Genus	Species*	Common Name
Not Listed	*Bromus*	*sterilis*	barren bromegrass, poverty brome, sterile brome
Not Listed	*Cynodon*	*dactylon*	Bermudagrass, chiendent pied-de-poule, common bermudagrass, devilgrass, grama-seda, manienie, motie molulu
Not Listed	*Dactylis*	*glomerata*	orchardgrass
Not Listed	*Digitaria*	*ischaemum*	small crabgrass, smooth crab grass, smooth crabgrass
Not Listed	*Lolium*	*perenne*	perennial ryegrass
Not Listed	*Lolium*	*pratense*	meadow fescue, meadow ryegrass
Not Listed	*Pennisetum*	*glaucum*	pearl millet, pearl-millet, yellow bristlegrass
Not Listed	*Phleum*	*pratense*	common timothy, timothy
Moderate	*Poa*	*annua*	annual bluegrass
Not Listed	*Secale*	*cereale*	cereal rye, common rye, cultivated annual rye, cultivated rye, rye
Not Listed	*Ranunculus*	*sardous*	hairy buttercup
Not Listed	*Aruncus*	*dioicus*	bride's feathers, goatsbeard
Not Listed	*Prunus*	*avium*	sweet cherry
Not Listed	*Prunus*	*persica*	peach
Not Listed	*Calystegia*	*sepium*	bearbind, devil's guts, hedge bindweed, hedge false bindweed, hedgebell, large bindweed, old man's night cap, wild morning glory
Not Listed	*Calystegia*	*sepium*	hedge false bindweed
Not Listed	*Ipomoea*	*coccinea*	Mexican morningglory, red morningglory, redstar, scarlet morningglory, starglory, woolly tidestromia
Not Listed	*Datura*	*stramonium*	Jamestown weed, jimsonweed, mad apple, moonflower, stinkwort, thorn apple
Not Listed	*Ligustrum*	*Vulgare*	European privet

* Because common names are listed, to keep the table simpler we have not listed some subspecies or variety names.

Table B-2. Legend for KyEPPC Listing 2013 for MACA.

KyEPPC Listing	Listing
Severe	Red indicates exotic plant species which possess characteristics of invasive species and spread easily into native plant communities and displace native vegetation in Kentucky.
Significant	Orange indicates exotic plant species which possess some invasive characteristics, but have less impact on native plant communities; may have the capacity to invade natural communities along disturbance corridors, or to spread from stands in disturbed sites into undisturbed areas, but have fewer characteristics of invasive species than #1 rank.
Moderate	Dark yellow indicates exotic plant species which seem to principally spread and remain in disturbed corridors, not readily invading natural areas; also some agronomic weeds.
Watch List	Bright yellow indicates exotic plant species that have either not been observed or well-documented in Kentucky, but have invaded native plant communities in neighboring states.

Appendix C. Exploration of the Mammoth Cave System

While as in all national parks there is a wide variety of resources that are protected, the Mammoth Cave System is the dominant resource around which the park owes its existence. In contrast to many natural resources, however, the cave is essentially hidden away from sight, and its geography and he resources it contains have only been revealed through a remarkable program of exploration and survey over centuries. This stretches back thousands of years to the Native Americans, and a modern, sustained effort over way for the last 70 years. Below we focus here on the exploration and survey of the cave system.

While the language of the park's creation noted three distinctive elements that included the caves and associated topography, the rivers, and the "rugged landscapes clothed in forests" (NPS 1983), and the park indeed protects important resources that have been degraded elsewhere in the region, it is the Mammoth Cave System—including the currently known extent, so-far separate caves that may be connected to the main system in the future, and passages yet to be explored and mapped—that creates the national and global significance of MACA. This section provides a summary of key events in the cave's exploration and associated events that over more than 4,000 years have revealed the remarkable extent of the cave system and the resources it contains.

C1. Ancient Exploration

The earliest residents of Kentucky were Native Americans who arrived in the areas some 11,500 years ago (Prentice 1993). This marked the beginning of the first of four traditions or cultural intervals, the Paleoindian Period (Table C-1). There is some complexity in the reporting of archeological dates and for the purposes of this report we used approximate and relatively simple conventions. Ancient dates that occurred before the birth of Jesus Christ with the commonly used convention "BC" ("before Christ" or in the recent and more secular "BCE" or "before common era" using the same dates) are listed as BP, or years before present. Subsequent dates (A.D. or Anno Domini are) simply listed by calendar year.

Although no sites directly datable using carbon isotopes from the Paleoindian Period have been found in Kentucky, there are diagnostic, blade-based lithic tools that represent a mobile, megafauna-oriented hunting economy (Justice 1987, Tankersley 1990, Prentice 1993). Indeed, the few isolated Paleoindian tradition tools that have been found within MACA may have been picked up elsewhere by other groups and redeposited at rock shelters, and in any case, no Paleoindian habitation sites have been confirmed within the park.

The Archaic Period (10,000–3,000 BP) saw regular habitation in the MACA area, with populations of hunting/gathering groups growing while hunting territories of these groups shrank correspondingly This was also a time of environmental change with the landscape evolving into a closed canopy forest habitat (Watson and Carstens 1982, Jeffries 1990, Prentice 1993). During this time, semi-nomadic, socially distinct groups are thought to have occupied the MACA area with seasonal shifts

Table C-1. Timeline regarding major cultural, and more recent organizational, intervals related to the exploration of the Mammoth Cave System (Hobbs et al. 2017).

Phase of Activity	Period	Dates (approximate BP or dates AD)*
Prehistoric	Paleoindian	11,500 BP–10,000 BP
	Archaic	10,000 BP–3,000 BP
	Woodland	3,000 BP–900 AD
	Mississippian	900 AD–1500 AD
	Proto-Historic	1500 AD–1700 AD
Modern Cave Exploration	Pre-NSS/Cave Research Foundation	~1790s–1954
	C3 Expedition and subsequent independent work	1954–1957
	Cave Research Foundation	1957-present
	Central Kentucky Karst Coalition	1976-present
	Collaborative Exploration and Scientific Efforts	1992-present

* For simplicity in this report very ancient dates are approximate and expressed as BP, or years before the present day. Dates over the last 2,000 years or so are indicated by the common convention AD (Anno Domini, sometimes seen as CE or Common Era).

By the late Archaic major changes were underway that include establishment of trading networks, as well as the domestication of agriculture. This is also when the earliest evidence shows that humans began exploring the park's caves, an activity that continued for about the next 2,000 years, well into the Woodland Period (Table C-1) (Nelson 1917, Neumann 1938, Watson and Yarnell 1966, Watson 1974, Crothers 2012). Radiocarbon dates from at least 58 in-cave samples shows that by about 4,100 years ago humans were exploring Mammoth Cave's Historic Entrance and Lee Cave, and not long after that Salts Cave was discovered (Kennedy 1990, 1996, Kennedy and Watson 1997). We know now that these are two entrances to the same huge cave system, but the term Salts Cave is still commonly used. The earliest cave dates are in close agreement, including one from Mammoth Cave (4120±70 BP) and another from Lee Cave (4100±65BP) (Freeman et al. 1973). Collection and analysis of a range of organic materials that have been preserved, including torch remains, wooden tools, textiles, human "paleofeces" (e.g., Yarnell 1969, Stewart 1974), and human bodies (Neumann 1938, Meloy and Watson 1969, Robbins 1971) have allowed interpretation of extent of their exploration and their activities. Detailed work by Patty Jo Watson and colleagues in Mammoth and Salts Cave has given rich detail with regard to plant use and the evolution of horticulture in the region during the late Archaic and early Woodland periods (Watson and Yarnell 1969, Watson1989). This has been through collection of plants and seeds themselves from the caves (gourds and squashes, for example), analysis of paleofeces, and even the intestinal contents of two desiccated bodies, including "Little Al," a nine-year old boy who died in Salts Cave and was later discovered in 1875, and a gypsum miner "Lost John," discovered in the 1800s and excavated in the 1930s almost 2.5 kilometers from the entrance of Mammoth Cave. Figure C-1 illustrates the estimated extent of ancient cave exploration.

There has been both clear evidence and speculation with regard to the motivations that caused these ancient explorers to make such bold expeditions, through perhaps 22 kilometers of the cave system through the Historic Entrance and Salts Cave, especially considering the technology of the day

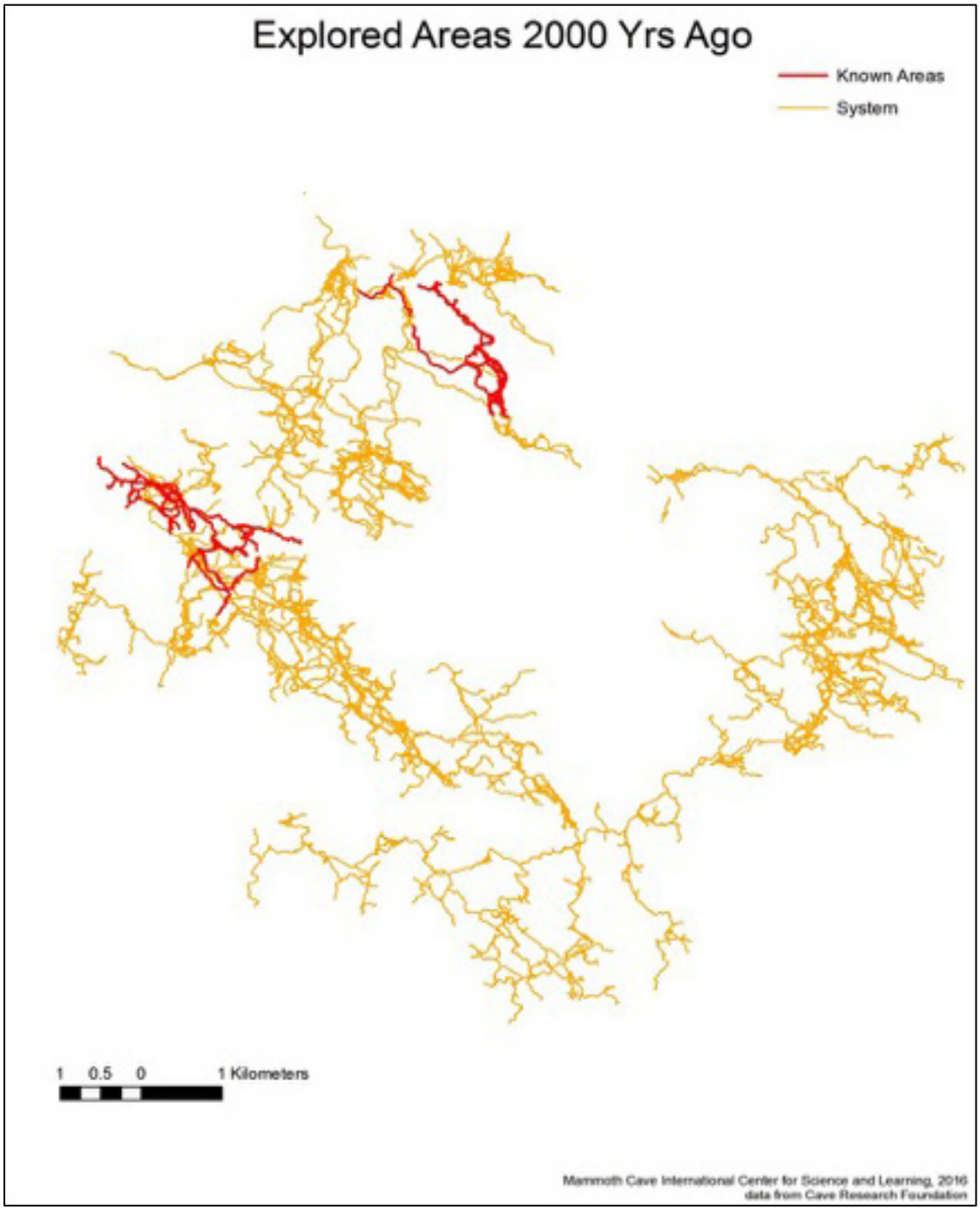


Figure C-1. Map showing the extent of ancient cave exploration—some 27 kilometers—in the Mammoth Cave System. Red shows known passages as of about 2,200 years ago, compared to the current known cave in yellow. Map by Dr. Rick Toomey, Mammoth Cave International Center for Science and Learning (MCICSL) using data from the Cave Research Foundation.

(Rick Toomey, Cave Resource Management Specialist and Research Coordinator, MACA Division of S&RM, November 2017, personal communication, Watson, 1974). Figure C-2 shows details of the passages within Mammoth Cave with evidence of ancient exploration that would have been from the Historic Entrance, and it can be seen that the ancient explorers traversed not only the large main passages but made forays into a number of smaller side passages. There may well have been both spiritual and adventure-related purposes, but it is clear that there was extensive mining of the sulfate minerals gypsum (CaSO4●2H2O), epsomite (MgSO4●7H2O), and mirabalite (NaSO4●10H2O) (Munson et al. 1989, Crothers 2012). Kennedy and Watson (1997) have suggested that this could have been used in powdered form as a paint pigment or medicinally—as both epsomite and mirabalite have cathartic properties—or in crystalline form for ritual purposes or trading. Figure C-3 shows saltpeter vats in the cave near the Historic Entrance.

Crothers (2012) detailed the search for minerals by the ancient explorers in Mammoth Cave and Salts Cave during the early Woodland Period and has provided some fascinating and very thoroughly investigated arguments to suggest that the ancient mining was connected to ritualistic "rites of passage" for young males. Hormonal analysis shows that paleofecal samples from the cave have in every case measured been produced by male explorers (Sobolik et al. 1996), and over 12 years of highly detailed fieldwork through six kilometers of the main trunk passage of Mammoth Cave between the Historic and Violet City entrance documenting over 6,000 artifacts, Crothers (2012) and his teams were able to draw conclusions based on spatial relationships. One is that 43% of the artifacts, including 45% of the paleofeces, were located in the Snow Room where the only deposits of epsomite and mirabalite are found in this part of the cave, and which occupies only 5% of the sampled passage length.

Comparing common themes in rites of passage from the rich anthropological literature with the evidence of cave usage at Mammoth Cave suggests that using the cave as a place of seclusion and where the cathartic minerals were consumed, along with evidence that explorers may have experienced chemically induced altered states of consciousness suggests that these spiritual needs may have been a significant motivation for trips into the cave. This is also consistent with patterns of drawings found scattered in this part the cave showing entoptic forms, ones originating in the artist's ocular anatomy rather than external light sources.

Major ancient exploration of the park's Cave apparently ended about 2,200 years ago (George Crothers, University of Kentucky, Kentucky State Archaeologist, November 2017, personal communication). The most recent dated material from the cave system was tissue from the Salt's Cave mummy which was reported at 1920–1960 years BP (Robbins 1971), but these measurements were made early on with respect to dating technology, and it was later suggested (e.g., Kennedy 1990) that isotopic fractionation processes that may occur within human tissue may have made the reported dates more recent than they should have been.

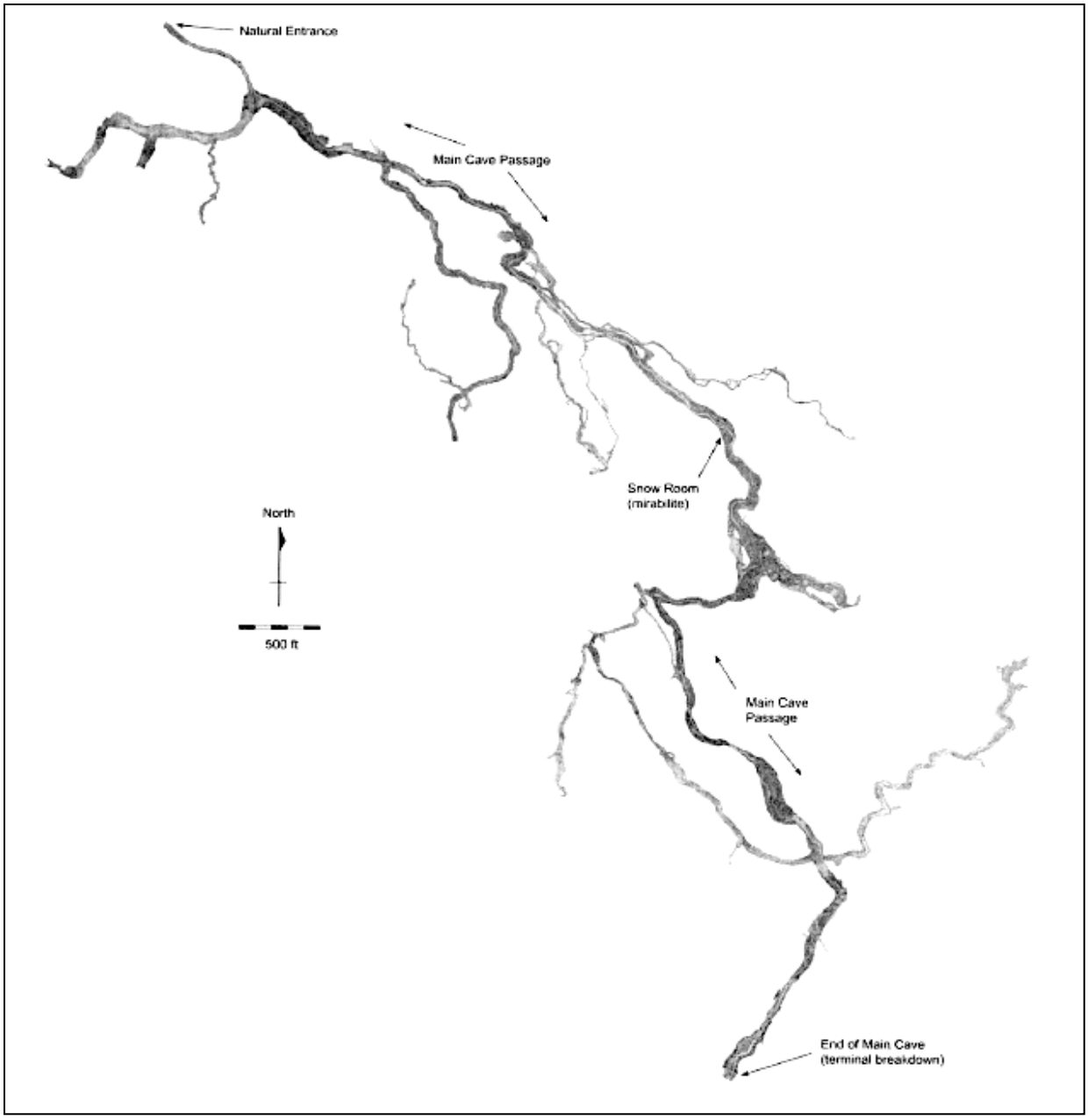


Figure C-2. Detail of passages with Mammoth Cave's Historic section that contain evidence of ancient exploration, corresponding to the western (red) region of exploration shown in Figure C-1 (from Crothers 2012 with data from the Cave Research Foundation).



Figure C-3. Richard Zopf of the Cave Research Foundation overlooks one of the well-preserved saltpeter vats in the Historic Section of Mammoth Cave. Mineral bearing sediment was carried from different parts of the cave and loaded into the vats. Water that had been piped in from the entrance waterfall was run through it, dissolving the soluble calcium nitrate. The resulting solution was then piped out of the cave and processed to create saltpeter. Photo by Art Palmer.

C2. Settlers Reach Kentucky

People of European descent began settling in southcentral Kentucky in the late 18th century, and the first new "discoveries" of Mammoth Cave and other caves in the park area followed. A commonly-told story is that a hunter named John Houchins found and entered the Historic

Entrance to Mammoth while chasing a wounded bear, but no record actually exists. It is known that by 1796 the nearby town of Bowling Green had been established about 56-kilometers to the southwest, and that an 81-hectare tract of land called the "Mammoth Cave Tract" had been surveyed and recorded by 1798. It read

> "Valentine Simon enters 200 acres of second rate land in Warren County by virtue of the Commissioner's Certificate No. 2428 lying on Green River beginning on a sycamore tree on the bank of said River thence running southward including two peter caves, thence angling down said river for quantity to include the improvement".

The two caves were Dixon Cave and the Historic Entrance to Mammoth Cave. Exploration of the cave that followed was in large part driven at first by the fact that sediments within some caves of the

southeastern US contain the mineral nitrocalcite (Ca(NO3)2•4H2O) (Palache et al. (1951) which was mined from the caves and processed by filtering through wood ashes to form potassium nitrate—saltpeter—a key ingredient for the manufacture of gunpowder. The other two ingredients, sulfur and charcoal, were readily available and so this brought increased interest to caves as a resource. Gunpowder was of course an important resource from the beginning of New World exploration, but with the hostilities leading up to the War of 1812 there was an obvious increase in the requirements for it, compounded by an eventual British blockade of the US east coast. Mammoth Cave became an important source (Figure C-3) and this motivated exploration into the cave from the Historic Entrance, along with the short trunk segment of Dixon Cave. The first known map of Mammoth Cave was made by 1811, An Eye Draught of the Mammoth Cave in Warren County [Ky] (Meloy 1968, Brucker 2008) (Figure C-4), which describes the then-known extent and resources of Mammoth Cave, noting that "Leeches" refers to the vats (Figure C-3) through which water was run to leech out the calcium nitrate.

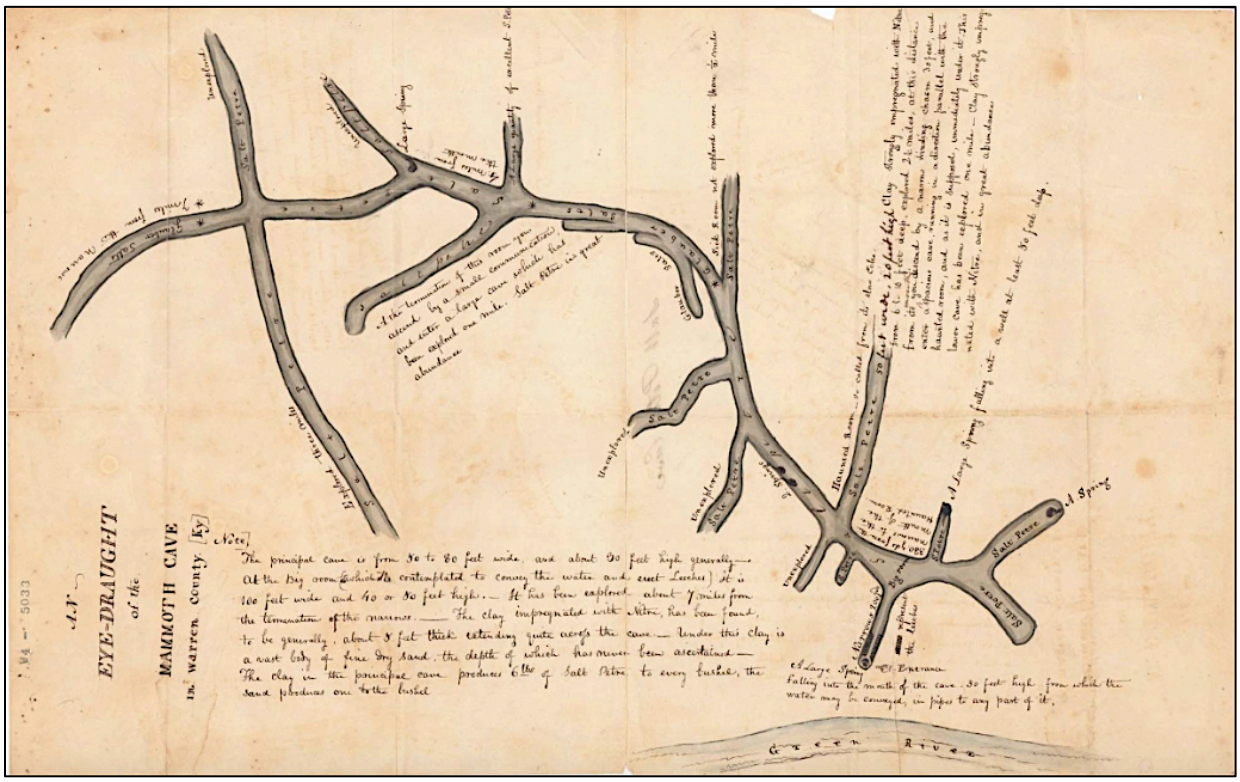


Figure C-4. First known map of Mammoth Cave, the "An Eye-Draught of the Mammoth Cave in Warren County [Ky]". Map from the archives of the Hagley Library in Wilmington, Delaware.

The principal cave is from 50 to 80 feet wide, and about 30 feet high generally—at the Big Room at which it is contemplated to convey the water and construct it is 100 feet wide and 40 to 80 feet high. It has been explored about 7 miles from the termination of the narrows. The clay is impregnated with Nitre, has been found to be generally about 5 feet thick extending quite across the cave. Under this clay is a vast body of fine dry sand, the depth of which has never been ascertained. The clay in the principal cave produces 6 lbs of Salt Peter to every bushel, the sand produces one to the barrel.

C3. Quantifying the Resource: Early Maps of Mammoth Cave

While this map was a sketch produced rather than a map produced by measured surveys, and thus varies considerably with modern surveys of the same passages, it marks a critical threshold in understanding of the cave system: the production of maps. Brucker (2008) described the critical nature of maps, especially or caves that are hidden way from view, for understanding resources and how they serve as a fundamental tool for any scientific or historical study of Mammoth Cave. He correctly noted that maps are the basis for management, interpretive, and engineering decisions.

Exploration continued as did the production of more sophisticated maps (Meloy 1968), several following not long after for the purpose of showing the locations of saltpeter deposits. After the end of the War of 1812 led to the end of saltpeter mining in the cave, the tourism industry that continues today began in 1816. In 1834 manager of the cave operation hired Edmund Lee, a professional surveyor to make the first instrumental survey of the cave, which shows more extensive passages of the upper levels (Figure C-5). For the first time the 1835 map that Lee produced shows passage profiles that help illustrate the three-dimensional relations of the passages.

The terrible legacy of slavery had a major impact on the cave's early history in the first half of the 19th century, both in terms of the saltpeter mining that used slave labor, and the emerging tourism industry. From the beginning of tourism at Mammoth Cave the guide force consisted of owned and leased slaves. One of these men who would develop a reputation among the greatest of Mammoth Cave's explorers was Stephen Bishop, who made many great discoveries by his eagerness to poke into small holes and climb down pits off of the main, large and easily accessible passages (Brucker and Watson 1976). Some of the more fantastic of these discoveries—the extensive network of lower level passages beyond Giant's Coffin, including the Snowball Room, Cleaveland Avenue, and Mammoth Dome—are now highlights of popular cave tours. He also found major underground rivers in the River Styx/Echo River area (Brucker and Watson 1976) and new species of cave adapted, eyeless fish. By the time that Stephen had drawn up the next map of the known passages in Mammoth Cave in 1842 (Figure C-5), the length had grown to some 32 kilometers.

Throughout the subsequent years, various exploration and mapping efforts continued to increase the understanding of the cave's geography and resources (see Meloy 1968, Brucker and Watson 1976, Brucker 2008) and the cave's length continued to grow. By any measure, a major effort took place over eight months of 1908 when German engineer Max Kämper visited Mammoth Cave (Figures C-6 and C-7) (Brucker 2008, Decroix 2008, Sides 2008, Olson et al. 2013b).

After some time visiting and exploring the cave, the cave's managers hired him to make an accurate map of the cave and provided him with a Guide Ed Bishop, the grand-nephew of Stephen. They made a remarkably accurate map of the cave, which shows about 56 kilometers of passages. Details of the map were kept secret (Brucker and Watson 1976, Shaw 2003) to prevent adjacent landowners from being able to make new entrances. This was still the most complete and accurate map extant when the national park was established, but was stored away in the park's files until it was rediscovered by NPS geologist Jim Quinlan in 1963.

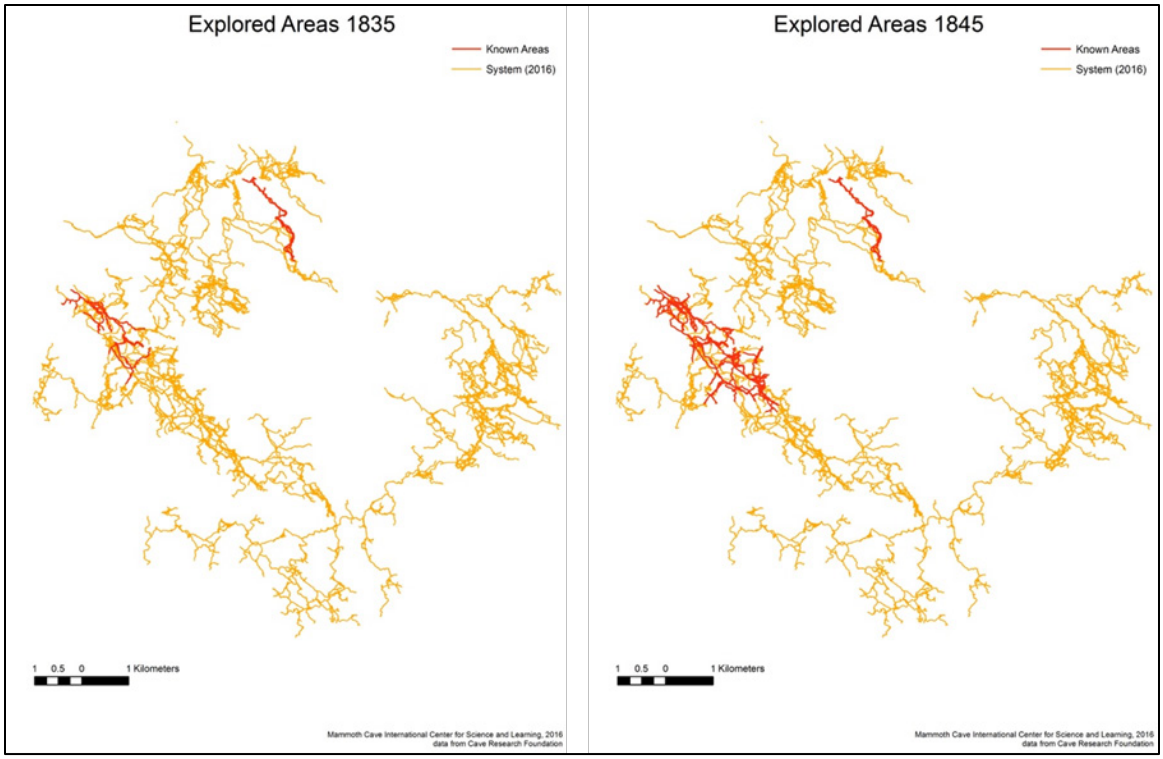


Figure C-5. The results of exploration led by Stephen Bishop can be seen by comparing the known passages in red based on the Lee Map of 1835 (left) and passages known by 1842 (right). Maps by Rick Toomey using data from the Cave Research Foundation.

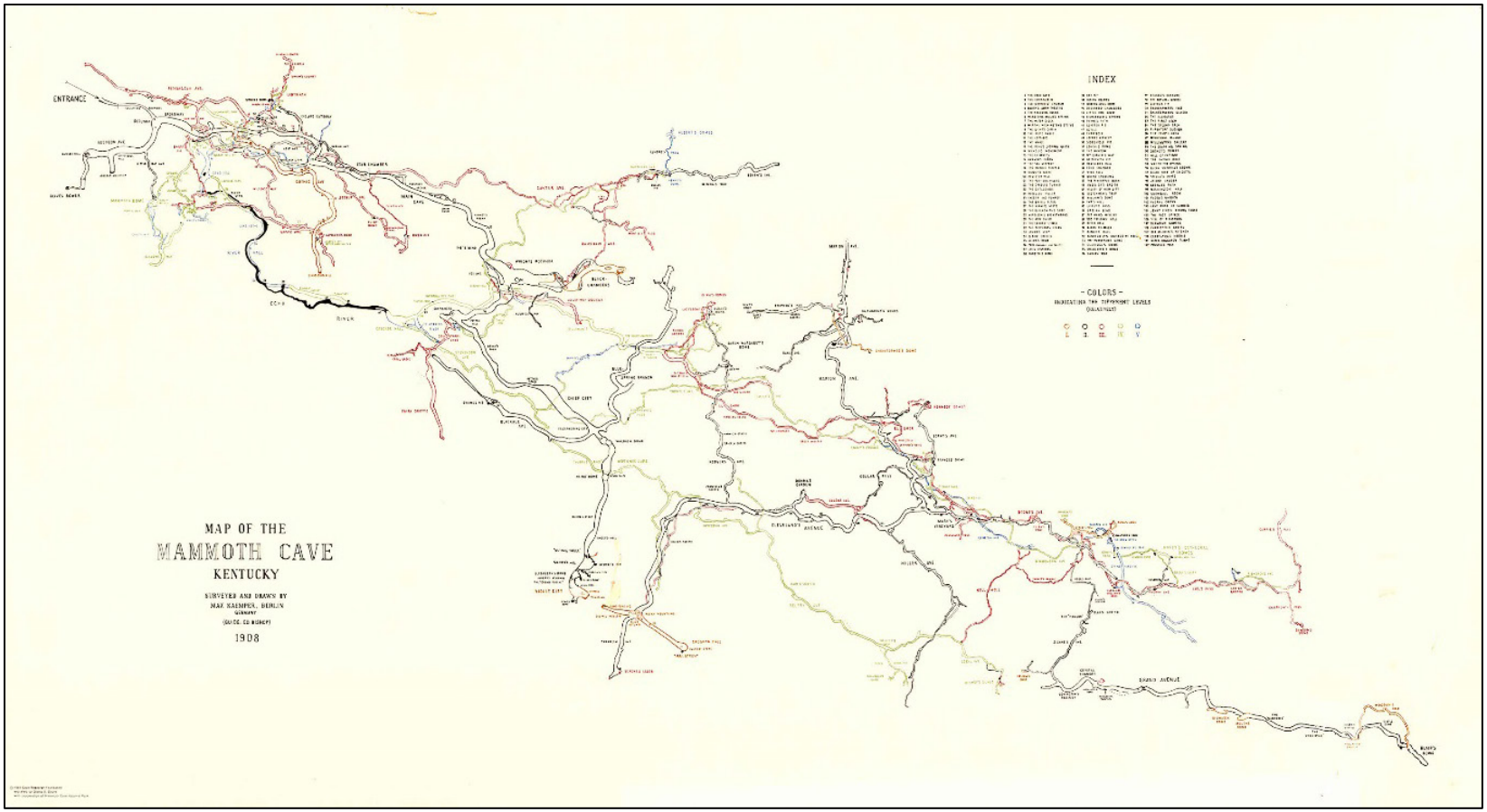


Figure C-6. 1908 map by German engineer Max Kämper and guide Ed Bishop shows about 56 kilometers of passages. This was the Scan courtesy of Bob Osburn, Cave Research Foundation.

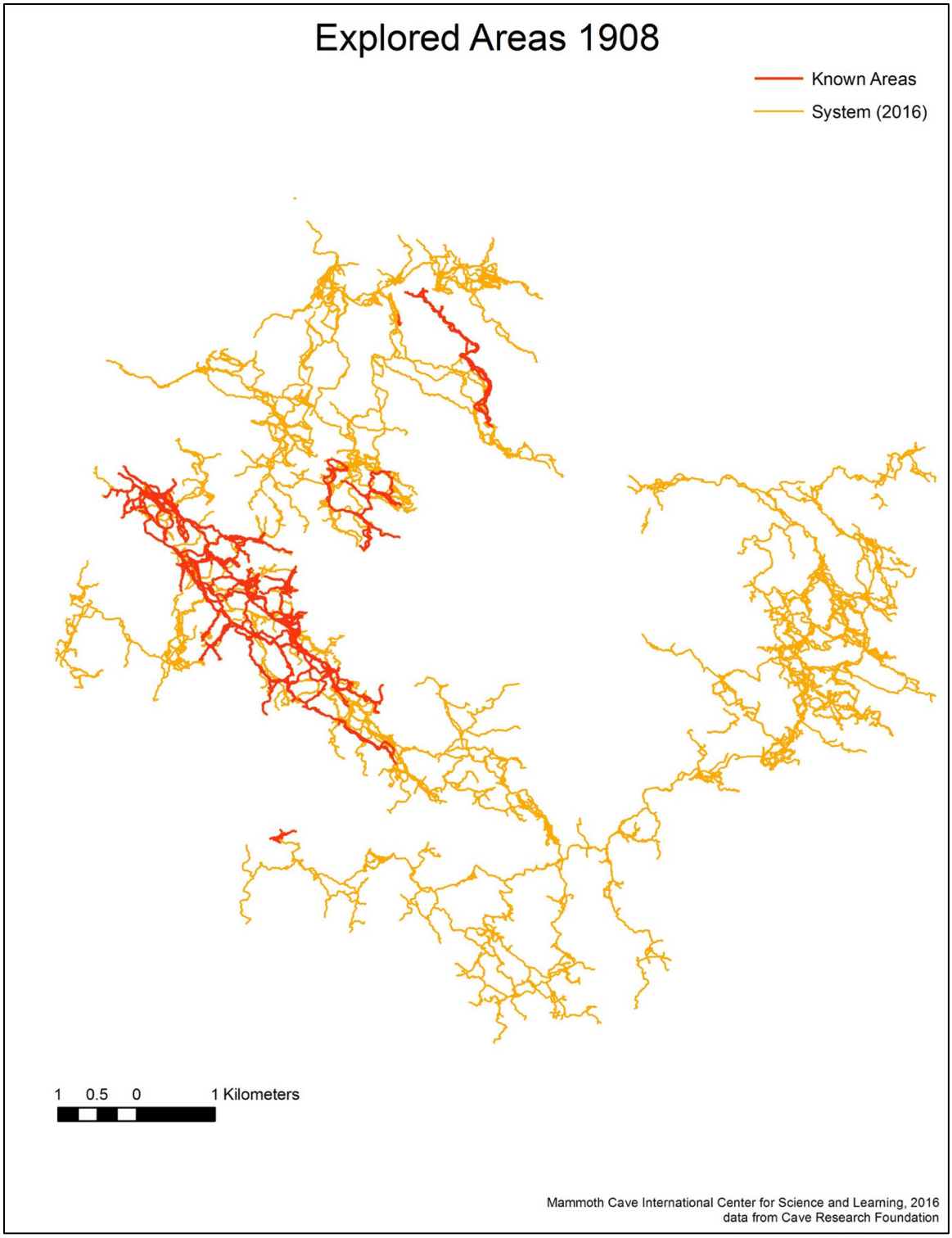


Figure C-7. Known passages by the time that Max Kämper left Mammoth Cave in late 1908. Map by Rick Toomey with data from the Cave Research Foundation.

C4. Modern Cave Exploration and Survey

Although numerous people continued the efforts to explore and understand the cave and the broader karst landscape, the modern era of cave exploration goes back to the 1940s when cavers unaffiliated with the National Park Service began making significant discoveries beneath Flint Ridge, just to the east of Mammoth Cave Ridge, under which the known passages of Mammoth Cave lie (Brucker and Watson 1976). A major effort took place in February 1954 when cavers affiliated with the National Speleological Society organized the Floyd Collin's Crystal Cave Expedition. Sixty-four cavers spent a week exploring Floyd Collins Crystal Cave, often now called Crystal Cave, which was on private property but the parcel was completely surrounded by the national park. Perhaps the main success of the expedition was learning that massive Himalayan-style expeditions were not particularly effective for the conditions in southcentral Kentucky caves. An intense period of exploration followed in beneath Flint Ridge with small parties pushing deeper and deeper into Crystal Cave and other nearby caves, and making connections between the caves. Crystal and Unknown Caves were joined together in 1955, followed by Colossal and Salts Caves in 1960. In turn, those two large integrated cave systems were joined together the following year to form the Flint Ridge Cave System (Figure C-8).

Early on, these secretive efforts were made without the knowledge of the park Service, but eventually negotiations between Park officials and the cavers led to the establishment of the Cave Research Foundation (CRF) in 1957. Monthly, highly organized expeditions continued to discover new passage beneath Flint Ridge as well as in Mammoth Cave, until in 1969 the Flint Ridge Cave System became the longest cave in the world with 104 kilometers of passages (Brucker and Watson 1976).

It was clear that integration of these two great caves systems would make a cave without peer on the planet, and CRF cavers worked hard for the next few years to do. The problem was that a large valley lay between the two caves, and so a connection would have to be through very low level passage. As detailed in the book *The Longest Cave* (Brucker and Watson 1976) CRF cavers worked towards a connection from both sides—Mammoth Cave and Flint Ridge—into the 1970s, and finally on September 9, 1972 cavers exploring from the Flint Ridge Side emerged into Mammoth Cave (Figure C-9). This moment has been called the "Everest of speleology" and the cave has been the world's longest—at that time 230 kilometers—ever since. After a long, wet and difficult trip through the Flint Ridge Cave System and the low, wet cave passages beneath Doyel Valley, they emerged into the large passage of Cascade Hall, across from a tourist trail from which they could see the path's handrail. Paraphrasing a *National Geographic* film about the cave and the connection after the long and arduous trip the cavers left the cave "with sublime ease, riding to the surface in an elevator." They had walked to the Snowball Dining Room, where an elevator was used each day to bring hot food down to tourists on the Half Day Tour. The new name of the cave was the Flint-Mammoth Cave System, based on the convention that longer of the two connected caves takes precedence in the name. Since that time the cave has more than doubled in length and with a number of new entrances since, the cave is now generally called the Mammoth Cave System. As before, much of the increase in length had been through the discovery and exploration of other caves that were ultimately connected to the main cave. In 1976 cavers from the Central Kentucky Karst Coalition (CKKC), unaffiliated with the Cave Research Foundation or NPS, discovered Roppel Cave in the area of Toohey Ridge to the east of MACA. Tens of kilometers of passage of this great cave were explored

in a few short years after a major breakthrough and as of 1978 the two caves were still a considerable distance apart. That year, by an incredible coincidence two independent teams working in Proctor Cave and Morrison's Cave—neither of whom knew about the other's activities— each discovered a major underground river on the same day (Coons and Engler 1980, 1981; Borden and Brucker 2000). Exploration eventually revealed that they were two ends of the same great river, and the two caves were connected through it in 1979. Logsdon River stretches between Mammoth and Roppel Caves, and through it the caves were connected by joint teams of CRF and CKKC cavers in 1983 to create the first cave system on the world to exceed 480 kilometers (Borden and Brucker 2000). Most recently Hoover Cave became the 26th entrance to the cave in 2005, and then Donkey Cave was connected. The current known length at this writing in 2020 is 663 kilometers (Gulden 2020)(Figures C-10 and C-11).

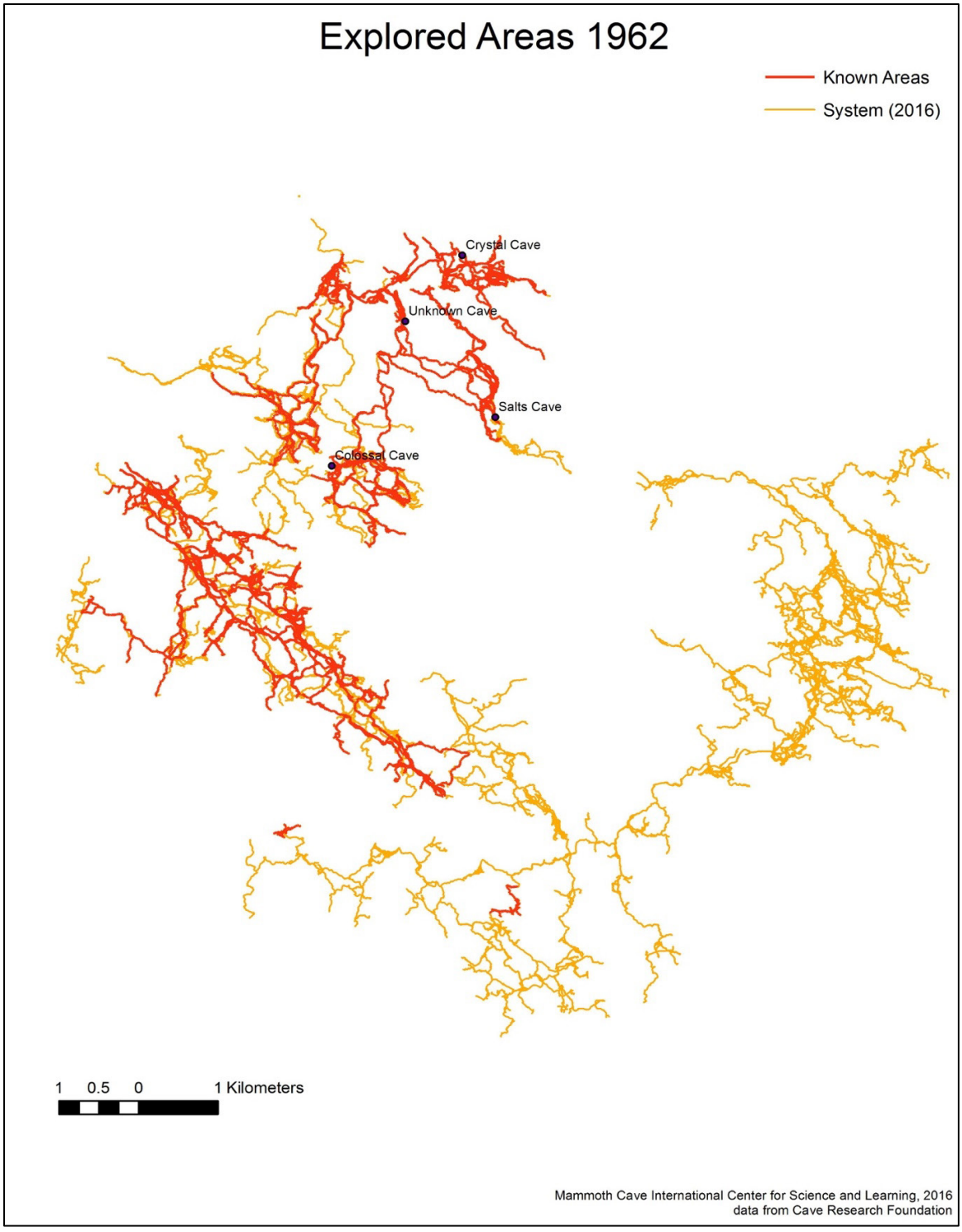


Figure C-8. Known passages of Mammoth Cave and the Flint Ridge Cave System by 1962, here showing about 120 kilometers, after major connections between several Flint Ridge Caves. Mammoth Cave had seen little exploration since the early 1940's but within a few years the combined length of the two caves would exceed 160 kilometers. Map by Rick Toomey with data from the Cave Research Foundation.



Figure C-9. An iconic moment in the history of cave exploring—six cavers emerge from the low, wet passages of Hanson's Lost River onto the tourist trail of Mammoth Cave's Cascade Hall and the world's largest cave reached a length of 230 kilometers (Brucker and Watson 1976).

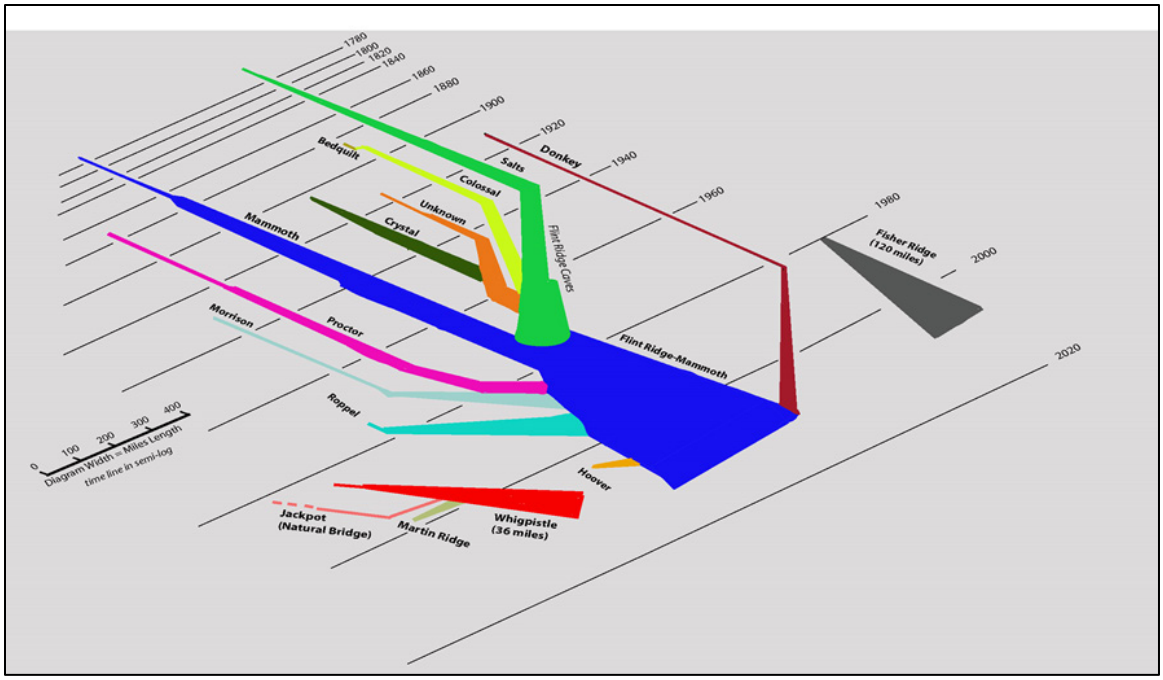


Figure C-10. Diagrammatic representation of the growth of the cave system conceived and drawn by Roger Brucker. From upper left to lower right are timelines and the beginning of each colored line represents the discovery of an individual cave. The width of the line represents the cave's length, growing as the individual caves were connected. Two so far unconnected caves, Fisher Ridge and Whigpistle, may connect to the main cave in the future. Courtesy of Roger Brucker, Cave Research Foundation.

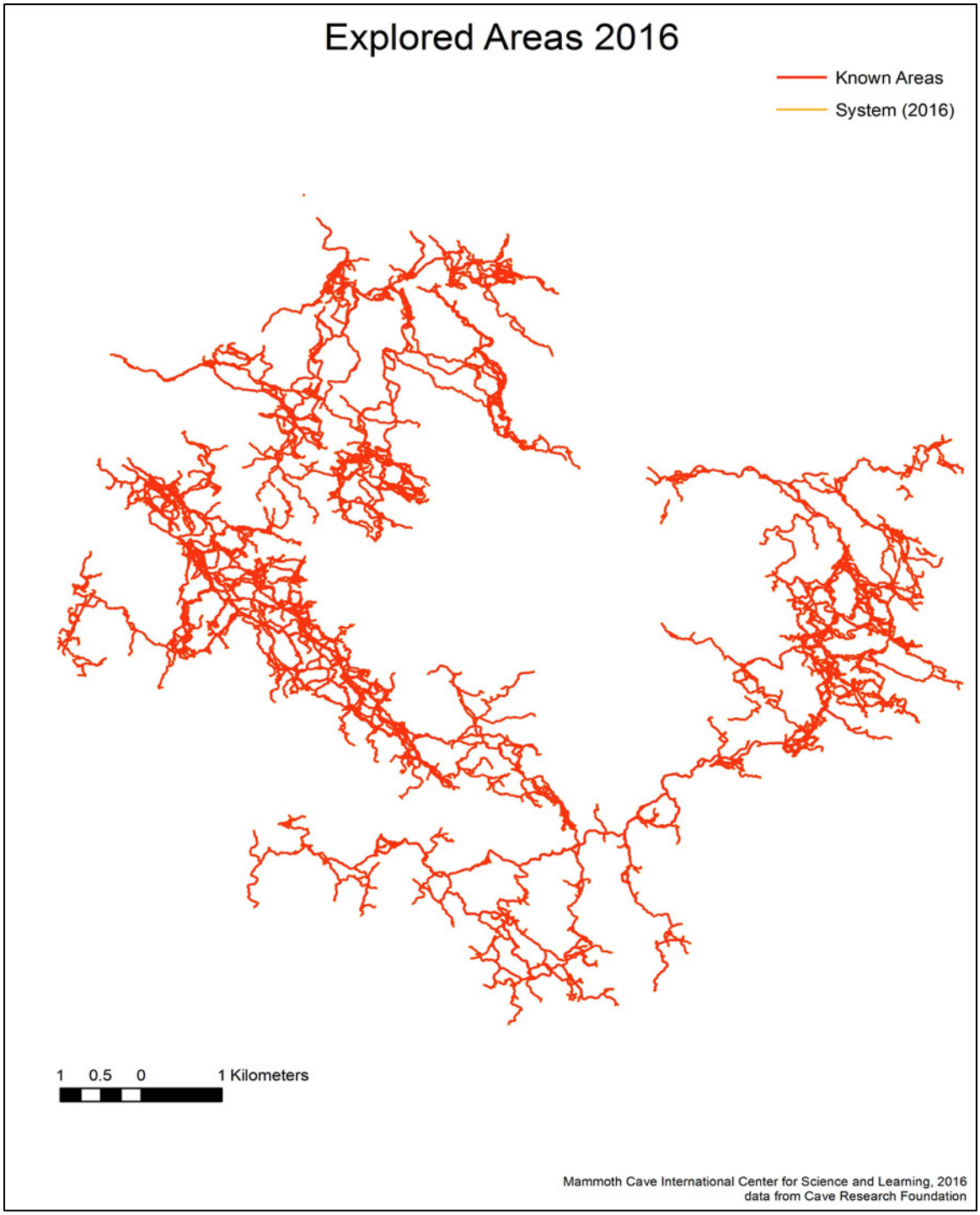


Figure C-11. Passages of the Mammoth Cave System as of 2016. Map by Rick Toomey with data from the Cave Research Foundation.

Appendix D. Globally Rare (G3–G1) NatureServe Associations Within Mammoth Cave National Park

This appendix (Table D-1) lists the twelve globally rare plant community types that have been identified at MACA by the KSNPC (Yahn 2018), as well as two others that are likely to occur but have not yet been documented.

Table D-1. Globally rare plant community types that have been identified at MACA (Yahn 2018).

Rare Natural Community	NatureServe Status	Type	MACA Community
East-central Hemlock Hardwood Forest (CEGL005043) [A.413G3?]	G3?	rich forest	occurs
Interior (Nashville Basin) Mesic Sugar Maple – Hickory Forest (CEGL004741) [A.1912]	G3G4	rich forest	occurs
Rich Appalachian Red Oak / Sugar Maple Forest (CEGL007698) [A.251]	G3	rich forest	occurs
Shumard Oak – Chinquapin Oak Mesic Limestone Forest (CEGL008442) [A.1912]	G2G3	rich forest	occurs
Appalachian Low-Elevation Mixed Pine / Hillside Blueberry Forest (CEGL007119) [A.131]	G3 dry (to mesic)	forest	occurs
Chinquapin Oak Unglaciated Bluff Woodland (CEGL004267)	G2G3	xeric forest-woodland	potential
Eastern Red-cedar – Blue Ash / Can. Leafcup – (West. Daisy) Woodland (CEGL003754)?	G3	xeric forest-woodland	potential
Nashville Basin Shingle Oak – Shumard Oak – Chinquapin Oak Forest (CEGL003876) [A.1912]	G2G3	xeric forest-woodland	occurs
Central Limestone Glade (CEGL005131) [A.1919]	G2G3	prairie/barren/glade	occurs
Kentucky Mesic Tallgrass Prairie (CEGL004677) [A.1192]	G1G2	prairie/barren/glade	potential
Little Bluestem – (Ashy Sunflower, Fewleaf Sunflower, Whorled Rosinweed) Grassland (CEGL007805)	G2G3	prairie/barren/glade	occurs?
Western Highland Rim Escarpment Post Oak Barrens (CEGL004686) [A.625]	G2G3	prairie/barren/glade	occurs
Southern Red Oak Flatwoods Forest [CEGL004412]	G2?	flatwoods	occurs
Southern Oak Flatwoods Highland Rim Limestone Cliff/Talus Seep (CEGL004708) [A.1905]	G3	wetland	occurs

Appendix E. Herpetofauna Images of Mammoth Cave National Park

While preparing this NRCA, the authors reached out to a variety of experts for both information and photos to use in this report and we appreciate the efforts of these scientists and their permission to use these photos to improve the report.

A very special collection of photographs was provided to us by John MacGregor, a herpetologist who has made a distinguished career as a biologist in Kentucky. John was an endangered species specialist with the USDA Forest Service and since 2003 has served as State Herpetologist with the Kentucky Department of Fish and Wildlife Resources. He first came to MACA in 1969 and since 2003 has conducted monitoring at the park, studying and photographing amphibians and reptiles there and throughout Kentucky (see Moore and Sloan 2007).

John has been joined in much of his work in the park by Bill Moore, who serves as a Data Manager/ Ecologist with the NPS Cumberland Piedmont Inventory and Monitoring Network (CUPN), which is housed at MACA. Moore began working for CUPN as an ecologist in 2003. Bill has worked on various projects involving herps, birds and bats. He currently serves as the forest vegetation monitoring lead within CUPN. Before coming to the National Park Service, he worked for the Kentucky Department of Fish and Wildlife Resources where he authored a booklet on Kentucky's snakes (Moore and Sloan 2007).

Especially with the emphasis on MACA's caves, these surface species represent a whole range of resources that few visitors to the park, or even scientists, will ever see. One of these, for example, shows a coal skink (*Plestiodon anthracinus*) that Bill found in 1986 after none had been seen in the park area since the 1930s. Even though most of the park's herp species are more common, many still live secluded lives amongst the logs, rocks and ponds of the park and it is only by knowledgeable and patient hunting can they be spotted and photographed at all. Others, like the photo below of four gravid timber rattlesnakes (*Crotalus horridus*) are ones that most park visitors likely would rather not see. These photos also document a changing landscape as the developing forest landscape has taken over former farms and changed living conditions for species such as the slender glass lizard (*Ophisaurus attenuatus*) that prefer open spaces.

As well as the importance of the documentation they provide, these are simply beautiful images. For us in this way these pictures thus represent a hidden and changing world of a park that many people think of in terms of the underground world of the caves. John has taken the time to pull these images from the depths of his computer's hard drive and we thought that this NRCA would make a great place to pull these together in one spot and make them available to a wider audience.

Captions on photos (Figures E-1 through E-28) identify the species and often provide a few words of background but for details about the conditions of the reptiles and amphibians of MACA we refer readers back to section 4.11. In the captions, we also use common names rather than scientific ones. They are grouped together in sequential order of animal groups, but not labeled as such.



Figure E-1. Marbled salamanders are common in the park. They lay eggs in autumn in dry vernal pools and the eggs hatch after the pools fill with rainwater.



Figure E-2. Midland mud salamanders live in seeps and mucky areas and seem very rare in the park.



Figure E-3. Northern red salamanders live along small streams in the park and are fairly common.



Figure E-4. Spotted salamanders are very common in the park and breed in woodland ponds in spring.



Figure E-5. Spotted salamander egg masses can be seen in upland ponds in February and March.



Figure E-6. A coal skink, apparently very rare on the park. There is one old record from Mammoth Cave Ridge from the 1930s, and Bill Moore found one in 2006.



Figure E-7. Five-lined skink—common on the park and often seen on the Sloans Crossing Pond boardwalk. Breeding condition males like this one develop bright red heads in April–May as testosterone levels build. Note ticks on the lizard in the photo!



Figure E-8. Slender glass lizards are becoming rare on the park as open habitat disappears.



Figure E-9. Close up view of a slender glass lizard on Flint Ridge in 1985. Although without legs these look superficially like snakes, a characteristic feature of lizards is that they have movable eyelids.



Figure E-10. Eastern copperheads are one of the most commonly encountered snakes at MACA.



Figure E-11. Timber rattlesnakes are fairly common in the park. They are not aggressive and will typically crawl off and hide if a hiker comes across one on a trail.



Figure E-12. This large male timber rattlesnake on the Great Onyx Road on Flint Ridge was about 1.6 m long.



Figure E-13. This group of four gravid females on top of a fallen oak were found by John MacGregor and Bill Moore in late summer when they checked out a report from an intern doing bird surveys. Timber rattlesnakes rarely climb but these four certainly did!



Figure E-14. Rough green snakes are seldom seen in the park but are probably common.



Figure E-15. Corn snakes are rather rare in Kentucky but doing well from the Mammoth Cave area north into southern Hardin County.



Figure E-16. Close up of a corn snake in MACA. Unfortunately, corn snakes are threatened because of popularity as pets and there is extensive trade in them in the US.



Figure E-17. A beautiful corn snake portrait.



Figure E-18. Northern pine snakes were common in the 1930s but have disappeared as forests have taken over the park. They require open areas with loose soil for burrowing. They are Kentucky's largest native snake, to about two meters, and are sometimes called "yellow bullsnakes" by local residents.



Figure E-19. Prairie kingsnakes live in fields, prairie remnants, and open woods, and spend most of their time underground in rodent tunnels hunting for mice. They are not common in the park.



Figure E-20. Ring-necked snakes are a small woodland snake that feed on insects, earthworms, and salamanders. They are by far the most common snake in the park.



Figure E-21. American bullfrogs are very common along Green River and at Sloans Crossing Pond, calling in summer.



Figure E-22. Eastern narrow-mouthed toads call from grassy pools in summer, especially by day after rains, and are fairly rare in the park.

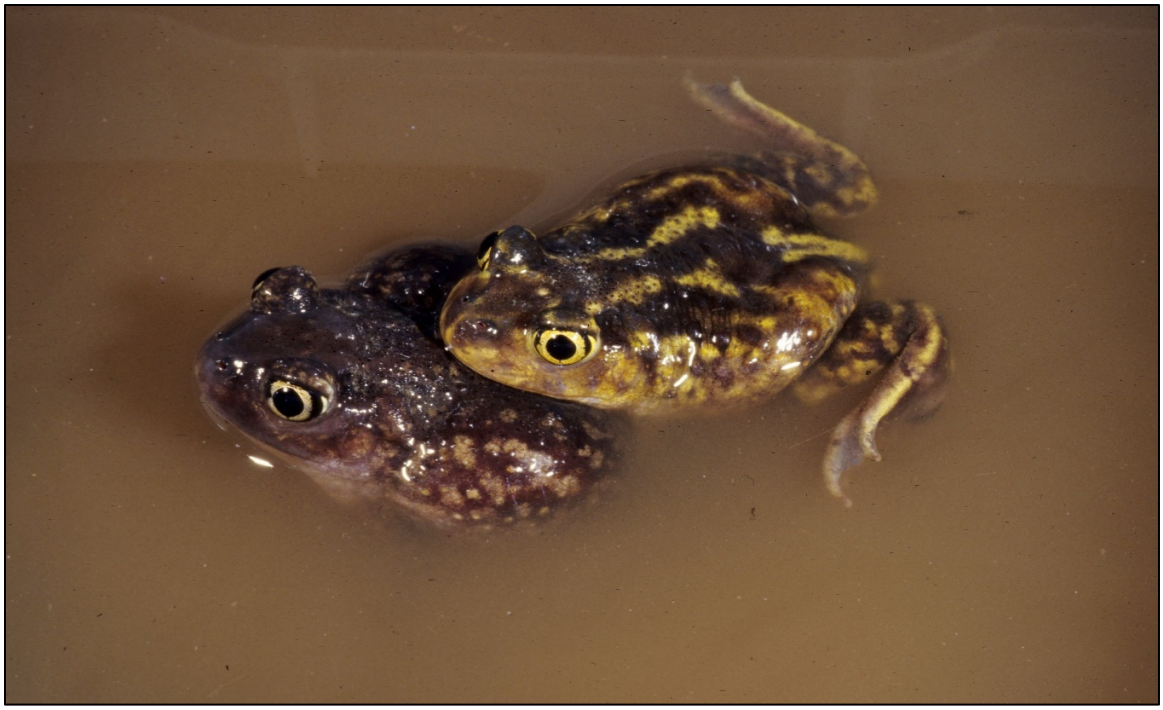


Figure E-23. Eastern spadefoots are common in the park and breed in vernal pools during and just after heavy rains from January–October; choruses last less than 24 hours.



Figure E-24. Green frogs are common throughout the park with summer choruses at Sloan's Crossing pond day and night.



Figure E-25. Spring peepers are common in the park and call mostly March–May.



Figure E-26. Wood frogs are very common in the park and breed in vernal ponds in January–February.

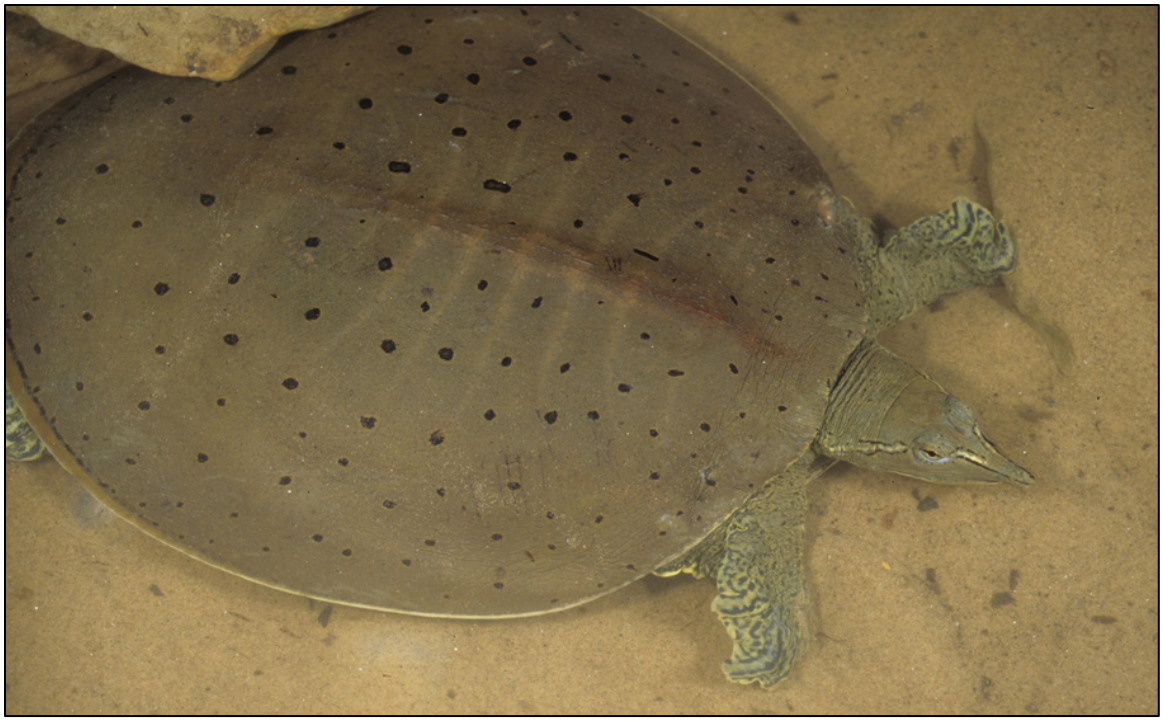


Figure E-27. The spiny softshell is one of several kinds of turtles commonly seen in Green River. Nine turtle species are known from the park (8 extant – the eastern mud turtle has probably been extirpated).



Figure E-28. The real danger…Seed ticks on duct tape dabbed from MacGregor's pants leg just after he had returned to his vehicle after looking for snakes. Arrrghhhhh!

Appendix F. 2017 Mussel Species Abundance per Site

Table F.1. 2017 Mussel species abundance per site (Compton et al. 2017).

Species	Site Number and Habitat Type																									
	GR1 IMP	GR2 IMP	GR3 IMP	GR4 FLOW	GR5 FLOW	GR6 FLOW	GR7 POOL	GR8 POOL	GR9 POOL	GR10 POOL	GR11 FLOW	GR12 FLOW	GR13 POOL	GR14 FLOW	GR15 POOL	GR16 FLOW	GR17 FLOW	GR18 POOL	GR19 FLOW	GR20 FLOW	GR21 FLOW	G22 FLOW	GR23 POOL	GR24 FLOW	GR25 POOL	GR26 FLOW	GR27 FLOW
Actinonaias ligamentina	–	–	–	1	–	1	–	–	–	–	2	–	–	1	–	–	3	–	–	1	6	1	–	–	–	–	–
Amblema plicata	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–
Cyclonaias pustulosa	–	–	–	7	–	1	1	–	–	–	11	2	–	2	–	1	11	–	1	7	11	4	–	–	–	3	–
Cyclonaias tuberculata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Cyprogenia stegaria	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–
Ellipsaria lineolata	–	–	–	3	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	11	–	–	–	–	–	–
Elliptio crassidens	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–
Eurynia dilatata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	1	1	–	–	–	–	1	–
Fusconaia subrotunda	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lampsilis cardium	–	–	–	1	1	2	–	–	–	–	4	1	–	2	–	–	1	–	–	–	–	–	–	–	–	–	–
Lampsilis ovata	–	–	–	2	–	2	–	–	–	1	1	2	–	3	–	–	1	–	1	2	3	1	–	–	–	–	–
Lampsilis siliquoidea	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Lasmigona complanata	–	–	–	–	1	1	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Lasmigona costata	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Leptodea fragilis	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	3	–	–	–	1	1	–	–	–	1	–
Ligumia recta	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	1	–	1	–	–	–
Megalonaias nervosa	–	3	–	3	–	1	–	–	–	–	7	2	1	4	–	1	5	–	–	–	4	1	–	1	1	–	–
Obliquaria reflexa	–	–	–	9	–	3	4	1	–	1	10	2	6	3	–	2	5	1	–	1	8	–	–	–	–	2	–
Plethobasus cyphyus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–
Pleurobema sintoxia	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	–	–	–	–	–	–
Potamilus alatus	–	–	1	7	8	3	15	2	1	1	14	7	1	4	1	1	6	–	–	10	14	3	1	1	–	1	–
Ptychobranchus fasciolaris	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Quadrula quadrula	–	–	–	8	6	12	2	–	–	2	19	2	5	4	1	2	3	–	–	4	11	4	–	1	–	–	1
Strophitus undulatus	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Theliderma metanerva	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–	–	–
Tritogonia verrucosa	–	–	–	3	1	1	–	–	–	–	11	1	1	–	–	2	11	–	–	4	4	1	–	–	–	3	–
Truncilla truncata	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	1	–

The Department of the Interior protects and manages the nation’s natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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