National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Cave Ecology Inventory and Monitoring Framework

Natural Resource Report NPS/NRSS/NRR—2015/948

ON THE COVER

Cave-adapted crayfish in Mammoth Cave (Rick Olson), Pseudoscorpion (Gretchen Baker), Millipede (David Hunter), Cave Cricket (Gretchen Baker), microbes (Hazel Barton), and Townsend's big-eared bats (Shawn Thomas).

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Gretchen M. Baker
Ecologist
Great Basin National Park
100 Great Basin National Park
Baker, Nevada 89311
Gretchen_Baker@nps.gov

Steven J. Taylor
Illinois Natural History Survey
University of Illinois at Urbana-Champaign
1816 S. Oak Street (MC-652)
Champaign IL 61820-6953 USA
sjtaylor@illinois.edu

Shawn Thomas
Formerly Physical Science Technician
Carlsbad Caverns National Park
3225 National Parks Highway
Carlsbad, NM 88220
sthomas@batcon.org

Kathy Lavoie
Professor of Biology
Dean, Faculty of Arts and Science
101 Ward Hall
SUNY-Plattsburgh
Plattsburg, NY 12901
lavoiekh@plattsburgh.edu

Rick Olson
Ecologist
Mammoth Cave National Park
P.O. Box 7
Mammoth Cave, KY 42259
Rick_Olson@nps.gov

Hazel Barton
Associate Professor
Department of Biology
University of Akron
Akron, OH 44325-1901
bartonh@uakron.edu

Marie Denn
Regional Aquatic Ecologist
Pacific West Region
333 Bush Street, Suite 500
San Francisco, CA 94104-2828
Marie_Denn@nps.gov

Steven C. Thomas
Monitoring Program Leader
Cumberland Piedmont Network
P.O. Box 8
Mammoth Cave, KY 42259
Steven_Thomas@nps.gov

Rene Ohms
Formerly Physical Science Technician
Jewel Cave National Monument
11149 US Highway 16 #B12
Custer, SD 57730
Rene_Ohms@nps.gov

Kurt Lewis Helf
Ecologist
Cumberland Piedmont Network
P.O. Box 8
Mammoth Cave, KY 42259
Kurt_Helf@nps.gov

Joel Despain
Formerly Cave Specialist
Sequoia & Kings Canyon National Parks
47050 Generals Highway
Three Rivers, California 93271-9700
jddespain@fs.fed.us

Jim Kennedy
Formerly Habitat Protection Coordinator
Bat Conservation International
P.O. Box 162603
Austin, TX 78716-3302
cavercrash@gmail.com

David Larson
Chief of Resource Management
Big Bend National Park
P.O. Box 129
Big Bend National Park, TX 79834
David_Larson@nps.gov

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This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available in digital format from the NPS Cave and Karst Program at (http://www2.nature.nps.gov/geology/caves/cave_parks.cfm) and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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Executive Summary

The Cave Ecology Inventory and Monitoring Framework (Framework) is intended to assist National Park Service (NPS) cave managers to better understand what lives in the caves that they are responsible for managing and how they interact with the cave environment. For many NPS units where cave resources have not emerged as a vital sign in their NPS Inventory and Monitoring (I&M) Network, additional guidance would be helpful. Designing inventory and monitoring programs for cave ecosystems poses particular challenges: many cave species are rare and/or cryptic, and their distributions can be highly patchy and variable over time. Logistics of accessing sites can be complex, and observers must take unusual care to avoid damaging the ecosystems they are tasked with monitoring.

The guidance in this document can aid managers in deciding what to inventory and monitor and ways that can be done. It also helps provide a national context, which may help parks conduct inventory and monitoring in a more cohesive manner. Due to the wide geographical scope of NPS caves and their many different types, the document is not an I&M protocol and it also does not prescribe exact protocols. Instead, this document provides peer-reviewed guidance for what types of inventory and monitoring are possible, a framework for deciding how to prioritize inventory and monitoring activities, and references to specific protocols that are already in place at other caves.

The principal goal of this Cave Ecology Inventory and Monitoring Framework is to encourage cave managers to understand as much as possible about local cave ecology and threats to cave biota in order to make informed decisions geared towards cave conservation and protection of cave ecological systems. In order to do this, the Framework provides managers with tools to determine variability and long-term trends in cave biota. Additional objectives of the Framework include helping cave managers prioritize monitoring activities and providing guidance on conducting in-cave monitoring work by promoting safe and sustainable methods.

Section 1.0 provides a background of the importance of caves, an introduction to cave ecology, an overview of NPS cave resources and what cave ecological I&M programs are already in place, as well as some general considerations for inventory and monitoring.

Section 2.0 provides cave managers with examples of what can be monitored, divided into four main areas: terrestrial cave ecosystems, aquatic cave ecosystems, plants, and microbes. Within each of these areas, potential targets are described and consideration is given to monitoring questions, focal species, techniques, sampling locations, and appropriate data analysis. In addition, references, related studies, and links to relevant monitoring protocols are provided.

Section 3.0 covers how to decide what to monitor. Before monitoring can proceed, data mining and inventories must first be conducted. Data mining will help managers decipher past efforts and understand the current state of knowledge on potential monitoring targets. This is an important step for planning inventories and avoiding duplication of efforts. Basic inventories include specific biota, cave habitats, and threats to caves. Specific biota inventories may focus on something the park is known for, such as bats, or for more obscure biota, like microbes or springtails. Park managers need

to know something about the cave habitats in their areas. Conducting assessments may also be a valuable use of time and money to better understand cave resources.

Section 4.0 includes basic information on data management, while section 5.0 concentrates on data analysis. Due to the rare and cryptic characteristics of some cave biota, additional and/or different data analysis techniques from what are used to analyze surface fauna may be required.

Developing and implementing a long-term cave ecological monitoring program is a complex and challenging prospect. National Park Service cave managers are well situated to act as catalysts for initiating and carrying out monitoring programs, however, they cannot, and should not act alone. Monitoring programs will be stronger and more likely to succeed with the input of other cave managers, resource specialists, researchers, cave conservation organizations, the NPS I&M Program and more. Section 6.0 outlines options for collaboration and partnerships, both within and outside of the NPS, in order to achieve monitoring goals.

Acknowledgments

This multi-year national endeavor would not have been possible without the initial enthusiasm of Denis Davis and Dale Pate. Reviews of this document by Don Seale, Greg Eckert, Rod Horrocks, and Cyndee Watson greatly benefited the manuscript. Help from the National Inventory and Monitoring office by Bruce Bingham and Steve Fancy and regional I&M coordinator Penny Latham guided the production of this report. Additional information was contributed by Chuck Bitting, Scott House, Nancy Nordensten, Emily Ring, Tom Strong, Steve West, and Kevin Wilson.

List of Abbreviations and Acronyms

BRMD	Biological Resource Management Division
CESU	Cooperative Ecosystem Studies Unit
CFR	Code of Federal Regulations
CRF	Cave Research Foundation
EIAF	Ecological Integrity Assessment Framework
FCRPA	Federal Cave Resources Protection Act
FOIA	Freedom of Information Act
GIS	Geographical Information System
GLMM	Generalized Linear Mixed Model
GRD	Geological Resources Division
I&M	Inventory and Monitoring
KWI	Karst Waters Institute
MKT	Mann Kendall Test
NCKMS	National Cave & Karst Management Symposium
NCKRI	National Cave and Karst Research Institute
NPS	National Park Service
NRSS	Natural Resource Stewardship and Science
NSS	National Speleological Society
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
RH	Relative Humidity
RPRS	NPS Research Permit and Reporting System
SCC	Servicewide Comprehensive Call
SKT	Seasonal Kendall Test
SOPs	Standard Operating Procedures
T&E	Threatened and Endangered
TAC	Technical Assistance Call
USFWS	United States Fish and Wildlife Service
WNS	White Nose Syndrome

Cave Ecology Glossary

Accidentals – Animals that find themselves in caves by accident.
Biodiversity – Degree of variation of life.
Cave – The Federal Cave Resources Protection Act (1988) defines a cave as "any naturally occurring void, cavity, recess, or system of interconnected passages beneath the surface of the earth or within a cliff or ledge, including any cave resource therein, and which is large enough to permit a person to enter, whether the entrance is excavated or naturally formed." For the purposes of the Framework, caves chosen for ecological inventory and monitoring should be of sufficient length or depth that environmental parameters differentiate it from surface habitats.
Cave Ecosystem – Community of living organisms in conjunction with the nonliving components of their environment that include both organisms that live entirely in the cave (e.g., cave obligate invertebrates) as well as those that may only come in contact with the cave periodically (e.g., bats) or in a small way (e.g., tree roots).
Dark Zone – The area of a cave that is perpetually without light.
Detritovore – An organism that eats detritus to receive its nutrients, for example a millipede.
Edaphic systems – Soil systems, especially as they affect living organisms.
Edaphobites – Soil inhabiting organisms that may also be encountered in caves, but which are more typical of the general soil environment.
Endemic - An organism found only in that particular area and nowhere else in the world.
Entrance Zone – The area of a cave closest to the surface that experiences a greater range of light, humidity, and temperature, and generally a higher level of nutrient input.
Epigean – Surface, or above cave.
Epigenic Cave – Caves formed by acids generated at or near the surface (Palmer 2007).
Epikarst – Area under the soil and above the bedrock; this transition zone is often fractured, providing an MSS (see below).
Erosion Cave – Cave that forms by the mechanical forces of moving water, and to a lesser extent, wind.
Flagship species – A species chosen to represent an environmental cause, such as an ecosystem in need of conservation.
Glacier Cave – A cave that is formed by the melting of channels in ice caps or glaciers.
Guanophiles – Animals associated with accumulations of guano, but not normally found in other settings.
Hypogenic Cave – Caves formed by acids generated partly or entirely at depth below the surface (Palmer 2007).
Karst – Landform that is often characterized by a landscape of soluble rock, containing depressions, sinkholes, and caves that provide a conduit for subsurface water.
Keystone species – A species that has a disproportionate effect on its environment relative to its abundance.
Lamp Flora – Algae, mosses, and fungi that grow near artificial light sources in caves.
Lava tube – A subterranean void formed when flowing lava begins to cool and subside.
Lentic – Still water, or a body of water.

Littoral Caves – See *sea caves.*
Lotic – Flowing water.
MSS – *Milleu souterrain superficial*, or mesovoid shallow substratum; a transition zone where you can often find both epigean and cave adapted animals
Obligate – An organism that is restricted to a particular environment; in this document we speak of cave obligate organisms.
Phreatic zone – Zone in the ground, below the water table, in which all the openings are filled with water (Palmer 2007).
Pseudokarst – Landform that can contain many of the same resources as karst systems but have a very different mechanism of development (e.g., lava tubes, talus caves).
Sea Cave – A cave formed by erosive wave action in ocean coastal areas and sometimes along the shorelines of large lakes.
Sinkhole – A depression or hole in the ground caused by some form of collapse of the surface layer.
Solution Cave – A cave that forms by the dissolving action of subsurface water, as it seeps or flows through voids or cracks in soluble bedrock.
Stygobites – An aquatic troglobite.
Stygophiles – An aquatic troglophile.
Talus Cave – A cave that is a void between boulders that accumulate on steep slopes. *Or* Voids within slabs of rock that have separated from the cliff face and accumulated at the base of the cliffs in piles are also considered talus caves.
Tectonic Cave – A cave that forms when large slabs of rock move apart during ground movement.
Troglobite – An organism that is limited to caves and similar environments. The most extreme forms show adaptations to the cave environment such as reduced eyes and pigmentation. They complete their entire life cycle within the cave.
Troglomorphic – An organism showing adaptations to the cave environment such as reduced eyes and pigmentation.
Troglophile – An organism that uses the cave for most parts of its life cycle, but has to return to the surface for some purpose, like feeding or reproduction.
Trogloxene – A species that uses caves, but is also found in other locations.
Trophic structure - Refers to the way in which organisms use food resources and how they provide energy for other organisms in the food web.
Twilight zone – Area of the cave between the Entrance Zone and the Dark Zone. It has characteristics of both.
Umbrella species – Species selected for making conservation related decisions, typically because protecting these species indirectly protects the many other species that make up the ecological community of its habitat.
Vadose zone – Zone above the water table in which water moves by gravity and capillarity. Water does not fill all the openings and does not build up pressures greater than atmospheric (Palmer 2007).
Water table – Upper surface of the phreatic zone (Palmer 2007).

1.0 Introduction

1.1 Background

Cave and karst resources occur in over 125 National Park Service (NPS) units, most of which are within the contiguous U.S. (Figure 1). In late 2008 the NPS Cave and Karst Office held a meeting in Lakewood, Colorado to discuss how national protocols could be written to address a variety of NPS units containing cave resources. It was decided to divide into smaller groups to focus on visitor impacts to caves, cave paleontology, cave inventory, cave air quality, cave water quality, and cave ecology. This document is the product of the cave ecology group, which communicated intermittently by email and teleconference for six years.

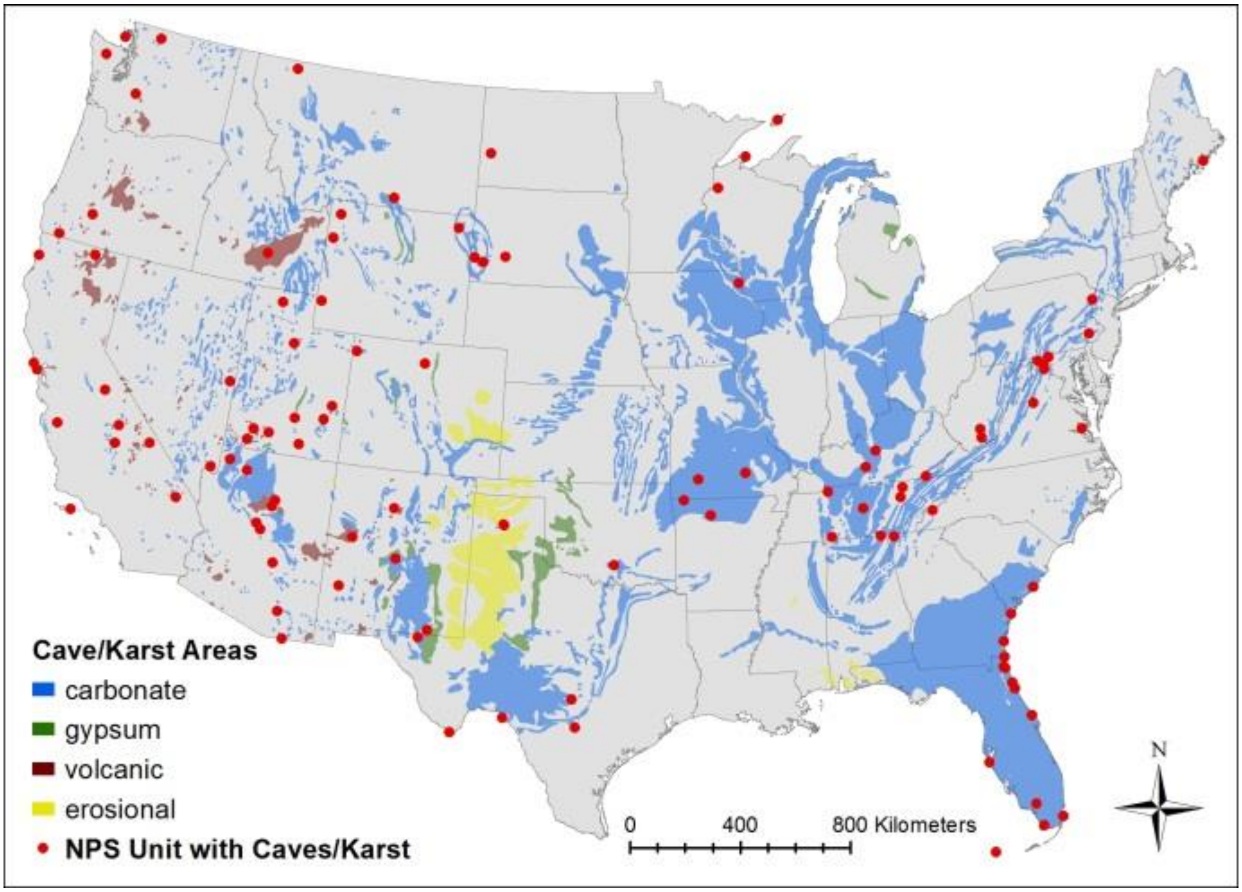

Figure 1. Cave/karst areas and NPS units with cave/karst resources in the contiguous U.S. Adapted from Croskrey 2012 and Tobin and Weary 2004.

Cave biological monitoring and inventory is a huge topic with great variety across the units of the National Park System. It may include studies on roots in lava tubes at Hawaii Volcanoes National Park, bats in talus caves at Pinnacles National Park, endemic microbes in Lechuguilla Cave at Carlsbad Caverns National Park, and Endangered Species Act-listed aquatic invertebrate species at Mammoth Cave National Park. Due to the large diversity of cave biological and ecological resources within the System, the project team determined that specific, one-size-fits-all protocols for all cave biological and ecological inventory and monitoring efforts were not practical or desirable. Rather, the team has worked to develop a decision-making tool that NPS units can use to determine their own local cave biology and ecology inventory and monitoring priorities and needs.

The *Cave Ecology Inventory and Monitoring Framework* (Framework) is intended to assist NPS cave managers to better understand what lives in the caves that they are responsible for managing and how they interact with the cave environment. For many NPS units where cave resources have not emerged as a vital sign in their NPS Inventory and Monitoring (I&M) Network, additional guidance would be helpful. This guidance can aid managers in deciding what to inventory and monitor and ways that can be done. It also helps provide a national context, which may help parks conduct inventory and monitoring in a more cohesive manner.

This document is called a "Framework" rather than a "Protocol." Framework is intended to mean a guiding document that outlines what is possible, how to decide what to do, and what is already being done. This approach is more appropriate for this document, which is national in scope and thus must be applicable to many different types of caves and habitats. Protocols, on the other hand, offer specific ways to conduct inventory and monitoring. Protocols are referenced in this document so that readers can find what has been done at specific parks and borrow or adapt methods where appropriate. This document provides a guideline of what can be done, followed by references to specific protocols. This organization may be sufficient information for managers to accomplish their objectives. In other cases, it may just be a starting point, as the unique nature of each cave park may require protocols tailored to that park.

1.1.1 Definitions of Caves and Karst

The Federal Cave Resources Protection Act (1988) defines a cave as "any naturally occurring void, cavity, recess, or system of interconnected passages beneath the surface of the earth or within a cliff or ledge, including any cave resource therein, and which is large enough to permit a person to enter, whether the entrance is excavated or naturally formed." For the purposes of the Framework, caves chosen for ecological inventory and monitoring should be of sufficient length or depth that environmental parameters differentiate it from surface habitats.

Karst is often characterized by a landscape of soluble rock, containing depressions, sinkholes, and caves that provide a conduit for subsurface water. This definition can be expanded to include pseudokarst, such as lava tubes or talus caves, which can contain many of the same resources as karst systems but have a very different mechanism of development. The karst landscapes of the National Park Service vary greatly, and are not always easily recognizable. For example, while some NPS sites contain vast sinkhole plains, others are known for submerged caves, deeply buried paleokarst or high-alpine cave systems.

1.2 Why Caves are Important

Worldwide, caves have always been of interest and fascination to people. Many great discoveries relating to our understanding of paleontology, human evolution, and human cultural evolution have been made in caves. The unique conditions in caves preserve records of animal and human activity, including burials, and clastic sediments and speleothems provide insights into past climates and surface conditions. Originally of interest to geologists and biologists as oddities, studies now appreciate caves as simplified natural ecosystems of interest to scientists in many disciplines and resource managers in many areas (LaMoreaux 2004).

Nearly 20% of the surface of the Earth is carbonate rock suitable for cave formation, including 40% of land east of the Mississippi River (White et al. 1995). Carbonate rocks are also important sources of oil and gas. Caves provide a window into the subsurface and can allow humans direct access to the groundwater system, including the Edwards Aquifer in Texas and the Floridian aquifer, both major reserves of fresh water for millions of people. These systems are dynamic, balancing water flow and solution of rock, while also being very susceptible to contamination from pollution and spills.

Many natural areas managed by the National Park Service include caves as the major attraction. These include Carlsbad Caverns National Park, Mammoth Cave National Park, Wind Cave National Park, Jewel Cave National Monument, Oregon Caves National Monument, and Timpanogos Cave National Monument. Parks that are more well known for their surface resources but also contain significant cave and karst resources include Great Basin National Park, Sequoia-Kings Canyon National Park, Grand Canyon National Park, Lava Beds National Monument, Craters of the Moon National Monument, El Malpais National Monument, Buffalo National River, Ozark National Scenic Riverways, and others.

1.2.1 Importance of caves as habitats

Caves are important as a distinct ecological resource that varies in substrate, biotic and abiotic components, and role in the ecological landscape. Caves provide subterranean habitat for many species, some of which are wholly dependent on caves to survive. The unique characteristics of cave environments offer the specific conditions required by many animals, as well as some plants that utilize cave entrances. At first, these habitats may appear to be isolated from the outside world, with a layer of rock separating the underground from sunlight, precipitation, and wind. However, a closer look finds that the surface and subsurface are connected in a variety of ways, as described in more detail in section 1.3.

Many caves contain cave-obligate biota (Figure 2), and without caves, these species would cease to exist. In North America there are over 1,100 known troglobites and stygobites (see section 1.3.1 for definitions of these terms or the glossary at the beginning of the document), with many more likely present in other subterranean environments, like aquifers and epikarst. Most cave species are largely unknown; they have small populations, restricted ranges, and low rates of reproduction, making field studies difficult, and few can be raised successfully in the lab.

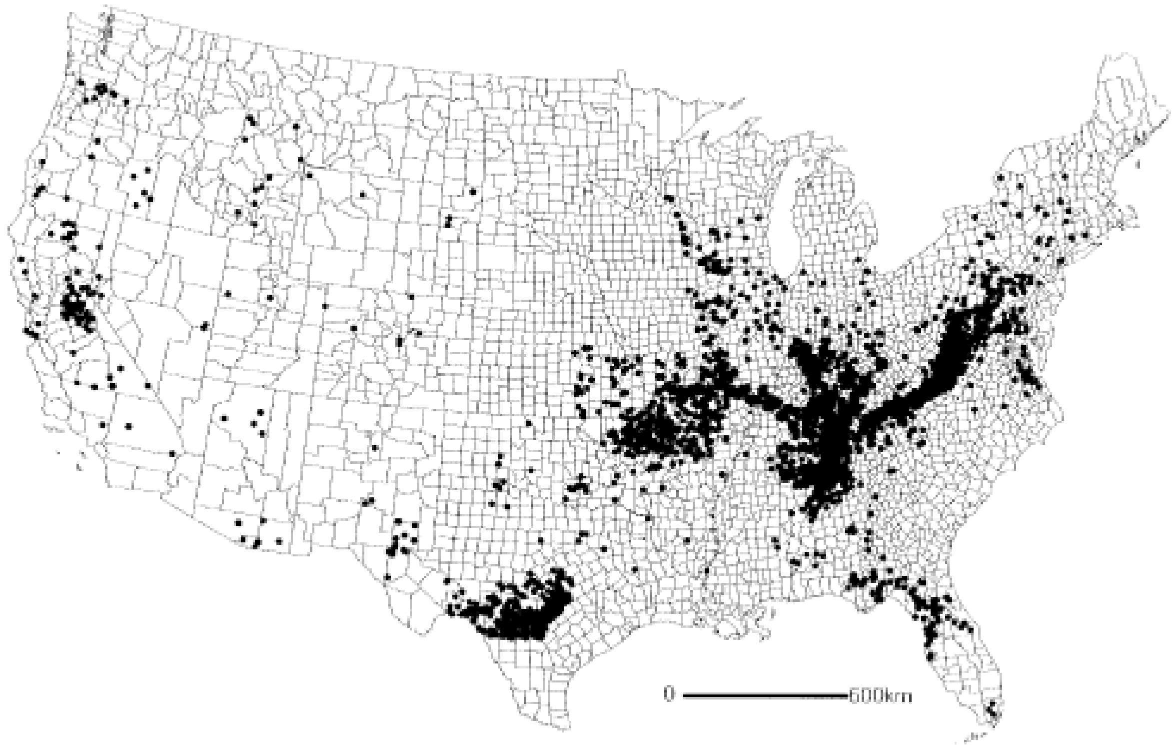

Figure 2. Cave obligate fauna in the United States. Each dot represents one cave obligate species. From Culver et al. (1999), used with permission.

In general, biodiversity in caves is low compared to surface habitats. There are generally fewer food resources, reduced subterranean habitat diversity, and decreased boundary ecotones between different habitats. Culver and Sket (2000) identified subterranean biodiversity "hot spots" with exceptional biodiversity, which they defined as having 20 or more species of both terrestrial troglobites and aquatic stygobites. Compare this to surface environments which may support many thousands of endemic species. Terrestrial cave environments are dominated by insects and arachnids, and the aquatic cave environments by crustaceans. The United States has three hotspots of subterranean biodiversity: San Marcos Springs (a phreatic environment) with 27 species, Shelta Cave in Alabama with 24 species, and Mammoth Cave in Kentucky with 41 species as of the year 2000.

There are 14 hotspots in Europe, one in Australia, and one in Bermuda. The *Sistem Rostojna Plania* in Slovenia has a stunning 84 species of troglobites. What do these biodiversity hotspots have in common? Culver and Sket identified four main factors: 1) high levels of primary productivity, usually by chemolitotrophic bacteria or root mats; 2) rich organic inputs of energy; 3) large size, which usually means a good diversity of habitats; and 4) permanent groundwater. The majority of these sites are threatened by human activity.

Understanding regional patterns is very important in studying subterranean biodiversity. Caves are often highly fragmented and separate from one another. For example, in West Virginia the maximum number of troglobites in any one cave is 14, but across the state there are 76 known troglobites, many considered to be threatened and endangered.

1.2.2 Threats to Cave Ecosystems

In order to protect cave ecosystems it is important to understand how external factors impact the system across local and regional scales. Damage or distortion to cave ecosystems can come from a myriad of sources, near and far (Figure 3). Starting with far out sources, air pollution from regional and even global sources can impact vegetation that trogloxenes such as bats or woodrats or crickets rely upon directly or indirectly for food supply. Such a negative change in vegetation status could then reduce the flow of food resources into caves that many cave-adapted organisms rely upon. Atmospheric contaminants have direct and indirect effects on cave ecosystems. Ozone causes foliar damage to vegetation (Carson 2001), and mercury from coal combustion is toxic to surface and cave wildlife, including some listed as endangered. Acid deposition linked to coal combustion causes direct damage to vegetation, leaches cations from soil, and mobilizes aluminum, which is toxic to plants and aquatic life such as fish (Olson 2001). All component ecosystems within the karst landscape, including those in caves, are generally dependent upon the primary productivity of vegetation communities. Other sources of impacts to vegetation include exotic insects such as the gypsy moth, emerald ash borer, wooly adelgids, and also exotic diseases such as chestnut blight, butternut canker, and dogwood anthracnose. Fire obviously affects vegetation, and there can be negative impacts from either fire suppression or excessive fire to both water budget and foraging habitat for trogloxenes. Excessive vegetative growth over a cave can also impact the subsurface.

Moving to a regional and local scale, water resources in karst and pseudokarst aquifers can be impacted by pumping that lowers the water table. For example, at Great Basin National Park, a proposal to pump massive amounts of groundwater from the adjacent valleys could lower the water table in cave and karst areas according to hydrology studies and aquifer modeling work (Elliot et al. 2006, BLM 2012). Several of the caves in Great Basin National Park are connected to the water table, which if lowered, could affect species both in and above caves, including the newly discovered amphipod *Stygobromus albapinus*.

Surface runoff from agricultural or industrial operations, urban areas, and also routine runoff from transportation corridors (highways and railroads) can be significant sources of water pollution. Spills along transportation corridors can be catastrophic for cave life (Brucker 1979) if these pollutants are carried into caves where they can affect both aquatic and terrestrial cave ecosystems. Trash-filled sinkholes can cause toxins to be dumped directly into cave systems. Impoundments on rivers for navigation or flood control can have far-reaching and major impacts not only on the river itself, but to cave aquatic habitats. For instance, Lock and Dam #6 on Green River adjoining Mammoth Cave National Park degrades habitat for seven aquatic species listed as endangered, including the Kentucky cave shrimp (Olson 2005). Dams on rivers can alter water levels, flow velocity, and flow

Figure 3. Summary of threats to cave ecosystems.

I. Cave Aquatic Ecosystem

- A. Altered Hydrology
  1. Flooding and siltation caused by dam impoundments and increased nearby impervious cover
  2. Lowered water table caused by excessive pumping
  3. Excessive or inadequate fire frequency in fire-adapted vegetation
  4. Drying of caves from vegetation clearing (including timbering)
  5. Drying of caves by excessive vegetation growth over a cave
  6. Drying of caves by paving and surface development

- B. Toxins and Nutrients
  1. Acute Input
     - a. Spills along transportation corridors
     - b. Industrial dumping
  2. Chronic Input
     - a. Agricultural chemicals
     - b. Runoff from roads and parking lots
     - c. Sinkhole dumps
     - d. Atmospheric deposition
     - e. Animal waste from feedlots or large operations
     - f. Leaking sewer lines
     - g. Leaking storage tanks

- C. Organic Enrichment
  1. Animal Wastes
  2. Human Wastes
  3. Overflow from Eutrophic Sinkhole Ponds
  4. Wood Debris (Construction in Cave, Sawmill Waste)

- D. Siltation (Other than from impoundments)
  1. Erosion from agricultural land and logging sites
  2. Erosion from construction sites

II. Terrestrial Cave Ecosystem

- A. Entrance Modifications
  1. Natural entrances blocked for security
  2. Artificial entrances opened for convenience
  3. Poorly designed cave gates that affect microclimate and nutrient flow

- B. Disturbance to wildlife
  1. Bats awakened from hibernation
  2. Migration pathways between cave and surface disrupted
  3. Unsustainable levels of human disturbance
  4. Substrate (sediment) compaction and alteration

- C. Lighting impacts
  1. Lampflora growth and chemical treatment
  2. Heat generation and atmospheric effects
  3. Toxins from broken fluorescent lamps
  4. Behavioral disruption of dark-loving fauna

- D. Introduction of exotic species
  1. Fire ants
  2. White Nose Syndrome
  3. Feral cats, pigs, mice, etc.

- E. Climate Change/Fire
  1. Changes to vegetation affecting surface foraging and water budget
  2. Impacts from weather extremes

direction in base-level cave streams. Unnatural sediment deposition may result in the decline in both the diversity and abundance of species in the cave aquatic ecosystem due to burial of vital rock-gravel habitats and preventing transport of organic matter from headwater inputs (Poulson 1992). Potential exists for contaminants to be introduced during hydrocarbon extraction.

In developed areas, including within parks, parking lot runoff laden with oil and heavy metals can pose a significant threat. Barr (1976) documented such contaminants entering Mammoth Cave's Historic Entrance from the Visitor Center parking lot. In response, the park installed parking lot filters in 2001, and these were moderately effective at reducing copper and zinc. Removal of diesel fuel from parking lot runoff was very effective (McMillan et al. 2013).

Most water borne contaminant transfer occurs during flood pulses; at low flow cave waters often have no detectable pollution. This makes contaminant monitoring difficult in many cases. For monitoring purposes, a distorted cave community composition expresses a "memory" that provides a signature of the contaminant class that predominates during floods and indicates the extent of overall degradation.

An overarching threat is climate change. Climate changes can affect the nutrient input into caves, and thus the life in them. In addition, many cave species have adapted to live in a habitat with very small fluctuations in temperature and humidity. Climate change may cause caves to become warmer and drier. It could also increase flooding and erosion, as well as other disturbance events. Climate change may even cause shifts in the range of bat species, which could have a direct effect on nutrient input and cave ecosystems.

Over time there have been many changes made to cave entrances in park caves for a variety of reasons. These have been classified using the best available information (Olson et al. 1997). Disturbance to wildlife, especially hibernating bats, can have serious effects from depletion of fat reserves[1]. For this reason, bat hibernacula are off limits for human entry, except for monitoring, during the hibernation period. Disturbance to other keystone species such as woodrats could affect not only these species, but the communities that are supported by their guano.

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[1] Bats are highly adapted to particular temperatures for successful hibernation. Changes in airflow and temperature can often drive out bats. Rafinesque Hall in Historic Mammoth Cave used to be home to a large number of hibernating bats, particularly Indiana bats and little brown bats, as evidenced by bones, paleofeces, and staining on walls and ceilings. Changes to the entrance to accommodate saltpeter mining and tourism, and possible blockage of a small natural entrance in the area, caused the temperature to increase 4-10° C making the roost unsuitable for these bats; they abandoned what had been a very successful roost to perhaps a million bats.

Heat from high intensity lighting can dry areas that would have remained moist. As the temperature rises, relative humidity drops. Adapted to humidity near saturation, cave life is highly vulnerable to desiccation compared to similar surface species, and mineral deposition may also be altered. Another major consideration in cave lighting design is the growth of photosynthetic organisms, alien to cave ecosystems. Their presence and the chemical measures used to control their growth constitute a major distortion to cave ecosystems (Olson 2002, Olson 2006).

1.3 Introduction to Cave Ecology

Cave ecology is the study of how cave biota interacts with each other and their environment.

1.3.1 Ecological Classification of Cave Organisms

There are numerous systems that have been developed for classifying cave organisms. The most widespread system, and most familiar to natural resources managers, classifies organisms into four categories (Table 2).

Table 1. Cave Organism Classification from least cave adapted to most cave adapted.

Accidentals	Accidentals are organisms that find themselves in caves by accident. These include everything from a turtle being washed in during a spring flood to an unfortunate cow falling into a pit. They have no adaptations to the cave and usually die, contributing nutrients to the food base.
Trogloxenes	Trogloxenes (cave-foreigners or cave-guests) are species that use caves, but are also found in other locations. Common trogloxenes include bats and some cave crickets, like *Ceuthophilus* spp., which only use caves as a roost or to overwinter, and a frog or snake seeking the cool of an entrance on a hot summer day,
Troglophiles	Troglophiles (cave-lovers) are animals that use the cave for most parts of their life cycle, but have to return to the surface for some purpose, like feeding or reproduction. Some cave crickets, like *Hadenoecus spp.*, are troglophiles. They reproduce entirely within the cave, but leave at night to feed on the surface.
Troglobites	Troglobites (cave-life) are limited to caves and similar environments. The most extreme forms show adaptations to the cave environment such as reduced eyes and pigmentation. They complete their entire life cycle within the cave. We sometimes separate terrestrial troglobites and aquatic stygobites.

These four categories are simplistic, arbitrary boxes that facilitate better understanding of cave ecology, and also are somewhat dated terminology. Nonetheless, we will use these terms as they are most efficient for communicating basic cave ecology concepts.

Some other classifications of cave organisms cave resource managers may encounter include:

Edaphobites -- Soil inhabiting organisms that may also be encountered in caves, but which are more typical of the general soil environment.

Guanophiles -- Animals associated with accumulations of guano, but not normally found in other settings – most typically, we think of the large numbers of invertebrates that accumulate on mounds of bat guano below larger bat roost sites in caves.

Stygophiles & Stygobites -- These terms are sometimes used to refer to aquatic troglophiles and troglobites.

An entirely different approach to classifying cave organisms is based upon their trophic position: detritovores, omnivores, carnivores, etc. We'll take this up a little later in discussing trophic structure.

1.3.2 Cave Habitats

Many habitat types occur in caves. A variety of environmental parameters that influence the nature of specific habitats overlay the structural habitat types discussed below.

Zonation

Physical conditions change as you move deeper into a cave. As you enter a cave there is often a noticeable increase in humidity and a change in temperature. It gets darker quickly until there is complete darkness. This zonation begins with the entrance zone, with surface-modified conditions, through a twilight or transition zone into the deep cave, where we encounter true cave conditions of nearly constant temperature and high humidity in total darkness. The transition zone has greater species diversity since it includes organisms found in both entrance and deep cave zones.

The constant-temperature zone tends to closely mirror the mean annual surface temperature. Between the constant temperature zone and the ambient surface temperature exists the dynamic variable temperature zone. This zone is generally thought of as a continuous gradient of temperatures between the constant temperature zone and the ambient surface temperature; however, this may not be the case when strong weather patterns rapidly alter ambient surface temperature. Passage morphology and types of cave winds (chimney effect vs. barometric) will influence the shape and extent of this zone. Populations of animals may change in the entrance and variable temperature transition zone depending on the season, while the species in the deep or constant temperature zone do not change much. Because surface conditions in more tropical areas are much more constant, tropical caves also have fewer seasonal differences.

In aquatic environments, temperature zonation is much less extreme since water temperature changes slowly. In summer, water may enter the cave only a few degrees warmer, and may adjust to match ambient cave temperature as quickly as the twilight zone. In winter, the water entering the cave may be slightly cooler, but is at cave temperature by the end of the twilight zone. Because water flow is quick and turbulent over long distances, there are only subtle physical differences and gradients in aquatic environments in caves. The phreatic zone (deep, constant water) includes permanent groundwater environments that are often accessible only by wells or diving . In upper level vadose (temporary and/or shallow water) pools and seeps we find short-lived species like isopods, amphipods, and planarians. In lower level vadose zones there are longer lived crayfish, shrimp, and cavefish. In general, animal species using the same foods in water are less diverse, but larger, and with more troglomorphic adaptations for energy conservation than species in adjacent terrestrial environments.

Light

Moving from the cave entrance to the deep cave environment, available light changes from conditions similar to the surface, through very dim light, to complete darkness (if the cave is long and/or deep enough). In the entrance and twilight zones, the presence of light allows some plant species to persist, with cyanobacteria (blue-green bacteria) growing in areas with the lowest levels of light. Similarly, in commercial caves, lighting used to highlight cave features for visitors may produce sufficient light to allow the growth of mosses and algae. Even in the deep twilight zone, the dim light may be enough for certain animal species to take advantage of the protected cave environment. For example, in many cave entrances, birds may be found nesting in sheltered areas. When colonial birds nest in cave entrances, their guano can also be an important source of nutrient inputs into caves. The complete darkness deeper in the caves give an advantage to those species, especially troglobites, which have adaptations that allow them to better sense their surroundings and detect food, mates, and preferred habitats.

Humidity

Just as light varies from the entrance to the deep cave, humidity also varies. Generally (and there are a variety of exceptions), deep cave environments tend to have very stable humidity levels, and relative humidity routinely exceeds 99%. Adaptations needed to maintain moisture may not be retained by troglobites, making these species vulnerable to abrupt changes in the humidity of their environment. For example, when a new entrance to a cave is created (e.g., valley wall collapse, new sinkhole formation, or excavation by humans) the change in airflow could result in a drastic reduction in relative humidity and subsequent impact to the cave biota. Small changes have effects over a long distance. Smaller caves and caves with more than one entrance tend to be much drier than similar caves with only a single entrance.

Temperature

Temperature is another environmental parameter affecting cave habitats. In a “typical” cave, the deep cave temperature is about equal to the mean annual surface temperature where the cave is located. Caves in southern Arizona are thus much warmer than caves in Montana, and, similarly, higher elevation caves tend to be colder than lower elevation caves. Moving closer to the cave entrance, however, cave temperatures increasingly fluctuate with surface temperatures. Some species of bats, such as the big brown bat, select overwintering sites particularly close to the cave entrance where temperatures are cold, therefore habitat requirements may vary. Other species have differing thermal requirements. The structure of the cave also influences the cave temperature. A high dome may serve as a warm air trap, which can be further warmed by colonial bats. Pits or low areas with no airflow outlet may create cold air traps, resulting in the presence of ice year round and providing habitat for cold-adapted animals.

Gases

Oxygen and carbon dioxide, as well as other gases, may also vary throughout caves. Where large quantities of organic debris accumulate in dead-end pits or are washed up against a sump or sediment plug where there is little air circulation, carbon dioxide (and potentially, but less likely, hydrogen sulfide and methane) can build up to levels that may be lethal to humans and other mammals. Invertebrates, with their reduced metabolic demands, may find such habitats perfectly suitable.

Water

As for all life forms, water is very important for cave organisms. Water defines many habitats, including cave streams, drips, drip pools, and seeps. These all form habitats for aquatic organisms. Seasonal inundation and flooding also help define the parameters of subterranean existence. Water or moisture levels help determine who can and cannot live in a particular setting – too dry, for example, and a cave cricket egg laid in the substrate may fail to hatch. Too wet and the same egg suffocates. In addition, even the smallest amount of water, such as drip water, can bring carbon and nitrogen into caves.

Morphology of the cave passage

The form (or morphology) of the cave passage also affects the distribution of species. An abundance of wall ledges and ceiling cracks might mean there is suitable habitat for woodrats to nest in areas relatively inaccessible to potential predators. Low ceiling heights commonly make for poor roost sites for bats – threats from predators such as raccoons (which could easily reach up and grab hibernating bats) and from flooding make these sites unsuitable. Cave domes can make excellent microenvironments for bats.

Substrate

The substrate of the cave floor can also provide a variety of habitats. For example, dry, rocky areas with sufficient organic debris provide shelter for spiders under rocks, waiting to prey upon smaller animals feeding on organic debris. Bare bedrock substrates, perhaps scoured by floodwaters in the past, may provide few microhabitats and appear fairly uninteresting; however exposed bedrock provides essential nutrients to the cave ecosystem that can be mobilized by microbial activity. Tiny drip pools less than an inch across may contain ostracods (seed shrimp, commonly less than 1/16th of an inch long) swimming in their relative depths, and springtails and mites may be found on the surface of such tiny pools.

Connectivity

In some caves that are developed near the land surface with relatively little overburden, the connectivity of the cave with the surface influences habitat and cave life. For example, tree roots can penetrate into the cave through cracks in the overlying bedrock, providing an unusually direct connection between sunlight energy captured by living plants and deep cave troglobites. Hawaiian lava tube caves are well known for this type of habitat, which harbors several endemic troglobitic species. Seepage of overlying or nearby water through tiny cracks may add nutrients to a cave.

1.3.3 Ecosystem trophic structure and energy sources

Typical cave ecosystems are decomposer ecosystems (Figures 3 & 4). In the absence of solar energy, these ecosystems depend upon organic materials which fall, blow, wash, wander, or are otherwise brought into caves. This plant and animal material dies (if it has not already), and a variety of fungi and bacteria begin the process of breaking down this material. This surface-derived organic material, perhaps a larger vertebrate that has fallen into a pit entrance or washed into a stream cave, can be consumed by larger organisms, such as invertebrates. The bacteria and fungi are fed upon by small invertebrates such as springtails and millipedes, which feed at the lowest trophic levels. These, in turn may fall prey to larger invertebrates – spiders, harvestmen, beetles, etc., and in situations where still larger predators – vertebrates such as cave fish or salamanders – are present, the various invertebrates can fall prey to these larger organisms (Figure 6). In most cave settings, larger animals which would form still higher trophic levels do not exist. It should be emphasized again that compared to surface habitats, caves have low biodiversity and a simplified trophic structure.

The above paragraph describes a typical trophic structure, but there are many variations. A few caves have novel energy sources. For example, upwelling deep waters may contain high levels of sulfur, which can be broken down by certain microorganisms that oxidize sulfur compounds. In turn, aquatic and terrestrial invertebrates can graze upon these microbes as an energy source, forming an ecosystem based on an energy source other than sunlight.

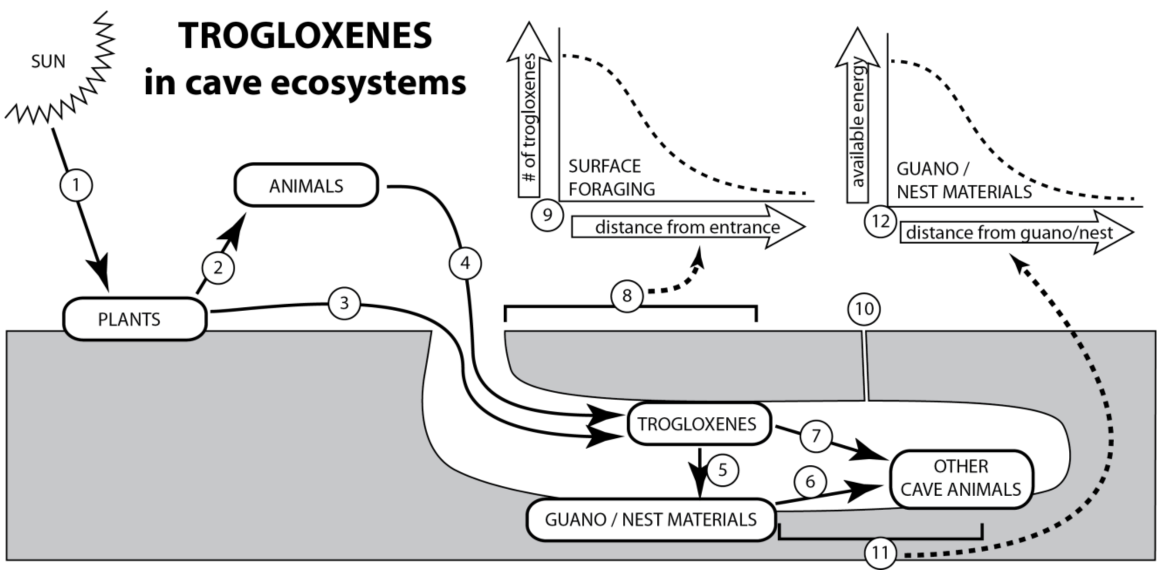

Figure 4. Energy entering cave by action of trogloxenes. Illustration by Steve Taylor.

1. Energy from sunlight converts to plant biomass;
2. Energy transfer to above-ground animals as they eat plants;
3. Surface foraging trogloxenes feed on plants, organic debris;
4. Surface foraging animals feed on animals (such as bats feeding on flying insects);
5. Nesting material, feces (guano), &/or food stores or caches transfer nutrients to the cave;
6. Other animals in the caves feed on the organic material brought into the cave by trogloxenes, or on the fungi & bacteria growing on organic materials;
7. Bodies, eggs, & young of trogloxenes serve as energy for other cave animals;
8. Foraging range is how far trogloxenes travel from cave to feed;

9. We expect higher numbers of trogloxenes closer to cave entrances;

10. Sometimes cave entrances are too small for humans to notice, but these can be used by some trogloxenes (mice, crickets, etc.);

11. Abundance and diversity of cave animals drops with increasing distance from guano &/or nest materials;

12. High concentrations of guano, such as at bat roosts, provide lots of energy, but the available energy decreases with increasing distance from the source.

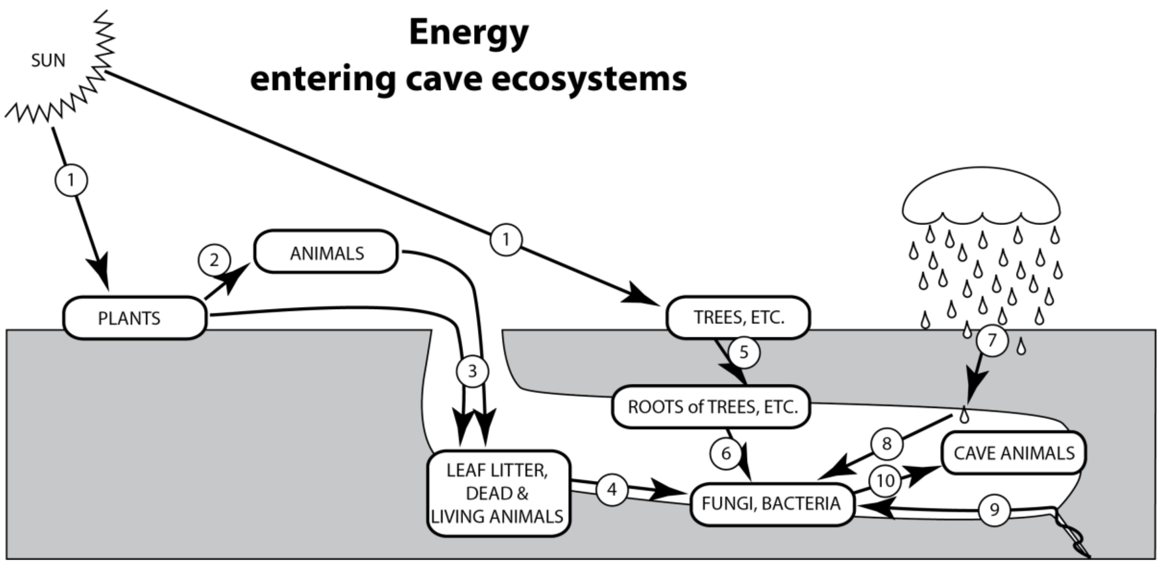

Figure 5. Energy entering caves, excluding trogloxenes (Figure 4). Illustration by Steve Taylor.

1. Energy from sunlight converts to plant biomass;

2. Energy transfer to above-ground animals;

3. Plant material falls, blows or is washed into caves, or may be brought in by animals. animals fall or wander into caves, or may be washed in during floods or brought in by other animals;

4. Plant and animal material broken down by fungi and bacterial;

5. Roots trees and other larger plants above cave may penetrate into cave;

6. Fungi, bacterial and cave animals feed on live and dead roots penetrating into cave;

7. Water percolates through leaf litter and soil, and may transport organic molecules and fine particulates into cave as drip water;

8. Fungi and bacterial utilize organic material in drip water as an energy source;

9. Inorganic energy sources, such as high-sulfur groundwater, are occasionally available in caves – bacteria can utilize these as a source of energy;

10. Small cave animals feed on bacterial and fungi, larger cave animals may feed on the smaller species.

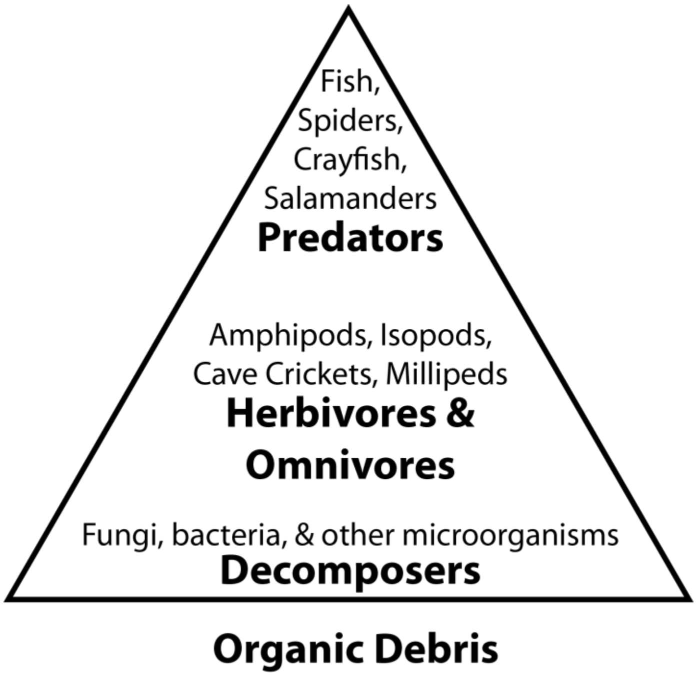

Figure 6. Illustration of cave food pyramid.

Cave ecosystems do not occur in isolation from the surrounding landscape as diagramed in Figure 7. Each component is shown as an oval which overlaps adjacent components, providing transition zones that have conditions and populations from all overlapping areas. Cave terrestrial ecosystems interact with adjacent cave aquatic systems, which can be influenced by underlying groundwater, epigean (surface) flowing water (lotic) and bodies of water (lentic). Between the cave terrestrial system and surface terrestrial systems are edaphic or soil systems. Soils modify water seeping through them before it enters the cave. Formation of caves is more rapid in areas with overlying organic soils due to production of more acids by microorganisms. Under the soil is the epikarst ("upon the karst") with a transition between soil and bedrock. This transition zone is often fractured bedrock, providing an MSS (*Milleu souterrain superficial*, as described in French who were the first to study it, or mesovoid shallow substratum (www.nsm.buffalo.edu/Research/SPELEOBIOLOGY_NOTES/index.php/Speleo/article/view/19/21) The MSS is a transition zone where you can often find both epigean- and cave-adapted animals.

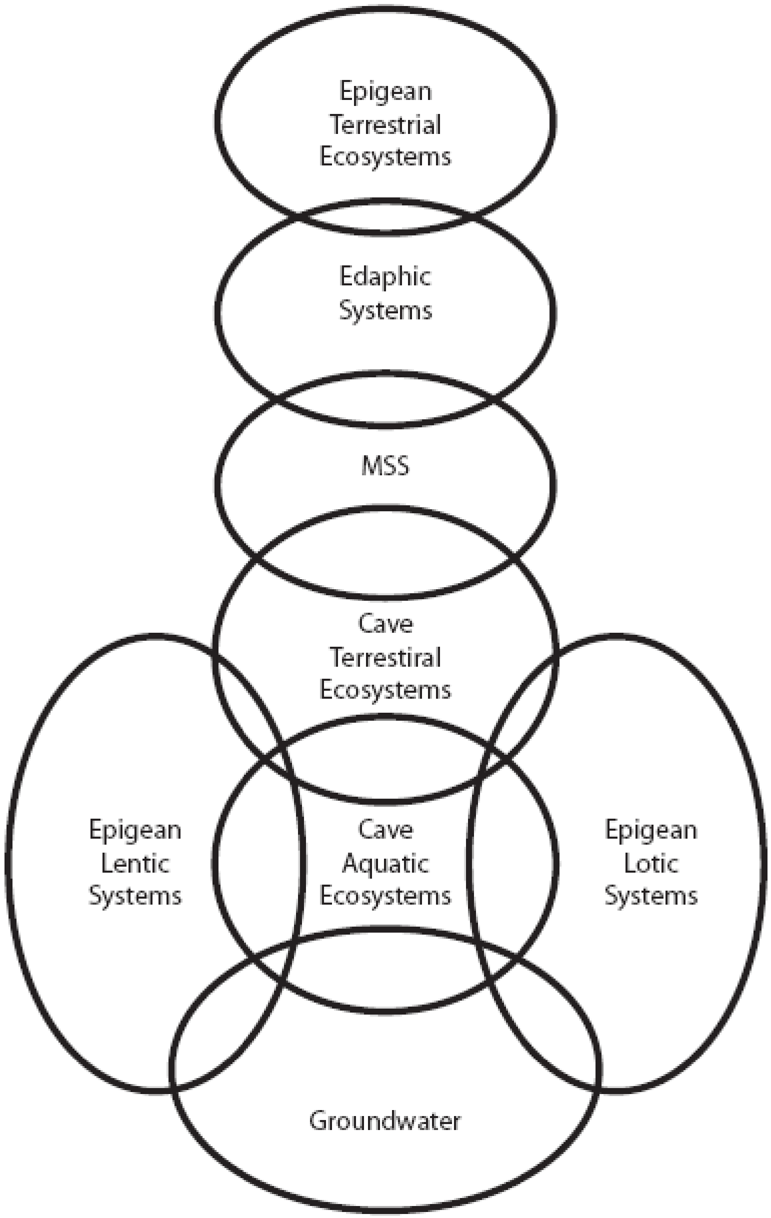

Figure 7. Diagram of general relationships between cave ecosystems and the landscape.

1.4 Overview of NPS Cave Resources

NPS sites contain a wide variety of cave types, and not all are part of a karst system. Non-karst caves include lava tubes, erosion caves, tectonic caves, talus caves, ice caves, and sea caves. This section describes the genesis of various types of caves as well as the ecology within them.

1.4.1 Solution Caves

Solution caves, sometimes called karst caves, form by the dissolving action of subsurface water as it seeps or flows through voids or cracks in soluble bedrock. The openings are enlarged over time into cave passages. These caves form by dissolution, a geochemical process by which water dissolves the rock and carries away the dissolved material. The water that forms solution caves usually has acidic or weakly acidic properties, which allows it to dissolve the bedrock more readily. The acidity comes from the natural acidity of rainwater, enhanced by microbial activity of the overlying soils or driven by microbial interactions with local geochemistry, as in the case of hypogenic caves.

Epigenic caves are formed by surface water sinking underground and dissolving rock. In solution caves with epigenic origins, the oldest passages are closer to the surface, and newer passages are closer to the water table. Hypogenic caves are formed by groundwater rising from below. The dissolving action in hypogenic systems is oftentimes enhanced by the mixing of waters of different chemistries.

Solution caves may also be formed by the action of sulfuric acid. The sulfuric acid is usually formed from hydrogen sulfide present in groundwater or seepage from fossil fuels. The H_2S is converted to sulfuric acid abiotically or through the growth of sulfur oxidizing bacteria using it as a source of energy (Engel, Stern, and Bennet 2004). This sulfuric acid speleogenesis is present in caves like Carlsbad Caverns and Lechuguilla Cave.

Solution caves are often found in limestone, but can also exist in dolomite, gypsum, marble, or any other soluble rock. In the National Park System, there are over 2,000 documented solution caves, distributed widely across the United States. Notable examples of NPS units containing solution caves include Buffalo National River, Carlsbad Caverns National Park, Grand Canyon National Park, Great Basin National Park, Jewel Cave National Monument, Mammoth Cave National Park, Oregon Caves National Monument, Ozark National Scenic Riverways, Sequoia & Kings Canyon National Parks, and Wind Cave National Park.

The ecology of solution caves varies greatly from region to region. Solution caves often contain streams or pools that can provide optimal habitat for species that depend on water. The generally stable temperature and humidity regimes of most solution caves provide a sheltered environment for several species. For instance, bats, invertebrates, and microbiota are often found in solution caves.

1.4.2 Lava Caves

Lava caves (sometimes called lava tubes) form when flowing lava begins to cool. The outer lava cools and solidifies first, and as the molten lava within continues to flow and ultimately subsides, a hollow tube is formed. Lava caves are often quite shallow, with multiple skylight entrances where the flowing lava failed to form a continuous ceiling or the roof-rock collapsed after cooling completely. The structure of lava tubes can resemble that of some solutional caves, since the passages follow the course of the lava flow much as a stream cave will follow stream channels. In the National Park Service, lava caves are found in western NPS units such as Craters of the Moon National Monument, El Malpais National Monument, Lava Beds National Monument, and parks on the islands of Hawaii and Guam.

Lava tube ecology is very different from solution caves because the youngest passages are nearest the surface, whereas in a typical karst system, deeper passages are younger. Fauna in lava tubes are also transitory compared to karst caves. The shallow nature of most lava caves can provide for greater input of surface nutrients and more crossover between surface and subsurface species. Many lava caves contain extensive root systems that grow through cracks and pores in the ceiling, as surface plants seek out moisture in the caves below. The roots can themselves provide habitat for microorganisms and invertebrates.

1.4.3 Erosion Caves
Erosion caves form by the mechanical forces of moving water, and to a lesser extent, wind. They can be found in almost any rock type, but are most commonly found in rock highly vulnerable to erosion, such as sandstone. Erosion caves in the NPS units are found in the desert southwest, in coastal parks, and in parks with highly-erodible rock such as Badlands National Park and Death Valley National Park.

Erosion caves are generally not extensive systems, and are often small pockets or rock shelters. They can provide significant habitat for trogloxene species looking to escape harsh environmental conditions outside the caves.

1.4.4 Tectonic Caves
Tectonic caves form when large slabs of rock move apart during ground movement. They most commonly form during land sliding or subsidence events in jointed rock and can form large fissures. Tectonic caves can form in any type of rock, since their formation processes are unrelated to erosion or dissolution. In the National Park System, tectonic caves are typically found in high alpine regions of the West.

Tectonic caves are usually not extensive, but can form deep fissure pits in excess of 200 feet. They can be cold sinks, providing cool habitat in the summer for trogloxenes. They often hold ice and snow year round.

1.4.5 Talus Caves
Talus caves (or boulder caves) are voids between boulders that accumulate on steep slopes. Slabs of rock that have separated from the cliff face and accumulated at the base of the cliffs in piles are also considered talus caves. They are generally not extensive, but some very complex talus caves that are multiple kilometers in length have been documented. In the National Park System, talus caves are

found in parks with large boulder slopes, such as Pinnacles National Park, Yosemite National Park, and other mountainous regions of the West where vegetation is sparse.

Talus caves can provide habitat for a variety of species, including bats and ground-dwelling mammals such as marmots and pikas.

1.4.6 Glacier Caves

Glacier caves are caves that are formed by the melting of channels in ice caps or glaciers. The term “ice cave” is often applied more broadly to any cave that contains ice. The glacier caves referred to in this cave ecology framework are caves that are formed in ice. In the National Park System, glacier caves are found in Alaska and Washington.

The ecology of glacier caves is limited to adaptive species that can survive freezing temperatures and changing conditions. Microorganisms are known to inhabit many glacier caves worldwide, but life in NPS glacier caves has not yet been widely studied.

1.4.7 Sea Caves

Sea caves (also called littoral caves) are formed by erosive wave action in ocean coastal areas and sometimes along the shorelines of large lakes. Sea caves can have impressively large entrances, but usually are not long or extensive. Exceptions to this include Painted Cave in Channel Islands National Park, which is nearly a quarter-mile long and 100 feet wide. NPS sea caves have been documented in several coastal NPS units.

Sea caves can provide habitat for a wide variety of species that inhabit the littoral zone, including crabs, urchins, barnacles, and mussels. Sea cave species must be resistant to forceful wave action, and must be able to survive during periods of high and low tide.

1.4.8 Epikarst

The epikarst is a boundary between surface soils, underlying bedrock, and the cave. The epikarst often has a mixture of species found in both environments. The epikarst is also very important in aquatic habitats in caves because it is the source of most of the water from ceiling drips and in pools and seeps. Infiltration is slow, and the water chemistry is influenced by conditions in the epikarst.

1.5 Overview of NPS Cave Ecosystem Management Practices

NPS units follow overarching documents to manage the caves within their jurisdictions.

1.5.1 Authority and Policies

The management of caves and karst areas in the National Park System follows the NPS Mission and the 2006 NPS Management Policies, as well as the Federal Cave Resources Protection Act of 1988.

The National Park Service Mission

"...to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." (1916 Organic Act)

"The authorization of activities shall be construed and the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established..." (1978 Redwood Act amending the Organic Act)

The Federal Cave Resources Protection Act of 1988

The NPS follows the Federal Cave Resources Protection Act (FCRPA) of 1988, which in part, states: (1) significant caves on federal lands are an invaluable and irreplaceable part of the nation's natural heritage; and (2) in some instances, these significant caves are threatened due to improper use, increased recreational demand, urban spread, and a lack of specific statutory protection. The FCRPA regulations at 43 CFR § 37.11(d) state that "The policy of the National Park Service, pursuant to its Organic Act of 1916 (16 U.S.C. 1, et seq.) and Management Policies (Chapter 4:20, Dec. 1988), is that all caves are afforded protection and will be managed in compliance with approved resource management plans.

Accordingly, all caves on National Park Service administered lands are deemed to fall within the definition of 'significant cave.'" The purposes of the FCRPA are to: (1) secure, protect and preserve significant caves on federal lands for the perpetual use, enjoyment, and benefit of all people; and (2) foster increased cooperation and exchange of information between governmental authorities and those who use caves located on federal lands for scientific, educational, or recreational purposes. The FCRPA establishes that "It is the policy of the U.S. that Federal lands be managed in a manner which protects and maintains, to the extent practical, significant caves." In order to comply with the intent of the FCRPA, cave resources must be inventoried, or existing inventories used, to determine the significance of individual caves.

The FCRPA also contains a Freedom of Information Act (FOIA) exemption, addressing the confidentiality of information concerning the specific location of significant caves to ensure protection of the resource. The FCRPA states: "Information concerning the specific location of any significant cave may not be made available to the public under section 552 of Title 5, United States Code [FOIA] unless the Secretary determines that disclosure of such information would further the purposes of this chapter and would not create a substantive risk of harm, theft, or destruction of such cave." 16 U.S.C. § 4304(a).

Management Policies 2006

NPS units have management policies that guide management of caves:

Section 4.8.2.2

"As used here, the term "caves" includes karst (such as limestone and gypsum caves) and nonkarst caves (such as lava tubes, littoral caves, and talus caves). The Service will manage caves in accordance with approved cave management plans to perpetuate the natural systems associated with the caves, such as karst and other drainage patterns, air flows, mineral deposition, and plant and animal communities. Wilderness and cultural resources and values will also be protected.

Many caves or portions of caves contain fragile nonrenewable resources and have no natural restorative processes. In these cases, most impacts are cumulative and essentially permanent. As a result, no developments or uses, including those that allow for general public entry (such as pathways, lighting, and elevator shafts), will be allowed in, above, or adjacent to caves until it can be demonstrated that they will not unacceptably impact natural cave resources and conditions, including subsurface water movements, and that access will not result in unacceptable risks to public safety. Developments already in place above caves will be removed if they are impairing or threatening to impair natural conditions or resources.

Parks will manage the use of caves when such actions are required for the protection of cave resources or for human safety. Some caves or portions of caves may be managed exclusively for research, with access limited to permitted research personnel. In accordance with the Federal Cave Resource Protection Act of 1988, recreational use of undeveloped caves will be governed by a permit system, and cave use will be regulated or restricted if necessary to protect and preserve cave resources. Under 43 CFR Part 37 regulations for the act, all caves in the national park system are deemed to be significant. As further established by this act, specific locations of significant cave entrances may be kept confidential and exempted from FOIA requests."

1.5.2 Categories of Cave Management

Caves may be classified to help managers better understand at a glance what the cave contains. One such system is found in NPS-77, developed originally for use in Lincoln National Forest by Jerry Trout and for use in Carlsbad Caverns National Park by Ronal Kerbo. This system is in use by some cave parks, such as Sequoia/Kings Canyon (Sequoia and Kings Canyon National Parks Cave Management Plan 1998), while other classifications are used by some parks such as desired future conditions at Carlsbad Caverns National Park (Carlsbad Caverns National Park Cave and Karst Management Plan 2006).

The NPS-77 system consists of a three-element rating for each cave, which includes a) a numerical indication of management type, b) a capital letter indicating the resources in the cave, and c) a Roman numeral indicating a cave's hazard rating. The classifications may affect monitoring decisions such as prioritization of certain caves, not monitoring a cave due to hazard rating, or seasonal monitoring based on resource rating. See Appendix B for an example of cave classifications.

1.6 General Considerations for Inventory and Monitoring

Designing inventory and monitoring programs for cave ecosystems poses particular challenges: many cave species are rare and/or cryptic, and their distributions can be highly patchy and variable over time. Logistics of accessing sites can be complex, and observers must take unusual care to avoid damaging the ecosystems they are tasked with monitoring. Programs aimed at monitoring microbial species are particularly problematic, as the majority of microbial species (99.99%; (Amann et al. 1996)) cannot be studied using traditional culture techniques and instead require expensive and time-consuming molecular techniques.

In addition to cave-specific considerations, a good long-term monitoring program for any habitat:

- is careful not to over-collect sensitive species;
- provides useful information to conservation managers;
- can track either communities or single species;
- doesn't neglect rare species that are not protected under endangered species legislation, but also considers prioritizing common species for monitoring;
- can focus on either charismatic species or inconspicuous-but-ecologically-critical biota;
- doesn't limit itself to tracking species that may become extirpated early or do not follow general trends;
- addresses questions that have management solutions;
- considers the possibility of a shifted baseline in altered habitats;
- tracks metrics that are of interest to the general public; and,
- creates ground-breaking, publishable ecological data.

Of course, obtaining all of these ideals is almost always infeasible, but careful planning before initiating any inventory or monitoring program can maximize the benefit for the government funds dedicated to the program.is important that any Long-term monitoring program must be able to withstand changes in personnel and technology. Some critical steps for planning an inventory and monitoring program are:

1) identify management program goals and objectives,
2) determine if inventory or monitoring is most appropriate,
3) create a sampling design appropriate for the monitoring questions and objectives,
4) discuss precautions for field observers to carry out to minimize habitat damage,
5) describe appropriate staff qualification, and
6) create procedures to record, verify, analyze, interpret, and store data.

1.6.1 Setting Goals and Objectives

The overall purpose of natural resource monitoring in parks is to develop scientifically sound information on the current status and long term trends in the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. Use of monitoring information will increase confidence in managers' decisions and improve their ability to manage park resources, and will allow managers to confront and mitigate threats to the park and operate more effectively in legal and political arenas. To be effective, the monitoring program must be:

- relevant to current management issues as well as anticipate future issues based on current and potential threats to park resources,
- scientifically credible, produce data of known quality that are accessible to managers and researchers in a timely manner,
- be linked explicitly to management decision-making processes.

One of the most critical steps in designing a monitoring program or protocol is to clearly define the goals and objectives of the monitoring effort. Developing good management objectives lays the foundation for all succeeding management and monitoring efforts. Management objectives need to be clearly written descriptions of a measureable stand, desired state, threshold value, amount of change, or trend that you are striving to achieve for a particular population or habitat characteristic (Elzinga et al. 1998).

The Vital Signs Monitoring Program has been developed by the I&M Program to look at the most important focal resources to get a pulse of how the park unit is doing.

The five Goals of Vital Signs Monitoring are:

- Determine the status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
- Provide early warning of abnormal conditions of selected resources to help develop effective mitigation measures and reduce costs of management.
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments.
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment.
- Provide a means of measuring progress towards performance goals.

Monitoring objectives provide additional detail about what the monitoring program or sampling protocol will do. The monitoring objectives explain 'what the protocol will do', and they often put boundaries or limits on what will be included in the monitoring by specifying particular study areas, species, or measures. The following checklist of questions should be applied to the set of monitoring objectives to see if they meet the test:

- Are each of the objectives measureable?
- Are they achievable?
- Is the location or spatial bounds of the monitoring specified?
- Is the species or attribute being monitored specified?
- Will the reader be able to anticipate what the data will look like?

An effective set of monitoring objectives should meet the test of being realistic, specific, and measurable.

A primary objective of this Cave Ecology Inventory and Monitoring Framework is to determine variability and long-term trends in cave biota using summaries of descriptive statistics for selected parameters as explained in more detail in section 2.0.

Additional objectives of the Framework include helping cave managers prioritize monitoring activities and providing guidance on conducting in-cave monitoring work by promoting safe and sustainable methods. Ultimately, the principal goal of the Framework is to encourage cave managers to understand as much as possible about local cave ecology and threats to the biota supported by caves in order to make informed decisions geared towards cave conservation and protection of cave ecological systems.

1.6.2 Inventory or Monitoring?

Inventories are designed to determine the presence, spatial distribution, and/or abundance of a taxa or habitat, while monitoring programs seek to assess and detect change over time. Both of these efforts are different from traditional research, which typically seeks to unveil cause and effect relationships, and natural history studies, which seek to describe life histories of species or organizational structure of communities. While this document may suggest useful tools and references for conducting research or completing natural history studies for cave biota and habitats, inventory and monitoring are its primary foci.

Inventory and monitoring programs have different design criteria: while inventories often are designed to efficiently search for a target in space, monitoring programs must have a design that allows for successful detection of changes when they occur and minimize the chance that the program will conclude a change has taken place when no change has occurred. Both inventory and monitoring programs can focus on collecting qualitative data (for example, rapid assessment categorical “condition” information or photodocumentation), census data, or sampled data. For any of these types of data collection, articulated goals and objectives and attention to quality control are needed.

1.6.3 Sampling Design Considerations

Sampling designs answer questions such as: What metrics will be tracked? How many observations are needed each season to be able to track changes over time (keeping in mind that there seasonal variations may be muted or nonexistent in caves)? Where do staff make observations? How frequently and in what seasons should observations be made? What equipment or technique will be used to standardize observations?

The answer to the question *What metrics will be tracked?* depends, of course, on the inventory or monitoring question(s). However some metrics provide better information with fewer superfluous data points than others. Some considerations when choosing metrics for inventory and monitoring:

- metric should be sensitive to change with alterations in the environment;
- metric response should be within management-relevant timeframes;
- metric should be affordable to measure;
- the potential for discrepancies between observers should be acceptable;
- when or if the metric changes, the resulting data should be meaningful, biologically interpretable, and useful for formulating a management response.

Questions include:

- How many observations are needed?
- Where and how frequently should observations be made?
- Are observations dependent on the desired minimum detectable change, the tolerance for sampling error, and variability in the environment?
- When do qualitative methods suffice rather than quantitative methods?

In general, the higher the environmental variability, the less ability a monitoring program will have to be able to detect small changes with high confidence. The minimum detectable change desired by a monitoring program should be identified before finalizing a sampling design. This parameter should be set to be fiscally realistic, biologically significant, and sensitive enough to inform management. For example, detecting a 2% change in the abundance of a population may be both cost-prohibitive with respect to the number of samples needed (if feasible at all) and less than biologically significant. On the other hand, a protocol which could only detect an 80% or greater decline in a population may be inexpensive, but would be inadequate for providing timely information to managers.

Similarly, tolerance for sampling error must be fiscally realistic and also provide managers with reasonable certainty about the results of the monitoring program. As a general guideline for a starting place, a 10% chance of error due to sampling bias (i.e., either a “type I” or “type II” statistical error) is an acceptable risk for many monitoring objectives. However, this threshold may be lower for very high value resources (where the cost of making a poor management decision due to sampling error is high), or, more likely the threshold may be higher in cases for monitoring targets for which designing a monitoring program which will yield a 10% sampling error rate is infeasible, due to the high number of observations required.

The ability to design a sampling program to meet minimum detectable change and sampling error objectives is heavily dependent on data variability and available monitoring techniques: proposed monitoring programs will need to be evaluated through a pilot sampling period. If pilot data are highly variable then the stated objectives may not be achievable. In this case either objectives will need to be less stringent or the sampling protocol will need to be revised.

Because time and money are finite resources among all NPS units, resource managers will most likely have to monitor a representative sample of caves from their available pool of caves. Thus, each monitoring cave must be carefully chosen to maximize the amount of information gained as a function of time spent in the field while minimizing risks to personnel and resources. Caves with existing monitoring programs that could be linked and/or co-located sampling sites are preferred over caves without extant monitoring programs. In Appendix C, we show a process to select monitoring caves that is useful to consider regardless of whether or not the NPS unit in question is densely populated with caves. In section 3.0, we provide a flowchart for managers to follow to help decide what to monitor.

1.7 Cave Ecological Inventory and Monitoring Currently in Place

Below are some examples of cave ecology currently being done in NPS units on a regular basis. These efforts are funded primarily by I&M, Servicewide Comprehensive Call, and park base funds. Many other NPS sites also have researchers actively studying cave ecology.

1.7.1 Mammoth Cave National Park

Cave ecological monitoring at Mammoth Cave National Park being conducted by the Cumberland Piedmont Inventory and Monitoring Network includes six "vital signs." These include: 1) cave crickets, 2) Allegheny woodrats, 3) cave bats, 4) cave aquatic biota, 5) cave meteorology (in conjunction with cave crickets and cave bats), and 6) cave water quality and quantity (in conjunction with cave aquatic biota). The *cave cricket* and *Allegheny woodrats* monitoring protocols were peer reviewed, approved, and implemented from 2005-08 (woodrats) and 2006-08 (crickets). They are undergoing major revisions and subsequent peer review prior to resuming monitoring in 2014. Cave cricket populations will be monitored at six developed caves and seven undeveloped caves using strip adaptive cluster sampling. Woodrat populations will be monitored at 75 cave entrances (including nine developed caves) using live trapping and occupancy estimation. Development of the *cave bats* and *cave aquatic biota* protocols began in 2012. These protocols are scheduled for peer review, approval, and implementation in 2014. Summer population of cave-dwelling bats will be monitored via exit counts at approximately 20 cave entrances, while winter populations of bats will be monitored via internal counts with the use of photography at approximately 10 hibernacula caves. Cave aquatic biota will be monitored along 10 reaches of subterranean rivers using visual surveys and occupancy estimation and modeling. *Cave water quality and quantity* monitoring at Mammoth Cave National Park was included in a comprehensive water quality and quantity monitoring protocol peer reviewed, approved, and implemented in 2005 (ongoing). Elements of this protocol will be incorporated into the cave aquatic biota protocol. A protocol for monitoring *cave meteorology* was peer reviewed and approved for implementation in 2009. Portions of this protocol will be incorporated into the cave crickets and cave bats protocols. See http://science.nature.nps.gov/im/units/cupn/monitor/index.cfm for the most current protocols.

1.7.2 Lava Beds and Oregon Caves National Monuments

The Cave Entrance Community and Cave Environment Long-Term Monitoring Protocol is a peer-reviewed protocol of the Klamath Inventory and Monitoring Network (Krejca et al. forthcoming). The protocol is shared between Lava Beds National Monument and Oregon Caves National Monument, the two cave parks in the Klamath Network. This long-term cave monitoring effort was developed from 2008-2012 (after "cave entrance communities" and "environmental conditions in caves" were chosen as Vital Signs for the Klamath Network) and officially implemented starting in

2012. The protocol focuses on seven parameters that were chosen based on their significance as cave resources or their influence on the integrity of the cave ecological system. The parameters include 1) cave meteorology, 2) ice and water levels, 3) human visitation, 4) cave entrance vegetation, 5) bat populations, 6) scat and visible organics deposition, and 7) cave invertebrates. Monitoring is implemented in 31 caves at Lava Beds N.M. and in two caves at Oregon Caves N.M. The majority of the 31 Lava Beds caves were chosen through a stratified random sample (from over 700 caves), with the exception of a small set of hand-chosen caves selected to ensure inclusion of sample sites containing hibernating bat populations and year-round ice resources. The two Oregon Caves N.M. caves were subjectively (not randomly) chosen from the six caves in the monument, with a major monitoring focus on the approximately three-mile long Oregon Cave and a lesser focus on one of the five small caves (< 200 ft long) in the monument.

In addition to the Klamath Network cave monitoring protocol, Lava Beds and Oregon Caves have long histories of monitoring ecological parameters, including bat populations and cave invertebrates. As of 2012, Lava Beds has an active bat monitoring program that includes Standard Operating Procedures (SOPs) specific to winter hibernacula surveys, summer maternity colony searches, evening emergence counts, and acoustic monitoring. These monitoring efforts primarily focus on Townsend's big-eared bats *(Corynorhinus townsendii)*, pallid bats *(Antrozous pallidus)*, and Brazilian free-tailed bats *(Tadarida brasiliensis)*, though acoustic methods are used to collect data on all 14 bat species at Lava Beds. Both monuments have engaged in short-term (1-2 years) cave invertebrate monitoring projects, though long-term monitoring of invertebrate communities will follow the Klamath Network protocol. Oregon Caves also conducts year-round "critter surveys" along the main tour trail in Oregon Cave. Critter surveys are conducted with varying frequency dependent on the season (ranging from weekly during summer to one survey per winter) and aimed at recording all detectable vertebrate and invertebrate biota (e.g., bats, moths, harvestmen, crickets) observed while walking the tour route.

1.7.3 Lehman Cave (Great Basin National Park)

Great Basin National Park had cave biologists Steve Taylor, Jean Krejca, and Mike Slay conduct a bioinventory of Lehman Cave in 2006 with the assistance of park staff. Following that initial effort, it was decided to monitor the cave monthly to determine the seasonality in the cave of different organisms. Those results are reported in Taylor et al. (2008). Park staff have continued monitoring cave biota on a quarterly basis at fourteen paired (on-trail and off-trail) stations in various areas of the cave that have been classified as high use, medium use, low use, and very low use. Bait is placed at each station, and 24 hours later, a 1-m radius is searched. Microhabit data including air temperature, soil temperature, relative humidity, dry bulb, and wet bulb, are recorded. Analysis of six plus-years of data has begun.

During the summer of 2013, wildlife cameras were placed at the entrance of 11 caves to determine wildlife use of cave entrances. The most abundant species were *Peromyscus* spp., humans, chipmunks, packrats, and squirrels. In addition, other species observed in cave entrances included cottontail rabbits, bats, skunks, foxes, insects, birds, and domestic dogs (Baker forthcoming). Additional cave entrance monitoring using wildlife cameras is planned.

1.7.4 Jewel Cave National Monument and Wind Cave National Park

John Moore conducted biological inventories in Jewel Cave and Wind Cave from 1992 to 1995 (1996). He concluded that due to their relative isolation from the surface (long cave systems with few, small entrances and little energy input), most macro-biota is found near sources of organic input, such as entrances and tour routes. However, the lakes in Wind Cave have been found to be teaming with unusual microbial life (Hazel Barton, pers. comm. 2013).

Jewel Cave National Monument conducts an annual hibernating bat count in passages near the Historic Entrance, using a methodology established in 1992 (Austin 2013). Bats are identified and counted by genus, and temperature and humidity measurements are recorded in each of the 24 search areas. The cave is one of the largest hibernacula in the world for Townsend’s big-eared bats, with an average of 832 individuals.

1.7.5 Chickamauga and Chattanooga National Military Park, Cumberland Gap National Historical Park, and Russell Cave National Monument

The Cumberland Piedmont Inventory and Monitoring Network Cave is in the process of initiating cave ecological monitoring at four network parks with significant cave resources. These units include Chickamauga and Chattanooga National Military Park, Cumberland Gap National Historical Park, Russell Cave National Monument, and Mammoth Cave National Park (previously mentioned). Vital Signs being monitored in the first three parks listed above include: 1) cave bats, 2) cave aquatic biota, 3) cave meteorology (in conjunction with cave bats), and 4) cave water quality and quantity (in conjunction with cave aquatic biota). Development of the *cave bats* and *cave aquatic biota* protocols began in 2012. These protocols are scheduled for peer review, approval and implementation in 2014. Summer population of cave-dwelling bats will be monitored via exit counts at selected cave entrances at all three parks, while winter populations of bats will be monitored via internal counts with the use of photography at a subset of hibernacula caves on all three parks (Note: Cumberland Gap National Historical Park has an extant winter cave bat monitoring effort at two park caves that began in 1993). Cave aquatic biota will be monitored along subterranean rivers at Cumberland Gap National Historical Park and Russell Cave National Monument using visual surveys and occupancy estimation and modeling. *Cave water quality and quantity* monitoring at Cumberland Gap National Historical Park and Russell Cave National Monument was included in a comprehensive water quality and quantity monitoring protocol peer reviewed, approved, and implemented in 2005 (ongoing). Elements of this protocol will be incorporated into the cave aquatic biota protocol. A protocol for monitoring *cave meteorology* was peer reviewed and approved for implementation in 2009. Portions of this protocol will be incorporated into the cave bats protocol.

2.0 Potential Monitoring Targets for Cave Ecology Inventory and Monitoring

2.1 Overview

This section provides cave managers with examples of what can be monitored, divided into four main areas: terrestrial cave ecosystems, aquatic cave ecosystems, plants, and microbes.
Within each of these areas, potential targets are described and consideration is given to monitoring questions, focal species, techniques, sampling locations, and appropriate data analysis. In addition, references, related studies, and links to relevant monitoring protocols are provided. Appendix D provides an annotated list of protocols and SOPs already in place in parks. If using I&M funding, site specific I&M protocols resulting from the protocol framework (after review and approval), will still need to be reviewed according to procedures developed in each region. Well-developed methods identified in the protocol framework will not need additional review; however, requirements for review of developing methods and technologies will be up to the Regional I&M Program Manager.

2.1.1 Flagship, Umbrella, and Keystone Species

Terms often applied to species that are considered especially important are flagship, umbrella, and keystone species. These terms are not mutually exclusive.

A **flagship species** is a species chosen to represent an environmental cause, such as an ecosystem in need of conservation. These species are chosen for their vulnerability, attractiveness or distinctiveness in order to engender support and acknowledgment from the public at large. Thus, the concept of a flagship species holds that by giving publicity to a few key species, the support given to those species will successfully leverage conservation of entire ecosystems and all species contained therein. One example is the Indiana bat, a federally-endangered bat that hibernates in caves. By protecting it, the caves it uses are also protected, including the other lesser-known species that live in them. The bat is attractive to the public and helps to promote awareness of the importance of protecting hibernacula. Another example would be the Ozark hellbender (*Cryptobranchus alleganiensis*), a salamander found only in clear, cool waters in Missouri and Arkansas.

Umbrella species are species selected for making conservation related decisions, typically because protecting these species indirectly protects the many other species that make up the ecological community of its habitat. Two examples are predators that rely on prey they find in caves, the Tooth Cave pseudoscorpion (*Tartarocreagris texana*) and the cave crayfish (*Cambarus aculabrum*). If these predators are protected, then the habitat where they live and thus the prey they eat, are also protected.

A **keystone species** is a species that has a disproportionate effect on its environment relative to its abundance. Such species play a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community. An example is the woodrat (and in fact, many trogloxenes). Just one woodrat can provide a great deal of energy input for a cave, which then influences a great number of the biota that inhabit the cave.

All three of the above environmental surrogates can be representative of a range of species and habitats. Nonetheless, they still suffer from the ~~failing~~ failure to embrace the full range of microhabitats utilized by small invertebrate species (Samways 2007). Recent assessment of available data suggests that such indicator species (flagship, umbrella, and keystone species) may actually be unreliable as surrogates for biodiversity, and it is recommended that several complementary surrogates for biodiversity and environmental conditions should be selected (Gerlach et al. 2013).

2.1.2 Listed or other special interest species that are not keystones

Many cave and karst species have been listed by the US Fish and Wildlife Service as a Threatened or Endangered Species. Some of these include bats (e.g., Indiana bat, Ozark big-eared bat, Virginia big-eared bat), aquatic species (e.g., Alabama cavefish, Illinois cave amphipod, Kuai cave amphipod, Peck's cave amphipod, Tumbling Creek cavesnail, cave crayfish, Texas blind salamander, Squirrel Chimney cave shrimp), and terrestrial invertebrates (e.g., Coffin Cave mold beetle, Bee Creek Cave harvestman, Tooth Cave pseudoscorpion). (See http://ecos.fws.gov/tess_public/pub/listedAnimals.jsp for the complete list of threatened and endangered animals.)

Individual states often have their own threated and endangered species lists that include additional species. Other species may be of special interest to managers, for example if they are endemic to a national park.

The NPS is mandated to monitor endangered species in most instances. Monitoring techniques for listed species usually follows the recovery plan for that species. If no recovery plan is available, as for species of special interest, managers should think about the best way to monitor with the least amount of impact. Often cave biologists with expertise in that area can provide advice.

2.2 Terrestrial Cave Ecosystem

A terrestrial cave ecosystem can vary widely from one cave to another, and even within a single cave. Included in this section are taxa that are likely to be encountered, including bats, woodrats, birds, cave crickets, and cave obligate invertebrates. We also consider other wildlife use of caves.

Some inventory and monitoring components are nearly the same for all terrestrial taxa. We mention them here and then in the individual taxa sections point out any differences.

Dominant threats

Dominant threats to terrestrial cave organisms center around habitat (both in and above the cave). Habitat loss or impact may be caused by human disturbance (e.g., unmanaged visitation, intentional vandalism), in-cave development (e.g., cave infrastructure, lighting, chemical use), land use changes above caves, vegetation structure changes above caves (e.g., wildfires alter infiltration), sudden environmental changes (e.g., freezes, flash floods), and food source contamination from heavy metals and/or pesticides. Some of these threats can be mitigated through land management actions, while others may be not be possible to control, such as major environmental changes driven by climate change or natural processes. Other threats include increased predators (e.g., more urbanization so more feral cats) and invasive species above ground or underground that could affect food sources or habitat (e.g., fire ants, fungi, springtails.)

Potential inventory and monitoring questions

The list of questions related to terrestrial cave organisms and cave use is highly diverse and potentially endless, though most cave managers will likely find common ground in wanting to determine some basic information about local populations:

- What species are present in caves?
- What caves/sites do they use?
- When are they present (e.g., year-round vs. seasonally)?
- How many are there (population estimates)?
- What is their population status (e.g., stable, decreasing)?
- How does the population or activity change seasonally?
- What can be done to protect them?

More advanced questions may follow after managers have succeeded in answering some of the basics about local populations. Many of these questions may be beyond the scope of inventory and monitoring and enter the realm of research. Additional questions may include:

- What microclimate parameters are the species of interest selecting for, and how does this vary based on season/use (e.g., summer maternity use or winter hibernation in bats)?
- What physical or morphological characters are species selecting for, and how does this vary based on season/use (e.g., cold sinks, single vs. multiple entrances)?
- Is there any correlation between the species of interest use and level of development of a particular cave or cave area?

- How do changes in environmental factors (e.g., temperature, relative humidity, barometric pressure) due to development or modification (e.g., artificial entrances, trail construction, gates) affect species?
- How does land use above caves impact species of interest populations?
- Have populations / species composition changed over time (decadal or century scale using paleontological data)?

Potential focal species/sites

The focal species for monitoring will depend on the species present in the area, as well as the status (state or federal protection), significance (relative local importance of that species and if they are facing threats), and feasibility of monitoring for a particular species. In addition, documentation of sites critical to the life cycle of a particular population should necessitate prioritized monitoring and protection for that site. In most localities, multiple species will be present. Priorities for inventory and monitoring often depend on available resources and trained staff; however, strong consideration should be given to endangered species, abundant/detectable species (easier to monitor), and sites that are used by multiple species. These priority monitoring categories will likely overlap, and implementation of robust, long-term monitoring efforts and proper data analysis may reveal proxies for estimating the status or trend of interrelated monitoring groups.

Potential inventory & monitoring strategies

Answering inventory and monitoring questions related to terrestrial species requires following a strategy or combination of strategies. Monitoring generally falls into three strategy levels or categories:

1. **Presence/absence inventories/monitoring** is used to develop faunal or species lists, is useful for determining site occupancy and informing species protection efforts, and may be used as a strategy to inform ecological monitoring efforts.
2. **Population monitoring** may be based on in-cave surveys, emergence counts, or acoustic monitoring and informs long-term trends in the status of populations.
3. **Ecological monitoring** attempts to understand the dynamics of species behavior and dispersal, including the habitat preferences of the species of interest, the life cycle needs that correspond to those habitat preferences, and the temporal patterns (daily or seasonal) associated with those habitats.

Potential inventory and monitoring techniques

When choosing inventory and monitoring techniques, consideration should be given to how much disturbance to the species a particular method would potentially cause. Long-term monitoring should aim to be as unobtrusive as possible to avoid the risk of impacting population stability. Species protection is an overarching goal that monitoring can and should inform; monitoring should never jeopardize the protection of populations. More obtrusive methods may be warranted for short-term projects such as inventories and research, as long as the projects are aimed at gaining valuable information and are conducted by qualified professionals with a vested interest in minimizing disturbance to the species. Methods justified for short-term needs, though, should be discontinued with the conclusion of the project, and the results should be used to inform the development of sustainable long-term monitoring efforts that yield valuable data while minimizing disturbance. Additional important criteria of long-term monitoring includes producing quality, useful data based on methodology that is as consistent and repeatable as possible. These conditions are necessary for data collection and interpretation that yield results capable of answering monitoring questions with confidence.

2.2.1 Bats

Bats are strongly associated with caves, and cave-dwelling bats are indeed critical components of cave ecosystems. Bats are also extremely important contributors to terrestrial ecosystems. All bats utilize terrestrial environments for foraging and hunting, though only a portion of bat species occupies caves. Most cave-dwelling bats are generally considered trogloxenes, as they spend part of their life-cycle in caves. Of the 47 bat species that occur in the United States, a significant proportion are known to use caves during part of their life cycle for some purpose, though to varying degrees. The Bat Conservation International publication *Bats and Mines* (Tuttle and Taylor 1988) includes a list of bat species that use mines. While mine use and cave use are not necessarily interchangeable, the degree of habitat similarity and overlap of usage warrants inclusion of the table in this document (Table 6) and provides a starting point for determining potential for bat species to utilize caves. Uses of caves include maternity roosting, hibernation, night roosting, fall swarming, and/or mineral acquisition. The consistency of cave use among a species, however, may be quite variable regionally, depending on the availability and conditions of local cave habitat. For example, a species that exhibits a strong affinity for cave roosting in one geographic region may be entirely tree-dwelling in a different area. Even bat species that are usually classified as strictly tree-dwelling (e.g., hoary bats, silver-haired bats) may on rare occasions use cave habitat.

Cave-dwelling bats are important in providing nutrients to cave ecosystems that are generally nutrient poor. Bats introduce nutrients though guano deposition at roost sites and along flyways; bat guano may constitute the primary nutrient source for the system, providing the foundation for cave biological communities, including microbes, fungi, and invertebrates. In other caves, bat guano may be a minor, but still important, component of an already nutrient rich system. Given the energy contributions of bats to a cave ecosystem, bat protection efforts propagate down the food chain when biological communities are sustained through natural guano input. Cave-dwelling bats use caves for a significant part of their life cycle, but for feeding, bats must forage above ground, where they serve critical ecological roles. As part of the terrestrial ecosystem in the United States, bats are generally nocturnal and follow either insectivorous (insect-feeding) or nectarivorous (nectar-feeding) diets. In the tropics, frugivorous (fruit-eating) bats often use caves. Insectivorous bats are the most common types in the U.S., and their feeding behavior contributes to controlling certain insect populations and reducing agricultural pests, providing billions of dollars' worth of ecosystem services annually (Boyles et al. 2011). Nectarivorous bats are important in the southwestern U.S. for their role as pollinators of many desert plants, including cacti and agaves (Horner et al. 1998; Fleming et al. 2001). Given the importance of bats to both surface and subsurface ecosystems, and because many bat species rely on cave habitat for their survival, monitoring of bats and bat roosts is necessary for understanding the health of bat populations and protecting critical bat habitat. Bat monitoring can reveal the status and behavior of populations and contribute to bat protection efforts by identifying important bat sites and determining their time of use in bat life cycles.

Table 2. Species List of Bats that Use Mines (adapted from Table 1 in *Bats and Mines* [Tuttle and Taylor 1988])

Species	**Group Size**	**Range**	**Use Time**
Ghost-faced bat *Mormoops megalophylla*	Dozens to hundreds	AZ & TX	Year-round
California leaf-nosed bat *Macrotus californicus*	Dozens to over a thousand	AZ & southern CA & NV	Year-round
Mexican long-tongued bat *Choeronycteris mexicana*	A dozen or fewer	AZ & southern CA	Summer
Lesser long-nosed bat *Leptonycteris yerbabuenae*	Hundreds to thousands	AZ & NM	Summer
Greater (Mexican) long-nosed bat *Leptonycteris nivalis*	Hundreds to thousands	TX & NM	Summer
Southeastern bat *Myotis austroriparius*	Hundreds to thousands	Southeastern U.S.	Year-round
California bat *Myotis californicus*	Up to a hundred	Western U.S.	Year-round
Western small-footed bat *Myotis ciliolabrum*	Up to a hundred	Western U.S.	Year-round
Long-eared bat *Myotis evotis*	Dozens	Western U.S.	Year-round
Gray bat *Myotis grisescens*	Hundreds to 50,000 or more	Southeastern U.S.	Year-round
Eastern small-footed bat *Myotis leibii*	Dozens	Eastern U.S.	Winter
Little brown bat *Myotis lucifugus*	Hundreds to a million +	Northern U.S.	Year-round
Arizona bat *Myotis occultus*	Hundreds	Southwestern U.S.	Year-round
Northern long-eared bat *Myotis septentrionalis*	Hundreds to thousands	Eastern U.S.	Winter
Indiana bat *Myotis sodalis*	Hundreds to 100,000 or more	Eastern U.S.	Winter
Fringed bat *Myotis thysanodes*	Dozens to hundreds	Western U.S.	Year-round
Cave bat *Myotis velifer*	Hundreds to 100,000 or more	Southwestern U.S.	Year-round
Long-legged bat *Myotis volans*	Hundreds	Western U.S.	Year-round
Yuma bat *Myotis yumanensis*	Hundreds to thousands	Western U.S.	Year-round
Canyon bat *Parastrellus hesperus*	Dozens	Western U.S.	Year-round
Tri-colored bat *Perimyotis subflavus*	Dozens to thousands	Eastern U.S.	Winter
Big brown bat *Eptesicus fuscus*	Dozens to hundreds	North America	Year-round
Allen's big-eared bat *Idionycteris phyllotis*	Dozens to about two hundred	Mostly AZ, also parts of NV, CO	Year-round
Rafinesque's big-eared bat *Corynorhinus rafinesquii*	Dozens to several hundred	Southeastern U.S.	Year-round
Townsend's big-eared bat *C. townsendii townsendii*	Dozens to hundreds	Western U.S.	Year-round
Ozark big-eared bat *C. t. ingens*	Dozens to hundreds	Ozark Mountains	Year-round
Western big-eared bat *C. t. pallescens*	Dozens to thousands	Western U.S.	Year-round
Virginia big-eared bat *C. t. virginianus*	Dozens to thousands	KY, VA & WV	Year-round
Pallid bat *Antrozous pallidus*	Dozens to hundreds	Western U.S.	Year-round
Brazilian free-tailed bat *Tadarida brasiliensis*	Hundreds of thousands	Southwestern U.S. north to OR	Summer

The recent emergence of white-nose syndrome (WNS) (Blehert et al. 2009, Cryan et al. 2010) has become the single greatest threat to North American bat populations. Since 2006 over six million bats have died from infection with *Pseudogymnoascus destructans* (formerly *Geomyces destructans*), the fungus responsible for WNS. The unparalleled wildlife impact of WNS has placed greater emphasis on the need for bat monitoring methods capable of detecting long-term population impacts, which will help cave managers understand the current status of bat resources and provide a reference for measuring the potential effects of WNS. Bat monitoring and surveillance will increase the possibility of early detection of WNS (Duchamp et al. 2010) and offer the greatest chance for conservation measures based on current scientific knowledge. The example of WNS is a reminder that cave managers must be diligent in emphasizing responsible caving practices among all users (e.g., staff, researchers, volunteers, visitors) in regard to preventing the spread of invasive species through regular cleaning and disinfecting of cave gear.

<u>Potential focused inventory and monitoring questions</u>

In addition to the questions posed at the beginning of the Terrestrial Cave Ecology section, these questions may help managers better understand what bats are doing:

- Does roost switching occur during the winter hibernation season?
- Are seemingly separate summer maternity colonies actually distinct populations or do they interact with each other, and if so, to what degree?
- Does fall swarming occur, and if so, at what sites?

<u>Potential inventory and monitoring techniques</u>

Common techniques for inventory and monitoring of bats include:

- In-cave surveys
- Emergence counts
- Acoustic monitoring
- Capture and release
- Telemetry
- Other techniques

In-cave surveys

In-cave or internal surveys are often the most efficient and accurate means of assessing bat populations, provided that counts are conducted in a consistent manner by trained surveyors. For population monitoring of bat species that hibernate, winter surveys are the most reliable way of understanding abundance and population trends of these species. During hibernation, bats are immobile and easiest to count; also, because the bats are in torpor, they are less likely to be disturbed relative to more active times of the year. It is important to note, however, that the consequences of disturbance during hibernation are likely to be greater, as a bat aroused from torpor increases its metabolism and raises its body temperature, which is costly to the stored energy reserves bats rely on to survive the winter. Therefore, winter surveys should be scheduled at most once annually to prevent additional arousals and disturbance, and surveys should be conducted by personnel that are capable of quickly, quietly, and safely moving through the cave environment to minimize the amount of time in proximity to hibernating bats. For more cautionary guidance about bat censuses in caves, see Tuttle 2003.

In-cave surveys during summer months can also be valuable for tracking the activity and habitat preferences of maternity colonies (females and their pups) and individuals (often bachelor males). Because maternity colonies are extremely sensitive to intrusion and may even abandon their pups if disturbed repeatedly, in-cave summer surveys should not be utilized as a technique for population monitoring. Rather, these should be considered presence/absence surveys with the goal of tracking the movement and whereabouts of maternity colonies. Surveyors should always immediately leave the cave (or cave area) upon discovering a colony. The information gained from in-cave summer surveys is necessary for building an effective bat protection program centered around implementing cave closures for critical maternity sites.

In-cave surveys provide opportunities for collection of limited environmental data, such as temperature and relative humidity, using handheld climate meters. Another advantage of actively searching caves for bats includes the ability to document the type of cave use (e.g., hibernation, maternity roosting, night roosting), which may be based on direct observation of bats or observation of other bat signs, such as guano piles and accumulations of moth wings or other insect parts. Of course, in-cave surveys also present the potential of identifying bat species that use the site. Direct in-cave observation may be enough to confidently identify some bat species with easily recognizable diagnostic features, however, many bat species require handling and measurement or acoustic recording for definitive taxonomic identification. If species identification is not possible, direct observation resulting in identification to the genus or family level is still valuable information. Other in-cave bat signs may provide clues to species identification or type of use. Bat guano can be identified to some taxonomic level based on observation alone (e.g., size, color, insect parts, associated roost characteristics); with funding and proper expertise, genetic analysis of guano can be used to identify species. Concentrations of moth wings or other insect parts may indicate maternity colony roosts or night roosts of solitary bats.

Photography during in-cave surveys may be used to increase accuracy of counts when dealing with large clusters of bats, as is common in the eastern U.S. In this case, photography likely also improves bat conservation efforts by minimizing time spent in a roost (since the actual counting is conducted later via photo analysis). Photography also provides data on bat health by recording visual condition of bats; photographs have been used to help diagnose and characterize the presence of white-nose syndrome, for instance. The benefits of photography, however, should be carefully weighed against the potential for disturbance, and photography should only be employed when necessary. In western U.S. caves where large aggregations of bats are rare, the need for photography to improve count accuracy is rare and limited to large clusters that cannot be confidently counted through visual observation alone. In many western hibernacula that are dominated by numerous solitary bats and small clusters, a complete census based on photography would actually increase disturbance potential through excessive use of flashes and additional time spent in the cave.

All teams conducting in-cave surveys need to be experienced, organized, small, fast, and quiet. It is of utmost importance that bat disturbance be minimized to the degree possible while collecting survey data. In accordance, the frequency of surveys conducted at a particular site should be limited and combined with bat protection efforts (such as cave closures and education) to provide for undisturbed bat habitat and long-term population viability.

Emergence surveys

Emergence surveys, also known as outflight counts, are most often used to gauge population estimates of known summer maternity colonies. These surveys are a low-impact alternative to estimating population size of maternity colonies during in-cave surveys, and they may sometimes be more accurate. As discussed above, summer in-cave surveys are valuable for determining presence-absence of maternity colonies; however, it is nearly impossible to determine a reasonable colony population estimate via in-cave observation since colonies are easily disturbed and tend to disperse when approached. In-cave presence-absence surveys are important, though, for guiding site selection and timing of evening emergence surveys.

Relatively small colonies of a few hundred bats or less can be counted with emergence surveys, using direct observation to manually record all exits/entries. Larger colonies numbering in the thousands exceed the threshold of manual counting ability and necessitate more complex methods involving standard photography (Humphrey 1971, Cross 1989, McCracken 2003) or thermal imaging/infrared videography (Betke et al. 2008, Hristov 2010). Though emergence surveys are more accurate than in-cave estimations of summer colonies (and cause less disturbance), they are still estimates. Many factors affect the confidence in emergence survey results, most notably bat behavior and visibility. Erratic flight behavior, swooping in and out of entrances, and traveling in clusters or dense streams increase the difficulty level for surveyors. Behavioral characteristics are often predictable based on the species in question. Bat outflights usually occur at or near dusk, making visibility a significant problem affecting survey quality. This factor may also vary predictably based on species and area. Margins of error resulting from these factors will generally increase in direct proportion to population size, duration of outflight, and number of cave entrances; these variables describe the complexity of the survey (Thomas 2011).

Emergence surveys are generally most valuable when applied to a roost that is known to be occupied (or at least a roost in which occupancy is highly suspected), for the simple reason that some level of population data is guaranteed since a colony is known to be present. Surveying known roosts will ensure that colony size estimates for a particular site outnumber zero counts. Though zero counts confirm absence and add value to long-term knowledge of bat occupancy patterns and habitat preferences, they do not necessarily indicate that a cave is not ever utilized as a summer roost. Active summer bat colonies frequently roost switch among sites throughout the maternity season, and sites that may be used as critical habitat during a specific time of year or in response to specific climate conditions could be vacant for the rest of the year. For many summer roosts that are only occupied for a portion of the maternity season, random emergence surveys (without in-cave determination of occupancy) could yield zero counts, despite the importance of these sites as summer habitat. Repeated implementation and supplementation with in-cave surveys may be necessary to confirm a cave as a summer roost; therefore, management decisions related to summer bat monitoring and protection efforts should be based on conservative interpretations of data if site records are limited.

Acoustic monitoring

The field of acoustics has spurned major technological research and development in the application of acoustics for countless purposes, including wildlife monitoring, and monitoring of bats is certainly among the fields of wildlife study most buoyed by the assistance of acoustic technology. Current knowledge of bats throughout the world has grown substantially based on acoustic studies. All of the bat species occupying National Park Service sites in the U.S. (excluding some territories) rely on echolocation for navigation and feeding. This adaptation has rendered these bats well suited to their environment, and also well suited to be recorded by bat detectors and analyzed based on vocal characteristics. Acoustic monitoring of bats relies on identifying characteristic frequencies, shapes, and patterns of bat calls that are unique to species (or assemblage of species). Numerous acoustic devices have been developed and marketed for bat monitoring, along with software programs designed to analyze the calls recorded by acoustic bat detectors. These devices are widely divergent in application, data quality, cost, etc. In turn, comparing the results of acoustic monitoring efforts is extremely difficult due to the diversity of acoustic monitoring equipment and methods available. While acoustic data may be difficult to compare among sites and areas, nearly any acoustic device chosen may yield valuable data for a particular site, when implemented with consistent methodology and informed by a valid research or monitoring question. A great benefit of acoustic monitoring is that it is generally a non-invasive monitoring technique, causing little to no disturbance to bat populations.

Acoustic bat detectors may be used for very specific applications, such as monitoring occupancy of a single, known bat roost over the course of a season or for conducting inventories by identifying species based on recorded bat calls. Acoustic monitoring technology can also be applied to assess landscape-scale patterns over many years. The possibilities are nearly endless but limited by practical considerations involving acoustic equipment and management of large datasets Provided that appropriate methods are used, acoustic monitoring can characterize the occurrence and activity levels (daily, seasonal, annual) of bat populations (Gorresen et al. 2008; Rodhouse et al. 2011). Multiple years of inventory and monitoring may be required to reveal natural variance in bat populations, making the practice of standard methodology and implementation absolutely critical to interpretation of long-term datasets.

In a general sense, acoustic monitoring methods can be classified as active or passive. Active monitoring occurs when surveyors are present and actively involved in the recording process. Examples of active monitoring include running a bat detector by hand while watching an emergence or driving a designated transect route at a consistent speed with a detector microphone mounted on the roof of a vehicle (Britzke & Herzog 2010, Thomas & Weller 2011). Conversely, passive monitoring occurs when detectors are deployed at a stationary location, usually for an extended period of time; surveyors are absent for the bulk of data collection. A major advantage of passive monitoring is the ability to collect large amounts of data with relatively little effort. Passive monitoring may be used to characterize a single site, or a network of sites may be established to understand landscape-scale bat activity.

Active and passive monitoring can both be used to collect data within caves or on the surface, depending on the monitoring goal. Bat calls recorded on the surface are often more diagnostic (based on foraging calls) and of better quality (less reflection) than those recorded within a cave. If the monitoring goal is related to a colony of a known species, then acoustic activity monitoring within a cave can be accomplished without concern for call quality; rather, a record of acoustic activity can be used to characterize occupancy (daily and seasonal) as well as daily emergence times and nighttime activity. Landscape-scale acoustic monitoring efforts are especially advantageous if designed with the purpose of being compatible across areas, based on shared methodology, allowing for monitoring data to be pooled and analyzed for regional patterns and trends.

Capture and release

Capture and release of live bats can be a valuable inventory and monitoring technique. This technique utilizes mist nets and/or harp traps, which when properly deployed over water sources, are successful at ensnaring bats without causing injury. Live capture and release requires surveyors who are trained to handle bats, have received rabies vaccinations (usually pre-exposure), and have titer levels indicating rabies immunity. Furthermore, surveyors must be experienced not just with handling bats, but also with knowing how to identify, age, and sex bats With such specialized prerequisites and non-trivial costs associated with maintaining vaccinations, capture and release as a monitoring method is limited by the availability of surveyors with these qualifications. When utilized, though, mist netting or harp trapping can be an extremely valuable method for obtaining inventory and monitoring data. Used in conjunction with acoustic techniques, these are among the best methods for establishing species composition and reproductive status for an area. They are also among the best methods for characterizing general bat health through visual inspection and wing damage index analysis. While capture and release yields valuable data when conducted by trained surveyors, it is a highly invasive method relative to most other monitoring techniques. Using mist nets and harp traps is also very time-intensive, requiring late nights monitoring nets after dusk. Sites must be carefully chosen to be productive, usually requiring nets to be placed over water sources utilized by bats; site placement should be considered when interpreting capture results. Mist nets and harp traps should never be placed in cave entrances without first assessing the number of bats inside, as the net or trap could quickly become overwhelmed, leading to increased bat injuries and potential deaths. The equipment required for mist netting and harp trapping can be expensive, and nets and traps need to be carefully handled and stored to prevent tears and tangles. As an inventory method, capture and release is a simple and effective technique for determining species presence and reproductive status. Monitoring applications, as with all monitoring techniques, need to follow consistent methodology informed by long-term monitoring goals.

Telemetry

Telemetry, or radio-tracking, is often used to locate bat roosts, as it is one of the most effective and practical means of tracking bats over landscapes. Another advantage of telemetry is its ability to estimate home ranges, or foraging ranges, of bats. Tracking bats with telemetry also yields information on habitat selection, including foraging habitat and possible day and night roosts.

Monitoring via telemetry must also, by necessity, incorporate mist netting. Though telemetry is extremely valuable for certain projects, it is often too costly and time intensive for routine monitoring. It can also be more invasive than other monitoring methods, as telemetry requires live capture of bats in order to place transmitters. The transmitter adds weight to the bat, which could affect flight ability and result in an energy cost to the bat; however, bats routinely survive telemetry projects, and studies suggest that little disturbance results from the transmitters, which eventually fall off.

Other techniques

PIT tags, wing bands, dyes, and other marking techniques have been used on many bat species over the years, each yielding information of varying utility. For a complete discussion, refer to Kunz and Parsons (2009).

Relevant Monitoring Protocols and Methods

National Park Service:

Cumberland Piedmont Network (Mammoth Cave National Park, Cumberland Gap National Historic Park): http://science.nature.nps.gov/im/units/cupn/monitor/cavebats.cfm

Klamath Network (Lava Beds National Monument, Oregon Caves National Monument): Krejca, J. K., G. R. Myers, III, S. R. Mohren, D. A. Sarr, and S. C. Thomas. *forthcoming*. Integrated cave entrance community and cave environment long-term monitoring protocol. Natural Resource Report NPS/KLM/NRR—2014/XXX. National Park Service, Fort Collins, Colorado. http://science.nature.nps.gov/im/units/klmn/publications.cfm

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Bat Population Database:

https://www.fort.usgs.gov/search/content/bat%20population%20database

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2.2.2 Woodrats

About 20 species of woodrats (genus *Neotoma*), also known as pack rats, cave rats, cliff rats, and other common names, inhabit a wide variety of habitats throughout North America. Many of these species use caves. Woodrats are nest builders, using a variety of plant materials to make nests, called middens. Some of these middens have been important to paleoecologists. Woodrats are generally considered trogloxenes but, like some species of bats, can be troglophilic in certain locations using cliffines, hollow trees, debris piles, and man-made structures as shelter.

The most studied woodrats in NPS caves are Allegheny woodrats (*Neotoma magister*), a native species in the eastern United States. They are primarily nocturnal. They are a territorial species so they are usually solitary, except when mating and raising young. After a mother gives birth, the young stay for two to four months. Then the mother ejects the young, or a youngster may force the mother and other young out of the nest. Generally one or two woodrats may be found around a single cave entrance area. In the East they are found in the woods and often associated with rocky habitat. In the Midwest and Southeast where rocky habitat is scarce, they may be found near fence rows, shrubs, and trees. They can move long distances (3.5 km) to look for mates, but they usually forage within 200 m from the entrance to get food. Some stay even closer, only going less than 50 m to find the food they need. Males tend to have larger home ranges than females. In the last 35 years there has been a noted decline in the northeastern portion of their range. Several states have listed Allegheny woodrats as threatened or endangered, and the US Fish and Wildlife Service has them listed as species of concern (global rank of G3-G4).

Woodrats, a facultative species that come and go, provide a good link between surface and subsurface ecosystems. They use caves primarily as shelter and incidentally supplement the cave environment with an input of organic material. Even one woodrat can greatly add to the organic material in a cave. Woodrats generally do not venture far into the cave, but have been known to travel hundreds of feet from an entrance. Fresh woodrat sign far from any known entrance usually indicates that a woodrat-sized entrance is nearby. Woodrats build a nest (sometimes concealed by a house/den made of sticks or bark) out of vegetative material, such as finely shredded bark or grass. They distribute dried leaves around the nest, possibly so that anything that approaches the nest will make noise. Woodrats often gather bones and shiny objects from outside of caves, which they incorporate into their nests. Woodrats use the nest for sleeping and rearing young. In the West, woodrats sometimes use juniper which may have a repellant effect on some fleas and other organisms. Woodrats tear down and rebuild nests fairly frequently. Their food sources, including nuts, fruits, berries, flowers, fungi, green vegetation, along with any leaf litter and sticks they bring in, provide a food source for cave organisms. These food collections (caches), along with other materials, are called middens. Woodrats establish a separate latrine area, and guano deposited there is important. Several cave invertebrate communities have been found utilizing these latrine areas; these guano dependent organisms include fungus gnats, predatory beetles, bacteria, and more. Occasionally woodrats die in caves and provide a large nutrient input to cave organisms. Woodrats often use the same middens and latrines over many generations. They are able to travel through dark cave passages by following urine trails. These trails can become polished when used for multiple generations.

In addition to the threats facing most terrestrial cave-dwelling creatures, woodrats face some additional ones. These include raccoon roundworm parasite; chestnut blight (at one time American chestnuts made up 25% of canopy in areas); sudden oak decline and gypsy moth infestation leading to a decrease in supply of key food sources (i.e., acorns).

Potential inventory and monitoring techniques

Both direct and indirect methods can be used to survey woodrats. The most common direct technique is to mark/recapture woodrats using live traps. Woodrats can then be ear tagged (although some ear tags may be lost) or have an ear tattooed. While the woodrat is in hand, it can be sexed, weighed, checked for age class, checked for ectoparasites, and assessed for overall health and reproductive condition. Woodrats are easily caught in live traps, but it should be noted that due to low density, a large number of traps must be used in order to get meaningful data (Woodman et al. 2007).

Indirect methods for surveying woodrats include:

- Scat monitoring, which is used by the Klamath Network (Krejca et al. forthcoming). For this protocol, they monitor scat deposition, mostly from rodents but also from other mammals and birds. The timed area searches used to detect scat are fairly simple, requiring minimal training or equipment, and they provide valuable information on the consistency and amount of nutrient inflows that support cave communities.
- UV light for looking at woodrat urine
- Tracking boards to determine if a woodrat is entering a cave
- Trail cameras to photograph woodrat use of a cave

References, Related Studies, and Relevant Monitoring Protocols

Cumberland Piedmont Network resource brief: http://science.nature.nps.gov/im/units/cupn/monitor/woodrats.cfm

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2.2.4 Birds

Overall, birds are vagile animals that occupy a variety of habitats. A few species are dependent upon caves for habitat, particularly cave swallows. Additional species are found in cave entrances, using the structures for nesting and foraging. These species include purple martins, violet-green swallows, hummingbirds, lark sparrows, common ravens, Say's phoebes (Lava Beds), turkey and black vultures (Mammoth Cave), and eastern phoebes and barn swallows (Russell Cave). Other bird species have the potential to use caves, such as red-tailed hawks, great horned owls, and barn owls. In lava tube areas where trench collapse systems are present, approximately 30 more species can be found, including canyon wrens and rock wrens. In addition, various raptors, such as American kestrels, prairie falcons, peregrine falcons, merlins, and screech owls are found near cave entrances during bat out-flights.

Birds are important to cave ecosystems because they are a facultative species that come and go, providing a good link between surface and subsurface ecosystems. They use caves primarily as shelter and subsidize the cave environment with an input of organic material. Even one bird can greatly add to the organic material in a cave. Birds generally do not venture far into the cave. Common ravens are probably one of the biggest contributors of energy to a cave because of their large nest size, the amount of fecal matter they leave, and the chicks that fall out of the nest to the cave floor.

Birds use caves for various reasons, including shelter (caves provide nesting areas and/or perches), foraging (insects and bats), escape predation, and possible refugia from parasitism (e.g., cowbirds). In some areas, birds may use caves differently than in other areas. For example, lava tubes in Lava Bed National Monument support the only known population of cave-roosting purple martins.

Dominant threats, in addition to those faced by most terrestrial cave fauna, include disturbance by humans, especially seasonal disturbance that coincides with breeding; natural predation by barn owls, along with other avian, reptilian, and mammalian predators; and habitat stability over time (i.e., are birds building themselves out of a nesting site?).

<u>Potential inventory and monitoring techniques</u>

Very few cave parks currently monitor bird use of caves. Lava Beds National Monument monitors purple martins via flight counts. They also conduct point counts that occur near cave entrances and are investigating ways of interpreting that data to understand how birds use caves. Carlsbad Caverns National Park has conducted cave swallow research for decades, using mist nests. The list below includes these techniques, as well as additional techniques that have the potential to be used.

- Nest counts—cave swallows build new nests each year (high collapse rate after a year)
- Pellet monitoring (e.g., owl presence/absence)
- Presence of nesting material in caves; whitewash on the walls
- Point counts near cave entrances/trench collapses
- Raptor surveys during bat outflights

- Bird outflight counts
- Mist nets: identifying, weighing, measuring, and sexing birds caught

References, Related Studies, and Relevant Monitoring Protocols

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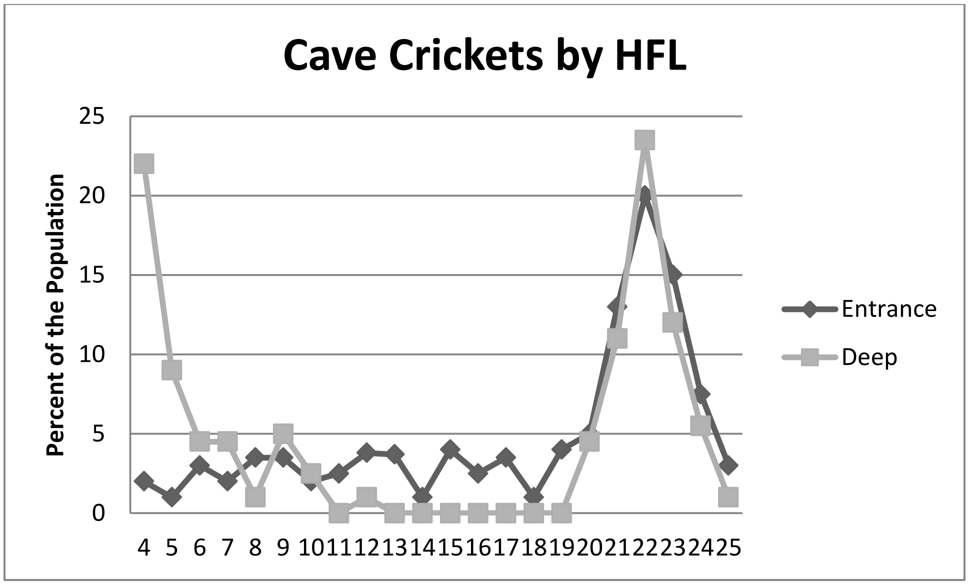
2.2.3 Cave Crickets

Cave and camel crickets are a varied group of insects widely distributed in caves around the world. In the United States most cave "crickets" are actually grasshoppers (Rhaphidaphorids). True Gyrillid crickets are found in caves in Hawaii and in Mexico. For a review of the biology and ecology of North American cave crickets, see Lavoie, Helf, and Poulson (2007). Cave crickets are important keystone species in many caves. They provide energy inputs in the form of eggs, guano, and carcasses that support specialized communities. The foraging success of crickets is influenced by the weather, as seen in the amount of guano deposited and the diversity and abundance of invertebrate guano communities (Poulson, Lavoie, and Helf 1995). In caves without large bat colonies the population structure and dynamics of cave crickets are often a significant indicator of the integrity of terrestrial cave communities. These genera are typically the primary conduits for the active, regular input of organic matter into the subsurface habitat (Lavoie et al. 2007). Cave crickets feed in the relatively productive surface habitat and deposit nutrients--in the form of eggs, guano, and bodies--into the subsurface terrestrial habitat where primary productivity is nonexistent. Cave cricket eggs and feces support subsurface communities that may include rare, sometimes endemic, obligate cave-dwelling invertebrates (Culver et al. 2000).

Cave and camel crickets show different degrees of troglomorphy in their metabolism and appearance. Elongation of legs is a good indicator of troglomorphy in crickets (Studier, Lavoie, and Howarth 2002). In Mammoth Cave National Park, *Ceuthophilus stygius* camel crickets are trogloxenes, using the cave as a refuge. Meanwhile *Hadenoecus subterraneus* cave crickets are troglophiles, completing their entire reproduction and growth in the cave, but having to leave at night to feed on the surface when conditions are close to the temperature and high humidity levels found in the cave.

Dividing crickets into size classes allows for differentiation of their use of particular areas. Figure 7 shows the distribution of *Hadenoecus* cave crickets by the length of their hind femurs (HFL). The smallest crickets (HFL 4-10 mm) are the ones recently hatched and through the first few molts. Mature adults have HFL greater than 20 mm. Entrance populations show mostly adults, and a fairly even distribution of younger size classes, reflective of species that live for several years. Deep cave sites that are suitable for egg laying show a distribution of the smallest and largest size classes. The intermediate size classes have moved out of the deep cave sites and closer to entrances to allow for surface foraging. In contrast, *Ceuthophilus* camel crickets would be graphed as a narrow curve that moves depending on the time of year because of their annual life cycle. They grow at the same rate, and all of them reach adult size in late August. Small, young crickets overwinter and begin growing in the spring.



HFL (mm)

Figure 8. Cave cricket distribution by HFL (Hind Femur Length) at entrance and deep cave sites.

Cave crickets are relatively rare in most caves, although in some they can roost in large clusters. When crickets occur in clusters, more quantitative methods are available for monitoring. When crickets are solitary, presence/absence in conjunction with occupancy modeling may be more appropriate. It should also be noted that some cave crickets live for multiple years (e.g., Mammoth Cave), so multiple age/size classes can be found in the same area. Some species of crickets can mature at different times of year.

<u>Potential inventory and monitoring techniques</u>
Six primary techniques are used to conduct inventory and monitoring on cave crickets:

- Timed area searches – used to determine what is detectable and what organisms should be monitored.

- Census by Transect -- The cave entrance is divided into appropriately spaced transects, and the total populations are counted within each transect. Crickets can also be easily separated by size class using estimations of the length of the hind femur. Seasonal movements and daily movement towards or away from entrances can be demonstrated. Census by transect works well both for clusters and individual crickets.

- Baited traps – Bait is placed for a specified amount of time. Used for areas of low occupancy.

- Adaptive cluster sampling -- If cave crickets are found in clusters, this method is robust. Randomized sample areas are chosen and transects are searched for clusters of cave crickets. If a cluster is found, more intense monitoring is focused at this location.

- Photography – Photos are taken in raw mode, then processed in Photoshop to count individuals. Photography works for smaller clusters. For larger clusters, you can import photos into ArcGIS, mark individuals, and then the program counts them. The program can also be trained to recognize features of the organisms and then count them (good success with bats). Photocounts results in demographic data with less human error by using computer programs.

- Exit counts – The number of cave crickets leaving the cave to forage are counted.

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2.2.5 Cave obligate invertebrates

Obligate, cave-limited (troglobitic) invertebrates, in particular those exhibiting obvious troglomorphies such as loss of pigment, loss of functional eyes, and elongate appendages, are indicative of subterranean habitats that have been relatively stable over recent geological time. Such species are commonly associated with stable conditions (temperature, humidity, etc.) and relatively low energy environments. Such animals typically mature more slowly than their above ground relatives and have a competitive advantage under conditions where food is scarce. These animals are typically found at lower densities relative to their surface cousins.

For cave-adapted invertebrates, monitoring generally requires having some basic inventory work, conducted by an appropriately trained biologist, done prior to monitoring. This allows the resource manager to have a list of most of the species to be expected. Where visual field identifications are to be made, it is helpful to have a collection of good macrophotos of the target taxa to facilitate field identification– a set of laminated identification cards with photos can greatly assist in field identifications. Bringing a camera with a good macro lens to photograph unusual taxa during monitoring, or a few vials to collect unusual organisms for later identification by an expert, keeping in mind protocols for the area, may be helpful. Various techniques can be used for documenting species, depending on the inventory and monitoring questions.

Potential focal species

For general monitoring, identifiable taxa may be target organisms – those relatively few distinctive looking troglobites or troglophiles which are reasonably abundant and which can readily be quantified, identified, and sampled by trained personnel. These might be larger organisms such as the large milliped *Plumatyla humerosa* at Lava Beds National Monument. Monitoring several such species, perhaps ones which function at differing trophic levels (spiders as predators, but then also a distinctive springtail, for example) or microhabitats, will produce more reliable results (Gerlach et al. 2013) and will provide more complete coverage of fine-scale microhabitats and their associated biodiversity (Samways 2007).

Where sufficient invertebrate expertise is available, it may be appropriate to monitor invertebrate communities – assessing species richness and diversity across different areas with caves, across different caves, and across time (different monitoring events). Such studies might include timed area searches, perhaps with baiting (to attract invertebrates to search area). Lethal pitfall trapping is probably best restricted to inventory studies and specific research projects, so as not to deplete populations with repeated trapping.

Potential inventory and monitoring techniques and considerations

Several inventory and monitoring techniques have proven useful for cave obligate invertebrates:

- Timed areas searches
- Pitfall trapping
- Habitat & Environmental Parameters
- Photography

Timed area searches

Timed area searches require delineating areas to be searched. The area is then searched for a fixed time period by appropriate personnel, with all target taxa (alternatively, all taxa) recorded by species (or morphospecies) and number of individuals. This effort can be converted to person/hours/m^2 to allow comparisons among sites and across survey periods. There are numerous ways to define search areas, and choice of approaches depends on the size and morphology of the cave or caves to be monitored, but also depends upon the likelihood of detecting target taxa. Search areas (zones, replicate plots) can be a segment of cave passage (X meters of passage, measured off with survey tape), or, where passage or rooms are more spacious, fixed size study plots, or linear transects (such as a survey tape laid out, with search covering 1 meter on either side of the tape for a distance of X meters). In most instances, size of search areas should be sufficiently large that numerous search areas are likely to detect the presence of the target taxa when the target(s) are present, but not so large that there is insufficient time to search the area, or there are too many of the target taxa to count in the allotted time. When particularly rare troglobites are the targets, sufficient numbers of search areas in appropriate habitat and at appropriate times of year (i.e., spatial and temporal considerations) should be used to have a reasonably good chance of detecting the species when present. A good cave map is extremely useful for marking search areas. Search areas can be fixed plots, randomly placed through the searchable portions of a cave, stratified (entrance, twilight, dark zones), or restricted to certain areas (dark zone only, or restricted to specialized habitats where species will only occur or where species are most likely to be detected). In caves with little energy and few invertebrates present, it may be advisable to set out bait stations to attract target taxa. If bait is used, care should be taken to remove it after each monitoring period, and considerations of possibility of other animals taking the bait away should be weighed. Placing baits in a well anchored cage or under a stone may work in some settings. Common baits include limburger cheese, rotting liver, peanut butter, etc. (consult with cave biologists familiar with your area). It should be noted that many species do not come to baits, especially predators like spiders, so you will not get a representative sample of those species. In addition, baits near the entrance could also attract surface species.

Pitfall trapping

Pitfall traps are more appropriate for inventories than for monitoring, as most implementations result in mortality. However, “dry” pitfall traps without a preservative may, in some instances, be appropriate. The bottom of these live traps should have paper towels or other “cover” for animals to hide under, and should not be left for more than a day or two. Pitfall traps are most useful for ambulatory invertebrates. Flies and web-building spiders are not likely to be caught in pitfall traps. This approach should probably be discontinued if mortality is observed in preliminary trials.

Habitat & Environmental Parameters

Terrestrial cave invertebrate monitoring should include associating each search area during each monitoring period with a standardized list of parameters. Standard environmental parameters include relative humidity (RH), temperature, air velocity and direction, and light levels inside the cave, and temperature, relative humidity, and recent precipitation outside the cave. Pay special attention in selecting an instrument for measuring relative humidity to ensure the selected device is effective and accurate between 85 and 100% RH, a typical range for deep cave humidities. Calibration of meters should follow manufacturer's recommendations. Substrate should be characterized in a standardized manner for each plot, with relative proportions of bedrock, calcite formations, organic debris, soil, clay, loose rocks, etc. In addition, a subjective measure of substrate moisture can be added, for example: dry, normal (damp to touch), wet (glistening).

Photography

Species-level identification may be possible in the field for some cave obligate invertebrates with appropriate training and a pictorial guide to area cave invertebrates. But in other situations, species-level identification requires the animals be collected and preserved so that tiny morphological structures can be examined by an expert under a microscope to determine species identity. Because of the slower maturation and low populations of these animals, collecting and preserving troglobites should not be a routine component of cave resource monitoring. However, in areas where cave resources have been well-studied, it may be possible to make reasonably accurate field identifications. A laminated set of identification cards, developed in consultation with an appropriately trained biospeleologist, may make this approach more feasible. Field identification requires that the field crew be reasonably aware of what other potentially similar-looking invertebrates might also be encountered.

Some obligate cave invertebrates, especially predatory species, such as spiders and pseudoscorpions, can be very reclusive and rare. A troglobitic pseudoscorpion might not be detected during each visit, even if the species is present in the subterranean habitat – such false negatives make it difficult to use such species for short term monitoring (Krejca and Weckerly 2007). However, data on these rarely encountered species collected over years may provide valuable insights into the condition of the cave ecosystem. Obviously, where extremely rare species are expected, their well-being needs to be carefully considered when lethal sampling methods may be implemented.

<u>Considerations for locating monitoring/sampling sites</u>

Monitoring troglophiles may be effective when monitoring considerations emphasize sample size. In many cave settings, several troglophilic species may be sufficiently numerous that one might expect to regularly encounter them during each cave visit. These species include some flies, springtails, and, closer to the cave entrance, a variety of other taxa. With sufficient training, it is possible to field ID springtails and flies to family, and with a few voucher specimens confirmed by an expert, it is feasible to assign presumptive generic or even species names to distinctive forms.

When monitoring cave invertebrates, it is important to keep in mind that for troglophiles, "more" is not necessarily "better." Larger numbers of individuals of taxa which have a competitive advantage when energy is more abundant may indicate undesirable organic enrichment – septic leaks, excessive visitation, human waste, etc.

Considerations for sampling interval

The interval between invertebrate monitoring events should balance several factors, including: 1) funding and resources available to conduct monitoring; 2) seasonality of both access to cave sites and activity of target organisms; 3) potential impacts of monitoring visits on the cave ecosystem and other cave resources; 4) statistical/data interpretation considerations such as variance in data, power, area of inference, sample size (number of caves, number of samples/cave, typical counts of animals in samples) and statistical significance; and 5) impact of visiting the cave.

Commonly, annual monitoring of terrestrial cave macroinvertebrates at a selected time of year is determined to be the best balance of the above factors, but this could vary greatly by the situation at a given Park.

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2.2.6 Other wildlife use of caves

While the above sections cover some of the most common terrestrial wildlife found in caves, many more species use caves, especially cave entrance areas. The cave entrance area can provide a refuge for animals seeking a more humid and moderate climate. In the Southwest U.S., over 81 species of vertebrates have been documented in 160 caves in the Chihuahua Desert, while in the Sonoran Desert, 74 species of vertebrates have been documented in 13 caves and 52 mines (Strong 2010). Mammals were the most dominant group of vertebrates, followed by birds, reptiles, and amphibians in the Chihuahuan Desert, while in the Sonoran Desert the number of reptile species was slightly higher than bird species. The most common mammals were ringtails and porcupines, followed by mountain lions, Townsend's big-eared bats, mule deer, and domestic goats. The most common birds were great horned owls, cave swallows, rock wrens, canyon wrens, and turkey vultures. The most common reptile species were three species of rattlesnakes. Other snake species, as well as lizard and turtle species were also found. Amphibians were infrequent, likely due to the arid nature of the region; of the three species found, tiger salamanders were the most common (Strong 2010).

In the Great Basin, a cave entrance study using remote cameras at seven caves in Great Basin National Park found that the most abundant species were small mice (*Peromyscus* spp.), humans, chipmunks, woodrats, and squirrels. In addition, other species observed in cave entrances included cottontail rabbits, bats, skunks, foxes, insects, birds, and domestic dogs (Baker forthcoming).

Vertebrate species may use the caves for roosting (e.g., great horned owls), denning (e.g., porcupines and mountain lions), nesting (e.g., woodrats and cave swallows), and hibernating (e.g., bats or bears). Some species use the cave for foraging, such as white-footed mice feeding on crickets (Strong and Goodbar 2005) or snakes hunting rodents or bats. In the desert Southwest, many species may use cave habitats simply as a respite from arid and hot conditions.

Monitoring for these species could use techniques specific for those species (e.g., traps, mist nets, photography, scat and track techniques). This is an area that has not been widely studied, and many caves do not even have an inventory of what vertebrate species use them. Thus, an inventory would be the starting point for many cave managers desiring to know what wildlife species use the caves they manage.

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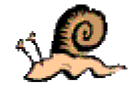
2.3 Aquatic Cave Ecosystem



When subterranean voids contain water, we enter the aquatic cave ecosystem. This could be an underground stream, spring, pool, or the water table. It could also be lake water (e.g., Apostle Islands National Seashore) sea water adjacent to the ocean (e.g., Point Reyes National Seashore), or sea water that is landlocked but connected via subterranean passages, also called anchialine pools (e.g., Kaloko-Honokohau National Historical Park).

The habitats in which specific cave aquatic communities are reliably found can be roughly divided between the unsaturated or saturated zone (Poulson 1992, Ford and Williams 2009). The unsaturated zone lies above the water table and may contain both ephemeral (e.g., isolated pools and streams) and permanent aquatic habitats (e.g., the epikarst). The saturated zone is permanently flooded (Ford and Williams 2009). Both unsaturated and saturated zones may contain cave passages.

Inputs to aquatic cave ecosystems can vary considerably from one cave to the next. Some include a single river that sinks into a cave and later reemerges. Others include multiple inputs from numerous streams and sinkholes. Diffuse groundwater inputs can be a significant contributor to aquatic cave ecosystems, with springs emerging in caves or water tables dropping to allow more access to deeper parts of the cave and then rising and restricting access.

Research indicates physicochemical parameters can significantly affect the distribution and abundance of cave aquatic biota (Simon and Buikema 1997, Sket 1999, Graening and Brown 2003, Panno et al. 2006). The varieties of land use atop NPS caves contribute to the range of groundwater quality, and thus, can affect habitat suitability for cave aquatic biota among its aquatic habitat.

Water quality monitoring data by itself tells resource managers at NPS units little about the impact of chronic and/or episodic stressors on cave aquatic biota. However, water quality monitoring creates a long-term data set for trend analysis and directly supports and aids the interpretation of aquatic biological monitoring.

Primary reasons for monitoring biological communities within NPS cave aquatic ecosystems are:

1. Monitoring cave aquatic community diversity, species richness, and relative abundance will yield information that can trigger targeted research, which will support future management actions aimed at preservation, protection, and restoration where needed.

2. Information on the baseline cave aquatic community may provide a basis for judging the effectiveness of efforts by park managers to conserve populations of the federally-listed species. For instance, if abundance trends of a species declined beyond a threshold to be established, then research into causes could support negotiations on agricultural land management standards upstream of the park.

3. Monitoring data will help identify declines beyond acceptable limits (to be established over time) in sensitive cave aquatic species, which again would induce targeted research to support management actions for mitigating impacts.

4. Status and trend data coupled with limits of acceptable change, to be developed as enough data are acquired, could support park efforts to deal with water structures outside of caves.

The overriding question addressed by this framework is: Are biological communities within the cave's aquatic ecosystem impaired by any biotic or abiotic stressor arising from within or beyond park boundaries?

Dominant threats

Dominant threats to aquatic cave organisms may be intensified any time the water they live in experiences a variation. Changing water levels, temperature, dissolved oxygen, pH, and nutrients may stress or even kill the cave organisms. Additional stressors include acute or chronic exposure to toxins, low level to extreme organic enrichment, mild to severe siltation, plus introduction and/or establishment of either exotic (such as rainbow trout) or epigean species (e.g., non-native ants at anchialine pools consuming native shrimp when pool waters recede during low tides). These stressors are often caused by changes in habitat (both in and above the cave). Habitat loss or impact may be caused by human disturbance (e.g., dumping in sinkholes, oil spills washing into storm drains that flow into caves), in-cave development (e.g., cave infrastructure, lighting, dams), land use changes above caves (especially urbanization and altered agricultural practices), vegetation structure changes above caves (e.g., wildfires alter infiltration), sudden environmental changes (e.g., flash floods, earthquake-induced waves (as seen in Devils Hole)), and food source contamination from heavy metals and/or pesticides. Some of these threats can be mitigated through land management actions, while others may not be possible to control, such as major environmental changes driven by climate change or natural processes.

Potential inventory and monitoring questions

The list of questions related to aquatic cave organisms and cave use is highly diverse and potentially endless, though most cave managers will likely find common ground in wanting to determine some basic information about local populations:

- What species are present in caves?
- What caves/sites do they use?
- When are they present (e.g., year-round vs. seasonally)?
- How many are there (population estimates)?
- What is their population status (e.g., stable, decreasing)?
- How does the population or activity change seasonally or annually?
- How do water quantity and quality correlate with the status of the species of interest?
- What is the community composition of a particular aquatic habitat within the cave?
- What can be done to protect them?

More advanced questions may follow after managers have succeeded in answering some of the basics about local populations. Many of these questions may be beyond the scope of inventory and monitoring and enter the realm of research. Additional questions may include:

- What water quality parameters are the species of interest selecting for, and how does this vary based on season/use (e.g., dissolved oxygen, nutrient availability)?
- What physical or morphological characters are species selecting for, and how does this vary based on season/use (e.g., water temperature, depth)?
- Is there any correlation between the species of interest use and level of development of a particular cave or cave area?
- How do floods/tidal extremes affect the species/community of interest?
- How do changes in environmental factors (e.g., temperature, relative humidity, barometric pressure) due to development or modification (e.g., artificial entrances, trail construction, dams) affect species?
- How does land use above caves impact species of interest populations?
- Have populations / species composition changed over time (decadal or century scale using paleontological data)?

Potential focal species/sites

The focal species for monitoring will depend on the species present in the area, as well as the status (state or federal protection), significance (relative local importance of that species and if they are facing threats), and feasibility of monitoring for a particular species. In addition, documentation of sites critical to the life cycle of a particular population should necessitate prioritized monitoring and protection for that site. In most localities, multiple species will be present. Priorities for inventory and monitoring often depend on available resources and trained staff, however, strong consideration should be given to endangered species, abundant/detectable species (easier to monitor), and sites that are used by multiple species. These priority monitoring categories will likely overlap, and implementation of robust, long-term monitoring efforts and proper data analysis may reveal proxies for estimating the status or trend of interrelated monitoring groups. For aquatic species it cannot be emphasized enough that measuring water quantity and quality concurrently with inventory and monitoring of the aquatic cave species is critical.

Additional information is provided here about monitoring two broad categories: top predators, which are often flagship species, and detritovores, which may be representative of the system. In addition, many species within each of these categories are stygobites. Stygobites often have adapted to low nutrient systems and have a lower metabolism than their surface relatives or even stygophiles, and thus live longer lives (Wilhelm et al. 2006). They may be more susceptible to competition by stygophiles if nutrient inputs are high.

Top Predators

- Fish-Many fish have adapted to the subterranean environment. One example is the Northern cavefish *Amblyopsis* in Mammoth Cave, which can live up to 60 years. Devils Hole Pupfish may be some of the most monitored subterranean fish in the world.

- Crayfish--Stygobiotic crayfishes can play a major role in aquatic cave ecosystems. They are found in the eastern United States, Mexico, and Cuba, with 41 species (Hobbs 2005). They are omnivores and highly-adapted to low-energy fluxes. They are able to persist for decades, and sometimes even to 100 years (Culver 1982). In Mammoth Cave, the cave crayfish O*rconectes pellucidus* may live up to 90 years.
- Amphibians-- a variety of amphibians use caves, but some of them, such as the Texas blind salamander (*Eurycea rathbuni*) are entirely aquatic.
- Crabs and Shrimp--Although not often found in inland caves, crabs and shrimp can be the top of the food chain in tropical and anchialine caves found in the tropics. The Kentucky cave shrimp feed on biofilms in caves in several counties in Kentucky.

Detritovores

- Isopods-- Subterranean isopods occur in caves throughout the world, with about 1,000 species described from 35 families (Hobbs 2005).
- Amphipods-- Amphipods are found in most aquatic subterranean habitats throughout the country. They are diverse, with 35 families, 133 genera, and over 800 species (Culver and Pipan 2009).
- Snails-- Cave-adapted snails in the family Hydrobiidae are numerous, with more than 350 species (Bole and Velkovrh 1986). They are often extremely tiny, with simplified body structures to adapt to the limited space.

Potential inventory & monitoring strategies

Answering inventory and monitoring questions related to aquatic species requires following a strategy or combination of strategies. Monitoring generally falls into three strategy levels or categories:

1. **Presence/absence inventories/monitoring** is used to develop faunal or species lists, is useful for determining site occupancy and informing species protection efforts, and may be used as a strategy to inform ecological monitoring efforts.
2. **Population monitoring** may be based on in-cave surveys and informs long-term trends in the status of populations.
3. **Ecological monitoring** attempts to understand the dynamics of species behavior and dispersal, including the habitat preferences of the species of interest, the life cycle needs that correspond to those habitat preferences, and the temporal patterns (daily or seasonal) associated with those habitats.

For all three of these strategy levels, monitoring water quantity and quality is recommended.

Potential inventory and monitoring techniques

As for terrestrial cave macroinvertebrate monitoring, aquatic cave macroinvertebrate monitoring should be preceded by basic inventory work conducted with an appropriately qualified biologist to develop a list of species likely to be encountered. Macrophotos of taxa can be helpful – a set of laminated identification cards with photos can greatly assist in field identifications. Bringing a camera with a good macro lens to photograph unusual taxa during monitoring, or a few vials to collect unusual organisms for later identification by an expert, may be helpful.

Approaches to monitoring of aquatic cave invertebrates (isopods, amphipods, flatworms, snails, and microcrustaceans) varies by type of aquatic habitat. These include:

- Timed area search
- Drip traps
- Baited funnel traps
- Quadrats
- Census

Timed area search

In drier cave environments with isolated drip pools, visual timed area search of pools may be appropriate. Such searches might include calculating the area of each drip pool, then counting the invertebrates, by taxon, in each pool. Amphipods may be underestimated with this approach, as some spend considerable time buried in substrates or under stones.

Drip traps

For microcrustaceans, it may be possible to conduct monitoring using drip traps to live-capture copepods and other small organisms dripping down from the MSS. It may be appropriate to bring a dissecting microscope into the cave to count the microcrustaceans before releasing them into drip pools. Species level identifications are not feasible, but copepods can be classified as harpacticoid, cyclopoid, and calanoid with some training.

Baited funnel traps

Where cave streams are present, approaches may vary with scale, turbidity, flow rates, degree of natural organic enrichment, and pollution. In relatively large, flowing, turbid, high energy cave streams, baited funnel traps can be used to monitor isopods and, especially, amphipods. These should be left in place a rather short period of time (probably hours at most) so that larger numbers of individuals do not accumulate (resulting in specimen death from anoxia and predation). The best bait for such traps is raw (uncooked) shrimp that has been allowed to decay for a day at room temperature – only a small piece is needed. Prior inventories by a trained biologist are needed to be able to determine the range of likely species to be detected, and it is often not feasible to field identify amphipods and isopods to species level where more than one species occurs in the area. Multiple funnel traps should be placed to get some estimate of variance among samples.

Where streams are small, clear and/or low energy (few organics), baited funnel traps may introduce unacceptable levels of nutrients into the cave system (resulting in an increase in microbial growth). For the same reason, baited funnel traps should not be used in drip pools.

Quadrats

In small, rocky, clear slow-moving streams, monitoring can be undertaken using quadrats constructed from PVC pipe. These quadrats are used to delineate search areas, and a pair of researchers (one searching, one data recording) can count all of the macroinvertebrates occurring within a quadrat. Concerns regarding the possible impacts of this activity, including trampling and substrate disruption caused by lifting stones, should be weighed prior to implementing monitoring.

Census

Census methods are concentrated on macro-organisms which can be identified in the field, since wholesale collecting of specimens for later identification in the laboratory often is incompatible with the objectives of a Park. These macro-organisms censuses can include total counts along a stream segment for fishes, salamanders, and other vertebrates, plus crayfish and shrimp. Other macrofauna are noted as they are encountered in the field, but total counts are not attempted. These organisms may include isopods, amphipods, flatworms, snails, and copepods. Many of the organisms are captured with small dip nets, measured, and examined for signs of health, reproduction, and food intake. All organisms are returned to the stream as quickly as possible, without harm, and at the capture location. At those sites where the stream is one meter deep or less, the surveys can be made by walking along and in the stream. At locations where the water depths exceed 1-2 meters, however, it is necessary to use wet suits or dry suits, fins, masks and snorkels.

At Mammoth Cave, vertebrates and larger macroinvertebrates are censused by two observers who either wade upstream or swim with mask and snorkel. All organisms are counted, and subsets of them are captured (with a dip net 10 x 20 cm with a 3mm mesh) and measured. The volume (by water displacement) of captured organisms may be determined, and various characteristics that might indicate the condition of individuals in the population are recorded. These characters include reproductive condition; the presence of food; the presence of deformities, eroded fins, lesions, and tumors; and regeneration or loss of limbs.

For sea cave monitoring, see http://jncc.defra.gov.uk/PDF/CSM_marine_sea_caves.pdf

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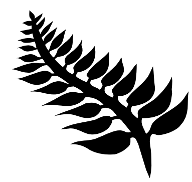
2.4 Plants

Plants are often not considered at first when thinking about monitoring cave ecology, but they can be an important part of the cave ecosystem. Vegetation near the cave entrance can influence what lives in the entrance and twilight zones. Ferns, mosses, and lichens are common within cave entrances, and the microclimate of some entrances may support rare and/or specialized plant species. In addition, the vegetation above the cave can have an impact on the cave environment via its roots, evapotranspiration, amendments to the soil, and more.

Lamp flora, or flora growing near artificial lights in the cave, often supports its own ecological communities. Since lamp flora is unnatural to the cave, eradication is usually the goal of cave managers, though short-term inventory and monitoring may be useful for quantifying impacts and determining mitigations.

2.4.1 Cave Entrance Flora



Cave entrance flora are plants that grow in and near cave entrances, and may be different from surrounding vegetation depending upon air flow direction, slope position, and aspect. There are two basic scenarios for caves with chimney effect airflow. If air exits the cave during the growing season at a particular entrance, then the plants there may be part of the ecotone between cave ecosystems and surface ecosystems. A particularly cool and moist microclimate may be noticeable if the entrance is in a sinkhole and cave air pours over the lowest lip of the sink. This will yield a thermocline at the level of the spillway where plants that prefer cool moist conditions will be found below this level and more typical plants will dominate above that “pool” of cool moist air. It may be possible at night to see waves at the interface of these two air masses, sometimes with a layer of fog above the thermocline. Shining a light almost parallel to the thermocline brings out the boundary layer structure best. The second scenario happens in winter at upper entrances with chimney-effect airflow. The relatively warm and moist air may facilitate mosses and other small plants. Potentially, this “moss” community could be very rich in non-vascular plant species.

In the driftless area (where ice age glaciers did not arrive) of the Midwest, steep limestone bluffs have cracks that open up to a talus slope. Snow settles down into the talus and can even form ice. This persistent cold creates its own down-draft, and where the cooled air exits, it can help support relict Pleistocene flora. Relict species may also occur in some cave entrance communities.

Algae and cyanobacteria (blue-green bacteria) will grow with any light source, natural or man-made. One will often see a transition in entrance sinkholes from surface vegetation to ferns, then mosses, then algae and liverworts, and finally dusky-green cyanobacteria. The plant growth is rich in invertebrates that have been little studied.

There is an earthy smell associated with most cave entrances due to the growth of actinomycete bacteria. These bacteria are normal soil microbes that also grow well in caves. They grow as colonies of white, yellow, pink, or other hues, close to entrances or in locations close to the surface where organic nutrients seep into the cave. You will often see them as discrete “dots”, but in lava tube caves they may form a dense coating on the walls and ceiling of the cave.

Cave entrances and twilight zones can serve as refugia for plants, often providing cooler and/or moister conditions.

<u>Skylight communities</u>
A skylight is an opening in a cave ceiling that opens up due to collapse, surface erosion, or water capture above an underlying cave. A skylight is a new entrance into a cave and may provide access to humans. It can develop a complete entrance community over time. Skylights are particularly common in lava tube caves and have been identified on the surface of Mars. Caves provide protection from ionizing radiation, and caves on other planets may harbor life and serve as a refuge for humans who might visit those planets.

Tree roots in caves may play an important role for invertebrates. Trees in karst areas may use water and reduce the amount that reaches a cave. Roots can fracture rocks in caves and around entrances. Vegetation is a source of energy and can be brought into caves by animals, washed into the cave, or falls into the cave (e.g., pinecones in entrances pits). Vegetation also attracts animals, which are additional energy sources for caves.

Dominant threats to cave entrance vegetation are those that also face terrestrial cave ecosystems (section 2.2). Monitoring/sampling sites should be located in a manner to minimize disturbance to the plant communities.

Potential inventory and monitoring questions for cave entrance flora are similar to those found in section 2.2 for terrestrial cave ecosystems. Potential focal species include relict flora/relict flora; sensitive species, especially those sensitive to changes in humidity and temperature; threatened and endangered species; natural heritage species; lichens; and fungi. Sites may need to be stratified based on entrance habitats. Temperature and humidity readings should be taken in conjunction with assessing vegetation.

<u>Potential inventory and monitoring techniques</u>
Depending on the monitoring objectives, several techniques are possible:

- Point-line intercept method if enough habitat is present
- Map area of focal species at a regular interval
- Count the number of cave entrances that contain the focal species
- Take samples of algae for identification
- Photomonitoring, with several techniques possible
- Mapping of social trails through thick vegetation

References, Related Studies, and Relevant Monitoring Protocols

To find the Lava Beds National Monument Cave Entrance Vegetation SOP, go to the following link, click on the Cave Entrance Communities & Environments tab, and then click on Final Report.pdf: http://science.nature.nps.gov/im/units/klmn/publications.cfm?tab=2

2.4.2 Lamp flora

Cyanobacteria (formerly known as blue-green algae), algae, mosses, and other plants induced by the lights we place in cave passages are called *lamp flora* in Europe (or *lampenflora*). The term lamp flora has been adopted in the United States. These photosynthetic-based species displace the natural microflora associated with the dark habitats of artificially-lighted caves. Such distortion of the cave ecosystem is often severe in passages decorated with calcite speleothems.

Lamp flora have been killed or removed by a variety of means including herbicides in Lehman Caves and steam in Mammoth Cave, Kentucky (Harris 1981). At Kartchner Caverns in Arizona, a 12% solution of hydrogen peroxide was used with limited success. Growths returned in a month compared with three to six months for areas treated with diluted bleach (RS Toomey III, personal communication 2002). However, Aley (1976) found even 30% hydrogen peroxide to be ineffective, and such high concentrations are dangerous. For many years, these unwanted growths have been controlled through periodic spraying of 0.5% sodium hypochlorite, which is household bleach. In Hungarian caves, 5% formaldehyde has been used successfully (Rajczy et al. 1987). However, use of manufactured chemicals can create ecological, aesthetic, and safety issues. Light management may be one of the best solutions, as wavelengths can be chosen that do not allow lamp flora to flourish. In addition, it should be a regular practice in caves with artificial lighting to use that lighting only when necessary, turning it off when that part of the cave is not being visited.

Potential inventory and monitoring questions for lamp flora are similar to those found in section 2.2 for terrestrial cave ecosystems. Focal species will depend on what is found during the inventory. Lamp flora not only differs from cave to cave, but also changes through time in the same cave. Monitoring/sampling sites can be located in a variety of ways depending on what question is being asked. Lamp flora will differ by moisture level, type of light, and area of cave (entrance/twilight/dark). Some areas may be too sensitive to conduct regular monitoring, especially wet formations. In addition to monitoring near lights, reference sites away from lights should also be included. When conducting an inventory or monitoring of lamp flora, be sure to document the past history of the area, particularly when it was last cleaned and the method used to clean it. An annual monitoring schedule may be adequate for most caves.

The primary inventory and monitoring technique used for lamp flora at this time is photomonitoring. An area near the light is photographed, and a GIS or photo program is used to calculate the area affected by lamp flora. This could be a good citizen science project using local caving grottoes.

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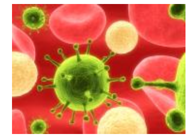
2.4.3 *Habitat above Caves*

Caves do not exist in isolation from their surroundings, as previously discussed (Figure 7). Habitat above caves is critical to caves. Trogloxenes, such as bats, cave crickets, and woodrats, shift resources from the habitat above the cave into the cave. Preservation of sufficient surface area, vegetation, stream flow, and other factors is a critical component of recovery plans under the Endangered Species Act. We know that changes on the surface have direct impacts on the underlying caves and populations of trogloxenes. Changes in surface habitat over thousands of years have been documented by studying middens in caves (Betancourt et al. 1990). Even habitat farther from caves can play an important role in the cave ecosystem, such as when bats leave the cave to go forage for insects. The number of insects available for bats is influenced by the vegetation types present, as well as water sources, development, and other factors.

2.5 Microbes



Microorganisms are ubiquitous in all environments, including caves, although their small size means they are often overlooked despite their important role in recycling nutrients, decomposition, geomicrobiology, and primary productivity. Microorganisms are the most diverse group of organisms in terms of numbers of species and metabolic activities, and include bacteria, archaea, fungi, single-celled protozoa and algae (although such photosynthetic species are limited to the entrance zone). Despite their small size, visible growth of bacteria can often be seen in the form of colonies, or in the case of fungi, reproductive structures (mushrooms and molds) may be seen. For an introduction to cave microbiology for non-specialists, see Barton 2006.

The interrelations among microorganisms and geological processes is studied in the field of Geomicrobiology (Barton and Northup 2006, Barton et al. 2005, Northup and Lavoie 2001). Microorganisms play important roles in formation of some secondary minerals in caves, such as saltpeter; in the deposition of carbonates, including moonmilk, helectites, pool fingers, cave pearls, and carbonate speleothems; silicate speleothems; deposition of ferromanganese deposits (Northup et al. 2003, Spilde et al. 2005); sulfur compounds; and larger scale biokarst (Cunningham et al. 1995).

At the entrance, photosynthetic microorganisms such as algae and C*yanobacteria* will be encountered. Once you proceed beyond the entrance, non-light dependent microorganisms thrive, particularly in areas of nutrient input, such as drip water coming into the cave or hydrogen-sulfide rich springs. These microbes can be observed by their paint splash-like white and yellow colonies on the wall, and from their distinctive earth-like smell. This smell is associated with production of geosmin by *Actinomycete* bacteria. In some lava tube caves, *Actinomycete* growth can completely coat the walls and ceilings of cave entrances with a white, dusty appearance (Garcia et al. 2009; Northup et al. 2008), or form a reflective surface known as “cave silver” when water beads up on hydrophobic colonies. *Actinomycetes* are important microorganisms in industry and have provided the majority of antibiotics currently in use.

Additional indicators of microbial activity in caves (Barton et al. 2005) include colonies on surfaces, indicated by unusual coloration; precipitation; ferromanganese deposits, usually as coatings; structural changes such as dissolutional pitting; and gooey biofilms and white filaments. Typical microbes use organic matter (all fungi, protozoa, and most bacteria) which is usually limited in most caves. In cave locations where organic matter does not enter the system, such as very deep caves and caves where little surface water enters the system, microbial ecosystems will rely on the geochemistry of the rock, including such elements as sulfur, iron, or manganese as a source of energy.

Microorganisms are often studied in the laboratory by culturing them on growth media. Cultivation is a powerful tool in medical and food microbiology, but less than 0.1% of environmental microbes can be grown using this technique, a number which reaches 0.01% in cave ecosystems (Angert et al., 1998, Barton and Northup 2006). In doing cultural studies from oligotrophic cave environments it is important to use low-nutrient media, such as diluted media and soil extract media, even water-agar, in an attempt to grow microbes of environmental interest (Pemberton et al. 2008). When studying fungi or indicators of human activity it is appropriate to use standard culture media (Vaughn et al. 2007). Another important consideration in cultivation is incubation temperature; attempting to isolate environmental microbes from a 15° C cave when you incubate at the standard 37° C is a common error.

Environmental microbiologists usually have to rely on non-culture techniques primarily using genetic analysis (Angert et al 1998: Barton et al 2004; Chelius and Moore 2004), which are costly and highly technical (Barton et al. 2004). It is important to use procedures and kits designed for isolation of environmental microbes, not those designed for medical samples. Other laboratory techniques such as fluorescence microscopy, electron microscopy (see Spilde et al. 2005), and enzyme and lipid analysis can also be useful.

A common concern in microbiological studies is presence vs. activity. Since microbes are ubiquitous, you will isolate microbes that may be present but not active. Another important consideration is quantification. When collecting samples, it is best to swab a standard surface area, measure the gram dry mass of soil, or measure the milliliters of water so that useful comparisons may be made.

Dominant threats to microbes are similar and overlap with threats to other cave biota. These threats include anthropogenic energy input, such as human detrital input (e.g., vomit in Lascaux Cave in France, lint, human waste); changes to cave infrastructure (in particular lighting and the introduction of decomposable substrates, such as untreated wood); introduction of chemicals (e.g., cleaning with bleach, chemical residues from WNS decontamination); and land use changes above the cave (e.g., development, roads), that could increase the likelihood of pollution or nutrients entering the cave.

Potential inventory and monitoring questions

Microbes differ from previously discussed organisms in that thousands can make up a community. These communities are often dependent on microniches, and a mere centimeter shift in any direction could result in finding a very different community of microorganisms (Macalady et al. 2008). Traditionally we thought cave microbes were a subset of microbes washed or carried in from the surface, but studies are showing widely distributed communities of what may be endemic microbes, adapted to grow best under cave conditions (Northup et al. 2008, Garcia et al. 2009).

With that said, microbes can still be useful in inventory and monitoring.

1. If fecal contamination is suspected, they can be used to track water pollution (e.g., coliforms). Changes over time will show the success of clean-up operations.
2. What is the trend in human impacts in a cave on a microbial level?
3. How is the microbial community changing over time and/or before-after some event?

Potential focal species

Human impacts (for example, *Staphylococcus aureus*, coliforms, and other species) can be indicative of human impact; however, it should be noted that a number of native cave species express many of the characteristics that could confuse them with introduced species. Because of this, it is critical that researchers are experienced in cave microbiology techniques and do not use tools and techniques that were developed for the medical setting, which can often lead to confusing and sometimes incorrect conclusions.

Potential inventory and monitoring techniques

1. To measure fecal contamination, fecal coliforms can be identified by water filtration followed by lactose fermentation assays and confirmatory tests. There are simple and effective kits available for quantifying fecal contaminants.
2. If cultivation is desired, culture media must be made that reflects the geochemistry of the cave environment being examined, reduced nutrient levels, and appropriate incubation conditions. Quantification of area/mass/volume of samples allows for comparisons.
3. Direct cell counting can be carried out to determine the size of microbial populations. Direct cell counting is best done by the filtration of water and staining. It is possible to count microbial cells in sediments, provided that fluorescent markers are used to allow differentiation of the microbial cells from particulate matter, which requires the use of a fluorescent microscope.
4. Electron microscopy can be used to reveal microbial presence, density, and physical appearance.
5. The best method of examining microbial communities in cave environments is through a molecular phylogenetic analysis of the 16S ribosomal RNA gene sequences, although next-generation sequencing technologies are rapidly increasing the types of analyses that can be carried out.
6. Measurement of microbial activities. Hach® test kits are available for on-site testing of many parameters, such as hydrocarbons, hydrosulfides, and dissolved methane (test for fracking); but the testers need to be aware that petrochemicals or methane presence are natural in some areas and may not be indicative of human impact.

Considerations for locating monitoring/sampling sites

Because of the large diversity of previously uncultivated microorganisms from caves, it is critically important that the intention of microbial surveillance is thoroughly established prior to beginning measurement. Microbial communities change greatly throughout the cave (Ikner et al 2007), so a cave manager must have a specific question in mind for investigating an area, such as looking at water pollution or human impacts (Vaughn et al 2011). Successful microbial sampling in caves often requires identifying the potential energy source for microbial growth in the cave and determining its impact(s) on microbial populations.

Considerations for data analysis and interpretation

Data analysis and interpretation is generally done by highly experienced cave microbiologists. Fortunately for cave managers, the number of these individuals is increasing, despite the science of cave microbiology still being relatively new. For instance, cave microbiologists know that in a cave about 40% of all species may be lactose-positive coliforms and test positive for *E. coli* but most are really a different organism; secondary and tertiary tests (for example mTec at 42° C) will show the real *E. coli*. They will also know the limitations of direct cultivation on assessing the microbial communities in caves, and can provide advice on the correct culture media to use. For example, if the community growing on plant detritus is to be examined, then a media that contains this material will provide a better growth media.

When using tools developed for use in the medical setting, such as BBL and API metabolic tests, it is unclear whether previously uncultivated cave species have the same metabolic profiles as human pathogens. If this is the case, the use of such medically relevant techniques can often lead to incorrect information, often biasing results toward finding human infectious organisms when they are not present. It should also be noted that many human bacterial and fungal pathogens share non-pathogenic relatives in the cave environment, and therefore their identification does not necessarily indicate the presence of human impact. A much more reliable technique is to use the 16S ribosomal RNA sequence and genetic comparisons; however, this is an expensive proposition, especially given the likelihood of tens-of-thousands of different microbial species present in each cave system.

Considerations for monitoring regime

Microbe communities can change from sampling event to sampling event and over short distances. Long-term monitoring most likely will not be feasible or effective, except for water quality/pollution assays. Inventories, however, may be useful if an NPS unit finds something very unusual in the cave and wants to learn what it is.

Discussion

Although microbial communities may be invisible, it is still important to preserve them. Using minimum impact caving techniques such as avoiding unnecessary touching, cleaning cave gear between trips, not leaving any crumbs or any other evidence that you've been in the cave will help keep the microbes in the most natural state possible; one crumb is enough to feed a million microbes for weeks or even months (Barton 2006).

One goal is to decrease lint from visitors, as the natural, organic fibers from clothing and skin and hair normally shed by people provide an external source of food for microorganisms. Microbial growth results in production of organic acids that can damage underlying rock and speleothems. Lint input could be limited by advising visitors of the best types of clothing to wear, having visitors walk through blowers before entering the cave to remove lint, or even by limiting access to the cave.

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3.0 General Guidance for Inventory and Monitoring of Cave Ecology

3.1 Deciding What to Monitor (Decision Tree)

Section 2.0 discussed potential targets for cave managers to monitor to better understand their cave ecosystems. However, monitoring everything mentioned in that chapter would clearly be unfeasible given time, money, and staff constraints. So how does a manger decide what to monitor? Here we provide a path for determining just that.

It should be noted that although this document concentrates on the Inventory and Monitoring Framework that is in place throughout the NPS, another method may be useful for managers. The Ecological Integrity Assessment Framework (EIAF) provides a detailed characterization of a resource or site as a precursor to identifying management strategies (Unnasch et al. 2008). The EIAF uses three steps: identifying what's important, developing metrics to characterize the integrity of the focal ecological resources and shifting to the management of focal ecological resources. The EIAF is currently being used in some Natural Resource Condition Assessments (e.g., Great Basin National Park).

When using the Inventory and Monitoring Framework, before monitoring can proceed, data mining and inventories must first be conducted. Data mining will help managers decipher past efforts and understand the current state of knowledge on potential monitoring targets. This is an important step for planning inventories and avoiding duplication of efforts. Basic inventories include specific biota, cave habitats, and threats to caves. Specific biota inventories may focus on something the park is known for, such as bats, or for more obscure biota, like microbes or springtails. Park managers need to know something about the cave habitats in their areas. Are the caves wet, dry, vertical, horizontal? Do they contain ice, bad air, or any other special features that could affect cave ecosystems? A threats inventory can begin with the basic question: What do we know or suspect is altered from the natural condition that would have negative effects on cave life?

Following inventories, managers can prioritize monitoring. Several categories of biota to monitor may appear:

- Threatened and Endangered (T&E) Species -- Often parks must meet goals for monitoring these species. They also have additional regulatory protections that go beyond those provided for other species. T&E species may not always reflect the overall health of the ecosystem. However, T&E species are generally more vulnerable to climatic changes or human disturbance, so a change in their population levels could be an early indicator of a problem with overall ecosystem health.

- Keystone Species -- Species which have a disproportionately large effect relative to their abundance. They play a critical role in determining and maintaining community structure of an ecosystem.

- Representative Species -- Species that can represent all or a portion of a cave ecosystem are cost-effective targets.
- Sensitive Species -- Species that are sensitive to change, where monitoring might be most likely to detect changes. In part this requires an assessment of what likely/possible changes might occur: wildfires? climate change? changing vegetation structure? new construction? changing hydrological regimes? oil & gas prospecting?
- Rare Species -- Rare and unique species that are vulnerable, and thus awareness of their condition is important; State Natural Heritage Programs are an excellent resource.
- Indicator Species – Species that indicate a problem, for example, coliforms indicate fecal contamination of water supplies. An indicator species can represent the health of the entire ecosystem.
- Special threats -- Species which already have known potential/impending threats, such as White-nose Syndrome in bats, might be particularly appropriate monitoring targets.

Below is a suggested flowchart for deciding what to monitor. Starting at the top, managers need to ask if inventories have been conducted. If not, that needs to occur before monitoring. Once results for inventories are available, managers can prioritize monitoring. We suggest that T&E species be considered first, as often there are mandates for their monitoring. Then we suggest monitoring for keystone species, as they will often give you the most bang for your buck. If resources are available, then proceed to monitoring representative/sensitive species. If more funding is needed, see Chapter 6.0 for partnering and funding opportunities.

Other considerations for what to monitor:

- What level of identification expertise is available in-house?
- Would it be feasible (time, money, personnel, resources) to obtain appropriate expertise?
- What would be the recurring, yearly cost incurred in monitoring?
- Will funding sources support long-term continuation of monitoring?
- How much time would it take to conduct the monitoring?
- How likely is it that the findings of the monitoring will have substantive impacts on management practices?
- If change or a "problem" is detected, what procedures do we have in place to decide what actions will be taken? What is the potential for actions to improve the situation?
- Will monitoring produce data that are of sufficient quality and quantity to allow for statistical analyses?
- Is the monitoring capable of detecting actual change, as opposed to variation within confidence intervals of the methodology?
- To what extent will the life history of the organism impact results of the monitoring?
- Could the monitoring cause damage (to the cave, to the organisms being studied) which exceeds the benefits of monitoring?

- What kinds of baseline data (perhaps inventory data) are needed prior to beginning a monitoring program?
- What kinds of data are needed prior to determining what should be monitored?

Splitting up funding priorities can be done in multiple ways. Finding ways to monitor various categories would be advantageous. Otherwise, if a cave might have several T&E species, and all of the funding goes to those, the representative species would never be monitored. One solution could be to base funding on rough percentages, with the top category receiving X% of available funds, the second receiving Y%, and if additional funding can be found, rare species would be monitored.

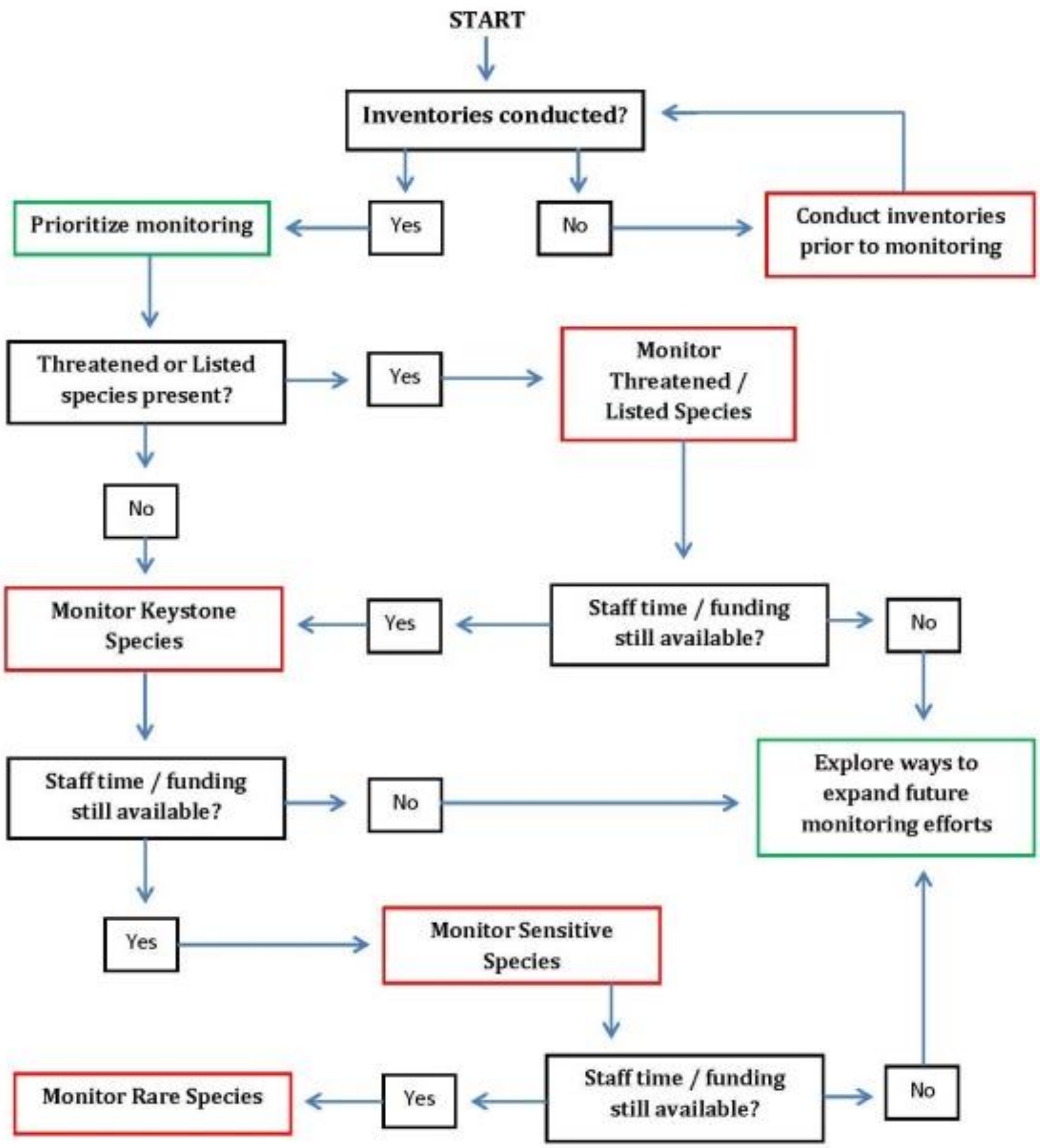

Figure 9. Decision Tree for Monitoring Cave Ecology.

Following prioritizing monitoring, it is essential to develop monitoring questions so that the proper methodology can be used. How many data loggers, how many caves, and for how long are all important considerations in designing an environmental monitoring program, along with considerations of cost and effort. The answer to all questions is: It depends. What are you trying to learn or what question will you try to answer? Is it for a specific location or specific cave, or park-wide to detect a small scale trend over 1-3 years, a system wide tend in 5-10 years, or decadal trends within 30 years (E. Ring, personal communication)?

3.2 Best Management Practices for Work in Caves

Caves are fragile environments. Speleothems, or cave formations, are often delicate features which have formed over thousands to millions of years. Many such formations are vulnerable to breakage if touched or inadvertently bumped into. Unlike a flower in a field which may grow back next year, a cave formation, once damaged, may take thousands of years to recover, if ever. Thus, monitoring of resources and specific areas selected for monitoring must be weighed carefully against the possibility of essentially irreversible damage to cave resources.

More subtle damage also can be caused by humans. Dirt and dust raised during resource management activities may settle on actively growing formations and become embedded in them as calcite is deposited. The ground underfoot is home to a wide variety of tiny organisms which may be trampled and crushed; even if these small animals escape immediate death, the footsteps of resource managers and other cave visitors can cause substrate compaction which may make formerly available habitat unusable to the organisms in the caves. Permanently marking sampling sites in caves may cause damage.

Due to the sensitive nature of the cave environment and the ease with which irreversible damage can occur, working in caves requires strict adherence to low-impact caving techniques. Anyone working in caves needs to be provided with proper training and knowledge regarding travel etiquette and preventative practices. If cave-specific guidelines have been established for a site, workers need to understand and adhere to these guidelines. If no specific guidelines have been established, workers should take a conservative approach to cave travel with the goal of minimizing impact.

Travel through caves may in some cases require following an established trail that may be delineated by flagging or reflective markers. Travel should generally proceed in a single-file line to confine impact to a narrow path. While traveling, cavers should maintain a pace that is comfortable to all members of the group. Traveling slowly and deliberately through particularly fragile cave sections is necessary to minimize the chances of impact, such as breaking cave formations or contaminating pristine cave pools. When resting, cavers should stay within the boundaries of the trail (if delineated) or find suitable surfaces within the travel route that avoid fragile formations or delicate substrates. When eating, cavers should hold all food items over a sealable bag to catch crumbs. When leaving a rest area, cavers should inspect the area to ensure that no trash is inadvertently left behind (Tuohy 1998).

Occasionally, caves may contain both “clean” and “dirty” areas. Clean areas are generally characterized by flowstone surfaces and calcite/aragonite deposits on walls and ceilings, whereas dirty areas may contain mud or silt deposits on the cave floor. To avoid tracking sediment from dirty to clean areas, alternate routes that bypass clean areas, if available, should first be considered. If alternate routes do not exist or are unsafe, changing areas will be required. In this situation, cavers will need to bring a tarp to change on and a set of “clean gear” to change into for crossing or working in clean areas. At a minimum, clean gear should include aqua socks or other suitable, non-marking footwear, an extra set of clothing, and an extra pack for containing dirty gear. Wet wipes can be used to clean durable items, such as helmets.

White-Nose Syndrome

White-nose Syndrome (WNS) is a disease new to North American bats that is devastating populations of seven hibernating bat species in North America. The cause is a fungus, *Pseudogymnoascus detructans,* that was confirmed as the causative agent of WNS in 2011. WNS was first reported from caves in New York State during the winter of 2006-07. It is now reported in or immediately adjacent to ten National Parks. The disease continues to spread through the movement of bats and possibly by humans, and has been confirmed in 25 states and 5 Canadian provinces. Since 2006 over six million bats have died.

Of the 45 species of bats found in North American, more than half hibernate and are potentially at risk of infection. To date seven species and subspecies of cave-hibernating bats are affected by WNS, including the Gray bat and the Indiana bat. Based on population-level studies, two species of bats are predicted to be extinct in 20 years, Indiana bats and Northern long-eared bats.
The fungus, *Pseudogymnoascus destructans*, was new to science. It grows best under low temperatures of 5-14° C (40-55° F) and high humidity typically found in caves used by hibernating bats. Infection changes the behavior of bats, with many flying during the day and during the winter in search of food. The bats rouse from hibernation, using up fat reserves at a higher rate than normal, causing them to leave the cave during the winter in search of food. The fungus is likely an invasive species from Europe. Genetic studies have confirmed that the fungi from both continents are the same. WNS was not known in Europe.

WNS has spread along bat flyways, showing the natural spread of the disease, but there are concerns that humans may also spread the disease and could move it long distances in a short time. The U.S. Fish and Wildlife Service (USFWS) recommends avoiding direct contact with bats, contaminated environments, or objects. Wear barriers, and disinfect yourself, clothing, boots, and any objects brought into the cave. Also important is to use covers to prevent contamination of your vehicle, allowing spread of the fungus.

With the spread of WNS in many NPS units, it is imperative that all working in NPS caves be familiar with the USFWS guidelines for WNS decontamination, as well as the most up-to-date information on White Nose Syndrome. This link contains the most current news: http://www.WhiteNoseSyndrome.org

3.3 Personnel Requirements and Training

Personnel designated to conduct cave ecology inventory and monitoring will need to be trained and capable of entering cave environments. For monitoring programs, in order to avoid biased data due to discrepancies between observers, staff must be consistently trained. Training should seek to standardize observations in different lighting conditions, in different habitats, and, perhaps most difficult, between years. Training should also ensure that all observers identify targets correctly. Training is necessary at the beginning of every field season, and recalibration is needed mid-season as well. Some monitoring targets discussed in this document will require employment of observers with more experience. Other protocols may be accomplished by staff with less experience and/or may be adaptable for implementation by dedicated volunteer groups.

Personnel must be aware of safe caving practices (e.g., Jones 2009), including vertical caving techniques where necessary. They must be able to follow minimum-impact caving practices, including packing out garbage and human wastes (Tuohy 1998). They must also receive training for the inventory and monitoring component that they are completing.

Qualified crew members may include park staff, researchers, grotto members, students, and volunteers. These crew members should be experienced in coping with the cave environment of that area, which may be wet, dusty, cold, hot, small, or vertical. Team members need to be physically fit and able to function in a variety of cave environments.

The project leader and experienced personnel will maintain their qualifications for monitoring. For new crew members, training sessions will include an orientation to the monitoring protocol, surface demonstrations, and on the job training.

3.4 Safety

Safety is the first priority for all NPS activities. Before beginning any caving, a Job Hazard Analysis (JHA) should be conducted. A sample ~~one~~ JHA is included in Appendix E. Prior to entering a cave, the plan for the cave trip should be established and appropriate for the task at hand and the available people for the trip. The trip leader should notify a surface contact of where field personnel are planning on going each day and when they will be back. Volunteer field crews should be trained on park check-in and check-out processes.

In addition to practicing low-impact caving, cave work requires careful attention to safe caving practices and use of proper caving equipment. Though responsible, experienced cavers rarely have accidents or injuries, proper training is required for those that may be new to the cave environment or out of practice. All personnel working in caves need to be equipped with a helmet (UIAA and/or CE certified), helmet-mounted light with adequate illumination, rugged ankle-supporting boots and clothing, kneepads, gloves, and a cave pack containing water, food, spare headlamps, extra batteries, medical kit, and containers for capturing human waste. Dependent on specific cave conditions (e.g., cold temperatures, presence of water, tight spaces), additional protective items such as cave suits, insulating layers, or elbow pads may be required. Vertical caving equipment, including descending and ascending gear, ropes, and rigging gear, may be required for negotiating caves that contain vertical drops and/or traverses. It is imperative that anyone performing work in a vertical cave be adequately equipped for vertical obstacles, and most importantly, be skilled and knowledgeable in vertical caving techniques. Additional safety measures need to be taken for wet caves and for caves with suspected bad air, such as taking an oxygen or carbon dioxide meter.

3.5 Scheduling Work

Scheduling cave inventory and monitoring will depend on many factors, including:

- when are caves most accessible,
- life history of the targeted species,
- availability of personnel,
- visitation of targeted cave, and/or
- recommendations of experts for that taxa.

If in doubt, it is best to consult experts in that field to determine when the work should be scheduled.

3.6 Monitoring Surrogates

If the species of interest is too delicate or too difficult to monitor, it may be possible to monitor it using surrogates. Surrogates could include abiotic factors such as temperature, humidity, precipitation; monitoring a closely-associated species (something that is prey or predator to the species of interest); or monitoring signs that the species leaves behind (e.g., scat or tracks). For instance, surrogates are used in monitoring water for fecal contamination. There are too many potential pathogens to test for, so we monitor *E. coli*, which is always present if there is fecal pollution, numbers are quantifiable with the amount of pollution, it does not multiply in water, and lives longer than other pathogens.

One example of monitoring surrogates is looking at the long-term effects of weather on cave crickets, which is done by monitoring guano community invertebrates (Poulson et al. 1995). Numbers and diversity of invertebrates change with the amount of cricket guano input, which is controlled by the weather, and which determines success of foraging by cave crickets.

The surrogate does not have to be a specific species. Schneider and Culver (2004) established subterranean species richness using intensive sampling and rarefaction curves in a cave-dense region of West Virginia. They calculated that 89% of species richness could be determined by sampling the largest 7 caves out of the 65 caves sampled. Using cave length as a surrogate for species richness gave nearly the same result as intensive sampling. Knowing the status and vulnerability of cave species facilitates their preservation, and many species, including rare ones, could be protected and monitored by focusing on study and preservation of the largest caves. But Schneider and Culver's

(2004) estimates suggested that only half of the species were collected, showing the need for caution in interpreting the results, and the need of intensive sampling to establish a useful baseline.

An example of surrogate monitoring is at Tumbling Creek Cave in Missouri, which is the only known habitat for the Tumbling Creek Cavesnail. In 1975 about 15,000 snails were found, and numbers steadily dropped to about 150. The snail was listed as Endangered in 2002. They have used a surrogate snail species to develop effective techniques and identify problems in raising the snails. The snail propagation facility uses water from a deep well, so it could serve as an emergency refuge for cave invertebrates in the event of a pollutant spill that would impact the cave (http://www.tumblingcreekcave.org/4_protection.html).

3.7 Lab and Office Methods

3.7.1 Specimen Vouchers, Tissue Samples, and Photo Vouchers

Answering some questions about cave biota and habitats may require collection of specimen vouchers and/or tissue samples. All research and collections in NPS areas require a NPS Scientific Research and Collecting Permit. Collections can assure future researchers and managers that identifications are correct. In addition they can have unforeseen benefits, such as retroactively determining when invasive species arrived at network parks or evaluating the relationships between species. Applications for NPS research permits are made online at: https://irma.nps.gov/rprs/Home

Although photography in cave environments can be challenging, regular photography of observed biota is essential; photographs should focus on species-distinguishing features, as many species are difficult to differentiate.

Final protocols for any monitoring program should include species verification procedures such as:

- voucher collection procedures,
- procedures for avoiding harm to populations while conducting verification,
- procedures for collection of incidental mortality vouchers,
- voucher documentation and storage procedures,
- photography guidelines, and
- photography and document archive procedures.

3.7.2 Proper Preservation of Specimens

For species that could not be identified in the field, care should be taken to photograph the unknown species at multiple angles both in-hand and in the natural environment. The camera should have a macro lens so field crews can zoom into unique features of the organism. A photographic scale bar or ruler should be included in the photos. Once out of the field, the images should be reviewed by park staff to see if it can be identified; if not, a specialist should be contacted. Once the species is identified, datasheets, databases, and the photographic key should be updated. For many invertebrates, photographs will not suffice for species-level identifications, especially where detailed invertebrate bioinventory work has not been completed.

For species that are deemed to be new records for that site, the team should determine if one of the people present has a collecting permit to make collections, and if so, they should collect the specimens in 95% Ethanol. Use the forceps, paintbrush, and/or eyedropper to handle them as delicately as possible to avoid breaking off setae, antennae or legs. Because many caves have been visited infrequently by invertebrate biologists, and the detectability of cave organisms is extremely low, there is a high likelihood that the researchers performing this SOP have the potential to record new localities, range extensions, or even new species. For this reason, the team should be prepared to make collections that can later be sent to taxonomic specialists for identification. Any specimens collected should have a label (often pencil on Rite-in-Rain paper) inserted in the vial with the following minimum information: Location in cave, Name of Cave, NPS unit, Date, and Collectors.

3.7.3 Shipping to Taxonomic Experts

It is important to contact taxonomic experts in advance. Taxonomic experts for some taxa are few and far between, as many are retiring. Each taxonomic expert may have a preferred way and timeframe for receiving material.

4.0 Data Management

We encourage cave managers to consider data management as an integral component of monitoring. Development of databases and data sheets should be tightly integrated with monitoring protocols to improve the efficiency and success of the monitoring program. This *Cave Ecology Framework* is not mandating that any park or region must follow one specific data management plan. Although it would be advantageous in many ways to have a nationwide cave ecology database, at this time neither funding nor time is available for such an endeavor. However, if all parks conducting cave ecology projects consider the recommendations herein, the potential for assembling a large nationwide database in the future, if desired, will be improved. We refer readers to the Klamath I&M Network protocols (Krejca et al. forthcoming) for specifics in data management with regards to a cave ecology program. For more general information, see http://science.nature.nps.gov/im/datamgmt/assets/docs/DMPlans/National_DM_Plan_v1.2.pdf.

Data management for a monitoring project is a cyclic process that begins during the planning phase of a project and continues until the close-out of the season. This process is then repeated each year the project is implemented and includes planning, training, data collection and entry, validation and verification processes, documentation, distribution of project products, storage, and archiving (Mohren 2007).

It is important to ensure that project personnel understand all necessary data management methodologies, including who is responsible for implementing the methods and the timelines they are expected to follow when conducting data management.

Important components of a Data Management Program for cave ecology include:

- Overview of Database Design
- Data Entry
- Photographic Data
- Map Data
- Quality Review
- Metadata Procedures
- Sensitive Information
- Data Certification and Delivery
- Data Archival Procedures

5.0 Data Analysis

Analysis of cave ecology data can be varied. Before any data are collected it is recommended that a statistician or someone with a great deal of experience with statistics be contacted. This person can help ensure that the data gathering will result in meaningful data. A word of caution, however; statisticians should be familiar with ecological principles and work closely with ecologists to ensure ecologically sound conclusions are reached.

Pilot data, or data gathered during a short-term or small-area pilot testing period, can help inform whether the data being gathered are useful. It can also be used to help conduct a power analysis to establish the sample size needed to determine an effect of a given size with a specified level of confidence.

We encourage the use of R as an integral component of any monitoring project. R is a powerful language and environment for statistical computing and graphics, runs on Windows, Mac, and Unix computers, and is freely available at http://www.r-project.org/index.html. The R Wiki provides an online forum at: http://wiki.rproject.org/rwiki/doku.php. R is rapidly becoming the analytical environment of choice for ecologists.

Many cave ecology projects target very rare species that are not conducive to data analysis used for surface ecology projects. This section touches on some of these considerations, as well as overarching considerations.

5.1 Power Analyses

In statistics, power is the proportion of times that the null hypothesis is rejected in favor of the alternative hypothesis given that the alternative hypothesis is true. Power analyses are used to determine the statistical power of sampling scheme given natural variability.

Examples of questions related to monitoring cave climate variables at Oregon Caves National Monument and Lava Beds National Monument (Krejca et al. forthcoming) include:

1) How many data loggers are needed to determine annual trends in temperature and relative humidity for the cave? How many years are needed to detect annual trends in both parameters?

2) How many caves are needed to monitor park-wide annual trends in temperature and relative humidity for each zone (deep, middle, entrance, outside)? How many years are needed to detect annual trends in both parameters?

5.2 Quality Assurance/Quality Control

Quality assurance (QA) refers to the overall *management system* which includes the organization, planning, data collection, quality control, documentation, evaluation, and reporting activities of the group. QA provides the information needed to ascertain the quality of data and whether it meets the requirements of the program. QA ensures that data will meet defined standards of quality with a stated level of confidence. *Quality control (QC)* refers to the routine *technical activities* whose purpose is, essentially, error control. The procedures carried out specifically for QA/QC purposes should be fully described in a Quality Assurance Project Plan (QAPP). More information on developing a QAPP can be found at: http://epa.gov/region9/qa/projplans.html.

5.3 Preliminary Data Analysis

A large suite of statistical parameters (for example, mean, standard error, median, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum, maximum, sum, and t-distribution confidence interval) could be calculated for continuous data (such as temperature data). The protocol lead should then inspect these parameters and determine whether any of them have changed significantly over time or differ more than expected between locations. Box-and-whisker plots may be useful in identifying outliers, both those that are true representations of the conditions of the vital sign and those caused by measurement errors.

5.4 Presence/Absence—Occupancy Estimation

Due to the need for reliable inference in monitoring programs and the high potential for imperfect detection of target organisms during monitoring, occupancy estimation and modeling can be a useful tool (Mackenzie et al. 2006).

5.5 Trend Analysis

It will take several years of data before it can be analyzed for trends using statistical methods. Below is information that may be helpful to perform trend analysis, based on other I&M Protocols (Caudill et al. 2012).

5.5.1 Visual Assessment

The first step in trend analysis is to plot the data that will be analyzed and look for apparent trends. If the data are highly variable, then use a smoothed line generated using an algorithm such as LOWESS (Helsel and Hirsch 2002). While trends observed in the visual assessment step may not be statistically significant, they can provide an overview of how a parameter has changed over time. For example, if the smoothed trend lines hint that a trend has been up for 10 years and then down for 10 years, a typical monotonic trend test might conclude "no trend" (Manly 2001). This conclusion might be less helpful to a resource manager than a conclusion that might be had by looking at a simple plot of values vs. time.

5.5.2 Parametric vs. Non-Parametric Trend Testing

There are two general types of trend analyses that can be performed: mixed-model parametric trend-testing and non-parametric trend testing using various Kendall tests.

5.3.3 Trend-Testing Methods

The Mann Kendall Test (MKT) is a statistical method used to assess trends in data sets. The advantages of this test are that it is widely-used, non-parametric, and applicable to any type of monotonic trend (i.e., not just linear changes).

The Seasonal Kendall Test (SKT) is used to detect trends in seasonally-variable data (e.g., Hirsch et al. 1982). The data are binned into seasons by the user, and MKT is performed for each season. The results from all seasons are then combined into a single test. Refinements to the SKT are corrections for serial correlation if 10 or more years of data are available (Hirsch and Slack 1984) and modifications to allow data from multiple sampling locations to be combined into a single test of regional trend (Helsel and Frans 2006).

The statistical analyses using MKT, Regional Kendall Testing, and SKT can be conducted using kendall.exe, a software program available from the USGS (Helsel et al. 2006).

5.5.4 Generalized Linear Mixed Models

Count data and, with manipulation, percentages and proportions are not amenable to traditional statistical analysis wherein the variance is assumed to be constant and the errors normally distributed. For example, data on proportions (e.g., the proportion of small cave crickets in an entrance population), where all categories of the data are known, exhibit variance that is an inverted U-shaped function of the mean (Crawley 2002). Thus, for example, to determine whether there are differences in the proportion of juvenile cave crickets among entrance populations, and the factors that might significantly affect those differences, the data can be analyzed using Generalized Linear Mixed Models (GLMM). GLMMs are similar to Generalized Linear Models but provide a more flexible approach when analyzing nonnormal data because the explanatory variables can be both random and fixed (Bolker et al. 2008). Random effects are factors whose interest lies in the variation among them, such as surveys replicated across sites or time, rather than the specific effects of each level.

5.6 Reports

Regular reports for any cave ecology monitoring will help managers better understand what is happening in the cave. Reports may follow standard scientific format (abstract, introduction, methods, analysis, results, discussion, literature cited), but will vary in length and focus depending upon the core topic addressed.

To the degree possible, efforts should attempt to summarize the status, trends, and dynamics in the diversity, distribution, and compositional changes in cave biological communities over time. We expect the report will have broad relevance to general management and interpretive planning at each park, as well as general interest to the public.

Periodical reports on the results of monitoring activities should be drafted following the guidelines provided on the "Natural Resource Publications Management Report Submission Procedures" website: http://www.nature.nps.gov/publications/nrpm/

5.7 Resource Briefs

Resource briefs are one to two page summaries about the current monitoring effort. These reports are designed to quickly inform resource managers about the work that has been completed and any significant results related to this effort. In addition, these reports are written in a non-technical manner so they can be delivered to all park staff who may be interested in our efforts.

6.0 Roles, Resources, and Partners

Developing and implementing a long-term cave ecological monitoring program is a complex and challenging prospect. National Park Service cave managers are well situated to act as catalysts for initiating and carrying out monitoring programs, however, they cannot, and should not act alone. Monitoring programs will be stronger and more likely to succeed with the input of other cave managers, resource specialists, researchers, cave conservation organizations, and more. This section outlines options for collaboration and partnerships, both within and outside of the NPS, in order to achieve monitoring goals.

6.1 National Park Service Roles and Resources

The NPS management of cave and karst resources operates through a complex, integrated web of parks, networks, regions, and national divisions that collaborate at multiple levels of involvement. Policy is shaped at upper management levels with input from parks, while the needs of parks steer the involvement and direction of national program support. Usually, inventory and monitoring of cave resources necessitates a park-based approach due to the unique character of local caves and cave biota. However, regional and/or national support and guidance is often appropriate when choosing monitoring parameters, developing methodology, soliciting reviews, and other programmatic needs.

6.1.1 Parks

Parks have the primary responsibilities for determining what the needs are for their management areas in order to fulfill the NPS mission. This may include periodic inspections of their cave resources, awareness of incoming threats, management of cave watersheds, and more. Parks then face the task of finding funding for the efforts they deem necessary. Fortunately, parks have many resources to turn to for assistance with cave and karst monitoring, including specialists at other cave parks and oversight from regional and national levels.

6.1.2 Networks

Parks with significant natural resources (270+ NPS units) are assigned to one of 32 ecoregional inventory & monitoring (I & M) networks that are drawn geographically. I & M networks share professional staff and funding to support natural resource baseline inventories and long-term monitoring of natural resource vital signs taking place within network parks, as well as associated data management. I & M networks are a valuable source for guidance and steering of natural resource projects. Networks encourage and facilitate collaboration among NPS units, and they often help parks develop relationships with researchers and partners that have mutual interest in natural resources occurring in the parks. More information on I & M networks and programs, including reports and protocols, is available through the NPS I & M website: http://science.nature.nps.gov/im/

6.1.3 Regions

The NPS is divided into seven Regions (Alaska, Intermountain, Midwest, National Capitol, Northeast, Pacific West, Southeast) that provide oversight to parks within their boundaries. NPS Regions employ natural resource specialists, ecologists, geologists, hydrologists, and geographic information systems (GIS) specialists who may be able to assist with cave monitoring questions.

Many regions also have funding available for park-sponsored projects. Contact information and links to additional resources are available through the Regions section of the NPS intranet.

6.1.4 Natural Resource Stewardship and Science Directorate

At the national level, the NPS operates several science-based divisions through the Natural Resource Stewardship and Science (NRSS) Directorate. These divisions specialize in natural resources such as air resources, biological resources, geologic resources, natural sounds and night skies, and water resources. Parks can request technical assistance and funding for natural resource projects by using the Technical Assistance Call (TAC) and the Servicewide Comprehensive Call (SCC), which are managed through this directorate. More information and contacts are available through the NRSS section of the NPS intranet.

The NPS Cave & Karst Program is a national program within the Geological Resources Division (GRD), and in most cases, this program will be the appropriate source for seeking assistance with cave ecological monitoring activities. Based in Lakewood, Colorado, the Cave & Karst Program offers support to all NPS units with cave and karst resources. The program may provide advice or referrals for simple requests or may suggest routing requests through the TAC if more complex support is required. Communication between NPS cave managers is essential, and the program supports this need by managing a listserve that is available by subscribing at: http://webmail.itc.nps.gov/mailman/listinfo/cave-karst. The listserve provides an avenue for managers to share cave-related information or request help on cave-related topics. More information and links to publications can be found on the Cave & Karst Program's website: http://nature.nps.gov/geology/caves/index.cfm.

GRD also houses a number of other programs, including paleontology, energy/minerals, and soils, that could potentially overlap with cave resources. Another NPS division, the Biological Resource Management Division (BRMD), provides general support for biological resources in the NPS. The BRMD is not usually cave-focused but does work with cave parks on cave-related wildlife issues, most notably white-nose syndrome (WNS). Other natural resource divisions are available to provide assistance to parks on cave-related matters if their areas of specialty are relevant. The National Inventory & Monitoring (I & M) Program is also a division of the Natural Resource Stewardship and Science Directorate and provides oversight to the 32 I & M networks.

6.2 Interagency Cooperation

Some caves extend beyond park boundaries, and certainly many karst watersheds do. There are many established precedents of the NPS working with adjoining land management agencies in the management and monitoring of cave resources. Agencies can also benefit from general cooperation across greater distances, ranging from specialized technical assistance with field activities to remote cooperation on policy development or general exchanges of information.

The *Interagency Agreement for Collaboration and Coordination in Cave and Karst Resources Management* was updated and signed in 2012. The agreement provides guidance for cooperation between federal agencies in the Department of the Interior (Bureau of Land Management, U.S. Fish and Wildlife Service, U.S. Geological Survey, National Park Service) and the Department of Agriculture (U.S. Forest Service). The agreement recognizes that agency cooperation can increase the effectiveness and efficiency of cave and karst management, provides agency authority and policy summaries, and identifies areas of cooperation. The agreement is available from several sources, including the NPS Cave & Karst Program website: http://nature.nps.gov/geology/caves/2012%2002%2024%20FINAL%20SIGNED%20CAVE%20KARST%20IA%20-%20FEB%2024,%202012.pdf

6.3 Partnerships

Parks across the country engage in innumerable partnerships to help achieve the NPS mission. Partners have become increasingly critical in assisting the NPS with implementing short-term projects, maintaining long-term monitoring programs, and responding to new challenges. Entering into partnerships often requires administrative and financial commitments from parks; however, the ability to acquire specialized assistance, the flexibility of arranging and scheduling activities, and oftentimes long-term cost savings may make partnerships an appealing and enduring path for advancing cave monitoring goals.

6.3.1 National Cave & Karst Management Symposium

The National Cave & Karst Management Symposium (NCKMS) provides a venue for cave and karst managers, professionals, researchers, and cavers to present on cave-related topics and share ideas and methods. This gathering of cave managers and cave enthusiasts is an ideal opportunity to form partnerships and advance the goals of cave conservation and monitoring. The first NCKMS was held in 1975, and they have occurred regularly since that time, generally every other year in rotating venues. The 2013 Symposium in Carlsbad, NM represented the 20th NCKMS. The National Cave Management Steering Committee provides oversight and organization of the symposia. The Steering Committee is primarily composed of representatives from federal agencies and independent cave conservation organizations. Papers and abstracts delivered at the symposia are published as Proceedings of the NCKMS. The NCKMS hosts a website at www.nckms.org/index.shtml

6.3.2 Cooperative Ecosystem Studies Units

The Cooperative Ecosystem Studies Units (CESU) National Network is comprised of national and local partners working to support resource stewardship by bringing together scientists, land managers, conservation professionals, students, and others to address shared resource issues. Federal agencies, tribes, academic institutions, nongovernmental organizations, and state and local governments represent some of the 300+ partners belonging to seventeen distinct CESUs. These regional CESU networks represent unique biogeographic areas that cover the U.S. and its territories. The NPS is a partner of the CESU National Network through a signed Memorandum of Understanding (MOU), and the NPS has a designated representative for each of the seventeen CESUs. More information is available through the CESU website: www.cesu.psu.edu

6.3.3 Academic institutions

While CESUs represent one avenue to potentially engage with academic institutions, assistance can also occur directly through an NPS Research Permit. Researchers, professors, post-doctoral students, and graduate students at colleges and universities often contact parks directly to request permits for conducting scientific research. Researchers working in cave parks or attending cave conferences provide a good source of specialized information, and cave monitoring programs can benefit from review by researchers with overlapping interests. In some cases, cave monitoring methodology may be developed in tandem with related research projects under an approved research permit. The NPS Research Permit and Reporting System (RPRS) is an online system for managing research permit applications, approved permits, specimen collections, and investigator annual reports. The system can also be used by parks to advertise research needs and indicate park-specific research guidelines. The RPRS can be accessed at https://irma.nps.gov/rprs/Home

6.3.4 Nonprofit and nongovernmental organizations

The NPS can seek assistance, guidance, and/or information from organizations that promote cave conservation and specialize in cave-related work. These partnerships are mutually beneficial and contribute to a wide network of professionals collaborating on cave management, monitoring, and research projects. A partial list of organizations that the NPS collaborates with on cave-related projects follows:

National Cave and Karst Research Institute
www.nckri.org
The National Cave and Karst Research Institute (NCKRI) is a nonprofit government-supported institute headquartered in the City of Carlsbad, New Mexico. Its goals are to conduct, support, facilitate, and promote programs in cave and karst research, education, environmental management, and data acquisition and sharing.

National Speleological Society
www.caves.org
The mission of the National Speleological Society (NSS) is to study, explore, and conserve cave and karst resources; protect access to caves; encourage responsible management of caves and their unique environments; and promote responsible caving.

Cave Research Foundation
www.cave-research.org
The Cave Research Foundation (CRF) is a private, nonprofit organization dedicated to facilitating research, management, and interpretation of caves and karst resources; forming partnerships to study, protect, and preserve cave resources and karst areas; and promoting the long-term conservation of caves and karst ecosystems.

Karst Waters Institute
www.karstwaters.org

The Karst Waters Institute (KWI) is a nonprofit institution whose mission is to improve the fundamental understanding of karst water systems through sound scientific research and the education of professionals and the public.

Geological Society of America
www.geosociety.org
The Geological Society of America (GSA) provides access to elements that are essential to the professional growth of earth scientists at all levels of expertise and from all sectors: academic, government, business, and industry. The Society's membership unites thousands of earth scientists from every corner of the globe in a common purpose to study the mysteries of our planet and share scientific findings.

Bat Conservation International
www.batcon.org
Bat Conservation International (BCI) is conducting and supporting science-based conservation efforts around the world. Working with many partners and colleagues, these innovative programs combine research, education, and direct conservation to ensure bats will be helping to maintain healthy environments and human economies far into the future.

6.4 Online Resources

In addition to the online presence and resources of the National Park Service and many of the partners listed above, there are numerous other websites that provide education and tools that can be of value to cave and karst management and monitoring. A partial list of online sites that specialize in topics relevant to caves and karst follows:

Karst Information Portal
www.karstportal.org
The Karst Information Portal is a digital library linking scientists, managers, and explorers with quality information resources concerning karst environments.

Speleogenesis
www.speleogenesis.info
Speleogenesis is a scientific network promoting scientific research and cooperation in karst hydrogeology with a special emphasis on speleogenesis.

White-Nose Syndrome
www.whitenosesyndrome.orgThis website is the central location for the coordinated North American interagency response to the devastating bat disease white-nose syndrome (WNS).

GIS for Caves & Karst
www.esri.com/industries/cavekarst
GIS offers a variety of tools and capabilities used in the management, analysis, and visualization of cave and karst information.

7.0 Conclusions

This *Cave Ecology Inventory and Monitoring Framework* is not an I&M protocol but provides peer-reviewed guidance for developing protocols. The background information and references provided are intended to give managers a solid starting point for pursuing inventory and monitoring of their resources. The Decision Tree will ideally guide managers through the process for deciding what to monitor.

It takes more than an idea and a framework to accomplish a project; it also takes funding and dedicated staff. The NPS Cave and Karst Program is currently conducting a data gaps analysis of cave and karst parks. This will help determine the greatest needs for additional cave ecology work and help direct funding to deserving parks. In addition, funding sources are available from a variety of sources as mentioned in Chapter 6.0.

The more we understand about cave ecology, the better we can protect the unique ecosystems that thrive below our feet.

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Appendix A: Cave Parks

The following NPS units have caves reported in them. This table was originally constructed by David Ek in 2001, and later updated by him, then by Gretchen Baker in 2008-13, followed by the National Cave and Karst Office in 2014. Yellow highlighted boxes indicate the most recent updates.

Park	Total Caves	Solution	Lava	Erosion	Tectonic	Talus	Glacier	Data Source
Abraham Lincoln Birthplace National Historic Site	1	1	0	0	0	0	0	
Acadia National Park	12	0	0	12	0	0	0	
Amistad National Recreation Area	30	30	0	0	0	0	0	
Aniakchak National Monument or Preserve	1	0	1	0	0	0	0	
Apostle Islands National Lakeshore	75	0	0	75	0	0	0	
Arches National Park	1	0	0	0	1	0	0	Karen Henker
Badlands National Park	50	0	0	50	0	0	0	*0 caves but thousands of pipes
Bandelier National Monument	2	0	2	0	0	0	0	
Bering Land Bridge National Preserve	113	0	100	13	0	0	0	
Big Bend National Park	7	7	0	0	0	0	0	
Big South Fork National River and Recreation Area	1	1	0	0	0	0	0	
Bighorn Canyon National Recreation Area	1	1	0	0	0	0	0	
Bryce Canyon National Park	1	1	0	0	0	0	0	
Buffalo National River	360	350	0	0	10	0	0	Chuck Bitting
Canyonlands	1	1	0	0	0	0	0	Karen Henker
Capulin Volcano National Monument	3	0	3	0	0	0	0	GRI Report
Carlsbad Caverns National Park	117	117	0	0	0	0	0	Dale Pate
Catoctin Mountain National Park	2	0	0	0	2	0	0	
Cedar Breaks National Monument	1	1	0	0	0	0	0	
Channel Islands National Park	369	0	0	369	0	0	0	

Park	Total Caves	Solution	Lava	Erosion	Tectonic	Talus	Glacier	Data Source
Chesapeake and Ohio Canal National Historical Park	25	25	0	0	0	0	0	Michelle Carter
Chickamauga & Chattanooga National Military Park	16	16	0	0	0	0	0	Steve Thomas
Colorado National Monument	2	0	0	2	0	0	0	GRI Report
Coronado National Memorial	9	9	0	0	0	0	0	Dean Schlinchting
Crater Lake National Park	51	0	0	51	0	0	0	Greg Holm
Craters of the Moon National Monument	344	0	342	0	0	2	0	Doug Owen email
Cumberland Gap National Historical Park	33	33	0	0	0	0	0	Jenny Beeler
Cuyahoga Valley National Park	2	0	0	0	0	2	0	GRI Report
Death Valley National Park	79	61	0	18	0	0	0	
Denali National Park	3	1	0	0	0	0	2	
Dinosaur National Monument	5	3	0	2	0	0	0	
El Malpais National Monument	290		290	0	0	0	0	Kayci Cook
Everglades National Park	1	1						Inside Earth, Lee Florea
Fort Donelson National Battlefield	1	1						
Gates of the Arctic National Park	7	7	0	0	0	0	0	
Gila Cliff Dwellings National Monument	7	0	0	7	0	0	0	Steve Riley
Glacier National Park	16	16	0	0	0	0	0	Glacier Cave Management Plan
Glacier Bay National Park	21	21	0	0	0	0	1	Wayne Howell
Golden Gate National Recreation Area	119	0	0	119	0	0	0	
Golden Spike National Historic Site	3	3	0	0	0	0	0	Cami McKinney
Grand Canyon National Park	511	511	0	0	0	0	0	Steve Rice email
Grand Teton National Park	17	17	0	0	0	0	0	
Great Basin National Park	46	46	0	0	0	0	0	Ben Roberts
Great Smoky Mountains National Park	10	10	0	0	0	0	0	
Guadalupe Mountains National Park	27	27	0	0	0	0	0	GRI Report
Haleakala National Park	24	0	24	0	0	0	0	

Park	Total Caves	Solution	Lava	Erosion	Tectonic	Talus	Glacier	Data Source
Harpers Ferry National Historical Park	2	2	0	0	0	0	0	
Hawaii Volcanoes National Park	155	0	155	0	0	0	0	
Jewel Cave National Monument	10	10	0	0	0	0	0	Rene Ohms
Kalaupapa National Historical Park	16	0	16	0	0	0	0	
Kaloko-Honokohau National Historical Park	4	0	4	0	0	0	0	
Kenai Fjords National Park	12	0	0	12	0	0	0	
Kings Canyon National Park	12	12	0	0	0	0	0	
Lake Mead National Recreation Area	2	2	0	0	0	0	0	
Lava Beds National Monument	700+	0	700+	0	0	0	0	Shane Fryer
Mammoth Cave National Park	384	384	0	0	0	0	0	Lillian Scoggins
Mojave National Park	44	40	4	0	0	1	0	Ted Weasma
Montezuma Castle National Monument	2	2	0	0	0	0	0	GRI Report
Mount Rainier National Park	5	0	0	0	0	0	5	
Natchez Trace Parkway	5	5	0	0	0	0	0	
Noatak National Preserve	4	4	0	0	0	0	0	
Obed Wild and Scenic River	1	0	0	1	0	0	0	
Olympic National Park	3	0	0	3	0	0	0	
Oregon Caves National Monument	12	12	0	0	0	0	0	
Ozark National Scenic Riverways	320	320	0	0	0	0	0	
Parashant National Monument	35	35	0	0	0	0	0	
Pecos National Historic Part	2	2	0	0	0	0	0	Paul Burger and Stan Allison
Pea Ridge National Military Park	1	1	0	0	0	0	0	
Pictured Rocks National Lakeshore	1	0	0	1	0	0	0	Tom Richer
Pinnacles National Monument	8	0	0	0	0	8	0	GRI Report
Point Reyes National Seashore	139	0	0	139	0	0	0	
Pu’uhonua o Honaunau NHP	6	0	6	0	0	0	0	
Redwood National and State Parks	2	0	0	2	0	0	0	

Park	Total Caves	Solution	Lava	Erosion	Tectonic	Talus	Glacier	Data Source
Rocky Mountain National Park	1	0	0	0	0	0	1	
Russell Cave National Monument	10	10	0	0	0	0	0	
Saint Croix National Scenic Riverway	12	0	0	12	0	0	0	
San Juan Island National Historic Site	1	1	0	0	0	0	0	
Sequoia National Park	240	240	0	0	0	0	0	GRI Report
Shenandoah National Park	2	2	0	0	0	0	0	GRI Report
Stones River National Battlefield	2	2	0	0	0	0	0	GRI Report
Sunset Crater Volcano National Monument	1	0	1	0	0	0	0	
Theodore Roosevelt National Park	6	0	0	6	0	0	0	
Timpanogos Cave National Monument	8	8	0	0	0	0	0	Cami Pulham McKinney
Valley Forge National Historical Park	6	6	0	0	0	0	0	GRI Report
War in the Pacific National Historical Park	12	12	0	0	0	0	0	
Wilson's Creek National Battlefield	3	3	0	0	0	0	0	GRI Report
Wind Cave National Park	44	44	0	0	0	0	0	Marc Ohms/ GRI Report
Wrangell-St. Elias National Park	4	3	0	0	0	0	1	
Wrangell-St. Elias National Preserve	4	4	0	0	0	0	0	
Wupatki National Monument	12	0	0	0	12	0	0	
Yellowstone National Park	6	5	1	0	0	0	0	
Yosemite National Park	11	1	0	0	3	6	1	
Yukon-Charley Rivers National Preserve	6	6	0	0	0	0	0	
	5095	2496	1649	894	28	19	11	

Appendix B: Example of Cave Classification Scheme

One way to classify caves is with a three-part rating, including management (Table 1), resource classes (Table 2), and hazards (Table 3).

Table 1. Cave classification of management type of cave.

Class	Description
1	Caves or passages which are developed. Developed caves provide an opportunity for most visitors to tour a cave without special clothing, equipment, knowledge, or skills.
2	Caves or passages which are undeveloped, and which may be visited only with an NPS, or NPS-designated or approved trip leader, and an approved permit. Such caves contain particularly sensitive geologic or cultural features.
3	Caves are undeveloped caves that may be visited by caving groups without an NPS, or NPS-approved guide.
4	Class 4 caves are closed to general use pending further evaluation or research.
5	Caves are closed to general use because they contain paleontological, archeological, geological, biological or other resources of special scientific value that would be easily altered, even by careful use of the cave.
6	Class 6 caves are closed to all use except the absolute minimum required for administrative purposes. These caves are closed because of extreme, unavoidable hazards for even the most skilled caver, (rockfall, disease, poisoned or dangerous atmosphere, etc.) or because entering them would cause irreparable harm to a fragile resource or to an endangered species, which is threatened by use of the cave.

Table 2. Cave classification by resource classes.

Class	Description
A	Class A Caves contain few or no features presently recognized to be unique. Mineral deposits would only include durable types such as flowstone and large stalactites or stalagmites. No historic or significant biological resources would be present in Class A caves. These caves can withstand frequent visitation from cavers with little or no resource degradation.
B	Class B Caves contain only mildly delicate speleothems including smaller stalactites or stalagmites than Class A Caves, short soda straws and large curtains. In general speleothems are of such a size or are located where they are unlikely to be damaged by normal cave use. Biological resources are not unique and are not sensitive to the activity of people. Class B caves have no paleontological or archaeological resources.
C	Class C caves may contain delicate speleothems such as rimstone dams, soda straws over 6 inches in length, narrow columns, stalagmites and stalactites, small helictites and thin curtains. In general speleothems are of such a size or are located where damage or vandalism is likely. Biological activity may include several viable interdependent species, all of which can withstand the activity of people. Paleontological and archaeological resources are limited and not significant.
D	Class D Caves contain speleothems that are of unusual quality and/or are extremely delicate and susceptible to breakage, or resources of value that could be seriously disturbed or destroyed by cavers. Examples of Class D speleothems include selenite needles, aragonite crystals, gypsum flowers or hair, dog-tooth spar crystals, long (over 12 inches) soda straws, moonmilk speleothems and large helictites. Other delicate resources could include pictographs, materials of archaeological value, soft sedimentary deposits, animal remains or a sensitive species of animal.
E	Class E caves contain resources of exceptional scientific value that would be seriously disturbed by frequent visits or by the visits of cavers unfamiliar with the cave's unique resources (resources may not be obvious). Such resources may be biological, geological, hydrological, archeological, ethnographical, or paleontological in nature. They may include rare or unusual speleothems.

Table 3. Cave classification by hazard classes.

Class	Description
I	Class I Caves are commercialized and feature a paved trail, handrails, a lighted route to follow, and a minimum of stooping or narrow passages, which can be easily negotiated by the average park visitor.
II	Class II Caves offer only minimal hazard to the caver. Characteristics include well-defined and obvious passage or passages; no passageways less than 60 centimeters (24 inches) in diameter that are used as the main route through a cave; no sudden drops over 1 meter (3 feet) high; no danger of flooding; small risk of hypothermia based upon the cave's air temperature, air flow and the temperature and amount of water in the cave; no known loose ceiling rock and few loose, floor rocks.
III	Class III Caves offer some potential hazard to cavers. They are mostly horizontal in structure and do not require rope work. Their characteristics include passages which may wind, curve and interconnect, but which are straight-forward and obvious; no passageways less than 45 centimeters (18 inches) in height or diameter that are used as the main route through a cave; no sudden drops over 3 meters (10 feet) and which are easily climbable; limited risk of flooding and hypothermia on the basis of the cave's temperature, air flow and the presence of water; no known loose ceiling rock; floor materials may be loose.
IV	Class IV Caves contain more extensive hazards than caves in Class I, II, or, III. Their characteristics include potentially confusing passages, which may exist on more than one level; passageways as small as 30 centimeters (12 inches) in height or diameter that are used as the main route through a cave; vertical drops less than 15 meters (50 feet) in depth some of which may require rope work; potential risk of flooding and/or danger of hypothermia based upon cave temperature, air flow and quantity of water in the cave; loose ceiling rock in larger passages and potentially unstable floors.
V	Class V Caves are the most hazardous from a structural standpoint. Their characteristics may include areas of confusing maze-type passages and multiple levels; passages less than 30 centimeters (12 inches) in height or diameter along main routes; vertical drops of more than 15 meters (50 feet) requiring ropes; a risk of flooding or a strong danger of hypothermia for the unprepared due to low cave temperatures and/or strong air flow and/or the presence of water; loose ceiling rocks in small passages and crawlways.
VI	Class VI caves contain extreme hazards due to unusual cave characteristics. This includes airborne diseases, dangerous gases, unpredictable flooding and the presence of unstable rocks of a size or in a location that is dangerous to cavers. Class VI caves should only be entered by highly skilled cavers employing specialized equipment and who have a compelling reason. Extra safety precautions such as special communications and pre-arranged rescue capabilities should be considered.

Appendix C: Process for Selecting Caves to Monitor

NPS units with an extant, searchable computer database with information on the caves within its boundaries make the process of selecting monitoring caves simpler. If the data are contained in paper files, the process is obviously slowed somewhat but the search criteria still largely apply. The following criteria may be considered more or less a sequential winnowing process to produce a short list of potential monitoring caves prior to field vetting. This example uses cave crickets at Mammoth Cave to describe the process of selecting caves to monitor.

1. If the cave database is searchable, an initial keyword search for files that contain the word “cave crickets” should greatly reduce the number of files that must be examined closely. Examine the resultant files for any description of relative abundance of cave crickets and use this as part of your decision matrix as to whether or not a particular cave should be included in monitoring.

2. Examine the file’s notes regarding ease of access to the cave. If getting to the cave is particularly arduous it should be included only if there is no alternative. Further, if the cave’s morphology is such that access can only be obtained by field assistants with technical skills (e.g., rope climbing) or tight spots that would complicate rescue it should likely be rejected.

3. Consult park maps to determine cave location with respect to the starting point of monitoring teams (i.e., offices). Location of the cave with respect to offices is an important criterion to consider beforehand because it will determine driving and/or walking distance. Travel time to and from the caves will likely have the largest effect on the amount of time monitoring crews spend in the field. GPS coordinates, if available from the file, should be downloaded or programmed into a GPS unit to facilitate finding the cave.

Through information gained from data mining, many of the same criteria used in the pre-vetting process are mentioned below. Often field notes on file can be vague and so clearly there is some value to confirming, in the field, the information gained during the data mining process. Field vetting is particularly useful if the notes from the database suggest a cave is marginally promising. The following criteria may be considered more or less a sequential winnowing process to produce a short list of potential monitoring caves to include in the scoring process. Standardized data sheets should be created for the field vetting process.

1. Trip times from base, including drive time/walking time, should be recorded on the field data sheet. Travel time may be an especially important criterion due to its potential to significantly increase time in the field. Potential monitoring caves can and should be considered with reluctance, and scored accordingly, if travel time is too great. Obviously, determining what constitutes a long journey is subjective but a long travel time could, all things being equal, result in rejection of a potential monitoring cave.

2. Ease of access, safety hazards, and sensitive resources should be noted on the field data sheet. Safety is an especially important criterion and any safety concerns about a potential monitoring cave should result in its rejection from the list.

3. The relative abundance of the monitoring subject in a potential cave is a significant criterion to note in the field vetting process. Notes on relative abundance of monitoring subjects should be recorded on vetting data sheets and cave maps. Cave maps are a useful part of field equipment in this part of the field vetting process. Cave maps can be marked, in pencil, where monitoring subjects found. Cricket guano deposits are particularly informative in determining where cave crickets regularly roost because roosts must be used over time to build guano deposits whereas clusters of cave crickets can be transient as they cycle to and from the cave entrance. A semi-quantitative method should be used to indicate relative abundance of cricket clusters on the map, e.g., circles of increasing size and numerical value, to facilitate scoring among caves during the Monitoring Cave Rating Process.

Prospective monitoring caves should be ranked from best to worst according to the criteria evaluated in the field vetting process. The ranking process involves assigning each criterion a weighted numerical value and using the sums of these values to rank the caves. The weights and importance assigned to each criterion in the rating process reflects their importance in obtaining adequate data during the sampling process. Not surprisingly, the semi-quantitative data on cave cricket abundance/population structure and cave ceiling height/relief obtained during the vetting process is weighted more heavily in the rating process than trip time and ease of access; this is because the farthest, most difficult to access caves were eliminated during the field vetting process. The cave with the highest summed value is ranked the best prospective monitoring cave and the rankings decrease sequentially to the worst ranked cave. The list generated in the rating process provides the user with defensible reasons why lower ranked caves may be excluded from a proposed sampling plan.

Appendix D: Protocols and Standard Operating Procedures

Monitoring Protocols and Standard Operating Procedures (SOPs) for specific protocols can be helpful to review for those considering similar work.

Here is an annotated list of Protocols and SOPs already in use:

SOP: Bats
Integrated Cave Entrance Community and Cave Environment Long-Term Monitoring Protocol, Klamath Network
This SOP gives instructions for surveying known small colonies (<1,000) of bats using a non-contact method: in-cave counts. These methods can be used any time of year, but are prescribed here for counting during the winter hibernation season at ORCA and LABE in order to focus on monitoring long-term population trends of the Townsend's Big-eared bat, *Corynorhinus townsendii*. Once at this website, click on Draft Long-term Monitoring Protocol and Sampling Procedures:
http://science.nature.nps.gov/im/units/klmn/monitor/caves.cfm

Protocol: Allegheny Woodrat Monitoring Protocol
Cumberland Piedmont Network
The Allegheny woodrat, *Neotoma magister*, is a native small mammal of interest on Mammoth Cave National and across the eastern USA, due, in part, to recent dramatic population declines. Woodrats are frequent visitors to the cave ecosystem and are important importers of organic matter, in the form of nesting materials, food caches, and fecal and urine deposition, into caves. These organic nutrients are known to support a specialized invertebrate cave community Richards 1989, 1990). Cave management and visitor activity may impact or inhibit woodrat access into and use of caves through imposition of physical barriers, such as cave doors, and various disturbance factors (noise, lighting, etc.). Woodrats, as surface foragers feeding on a wide variety of plant materials and parts (e.g., fruit, nuts and seeds, fungi, leaves, etc.) also relate to the terrestrial ecosystem, and may reflect larger-scale changes in vegetation communities through long-term changes in population performance and structure. The combination of being relatively widespread, important to the cave ecosystem, potentially sensitive to cave management and visitation impacts, and a strong dependent relationship with surface vegetation-based ecosystem performance make woodrats a useful indicator for park-level monitoring.
http://www1.nrintra.nps.gov/im/units/CUPN/monitor/woodrats/docs/MACA_Woodrat_Protocol_v3.1.pdf (access to NPS only)

SOP: Scat and Visible Organics,

Integrated Cave Entrance Community and Cave Environment Long-Term Monitoring Protocol, Klamath I&M Network

Scat monitoring detects and gauges the potential flow of surface nutrients into caves via waste from terrestrial mammals (especially rodents), bats, and birds. Caves will be divided into zones and the number of rodent scats in each zone will be noted by assigning it to one of four categories: None, 1–10, 10 – 100, or >100 scats. Other sources of organic input will also be noted such as nests, deceased organisms, and litter. Little training is required to implement this protocol. The KLMN will have primary responsibility for scat monitoring. To find this file go to:

http://science.nature.nps.gov/im/units/klmn/publications.cfm?tab=3

Click on 2010 Draft integrated cave entrance community and cave environment long-term monitoring protocol *Multiple Files (Zip).* Scroll down to SOP10_Scat_and_Visible_Organics and download.

Protocol: Cave Cricket Monitoring Protocol, Mammoth Cave National Park
Cumberland Piedmont Network
This monitoring protocol was written with emphasis on the cave-dwelling Orthopteran species, i.e., *Hadenoecus subterraneus*, inhabiting most caves found within Mammoth Cave National Park (MACA) boundaries. However, two cave cricket genera, i.e., *Ceuthophilus* spp. and *Hadenoecus* spp., are keystone species in caves throughout Department of Interior, Department of Defense, and United States Department of Agriculture land holdings in the southwest, including Carlsbad Caverns National Park, Fort Hood, and Lincoln National Forest, and in the southeast, including MACA, Russell Cave National Monument, Cumberland Gap National Historic Park and Chickamauga-Chattanooga National Military Park, respectively (Campbell 1976, Hubbell and Norton 1978, Studier et al. 1987, Studier and Lavoie 1990, Hobbs III 1994, Cokendolpher et al. 2001, Mays 2002, Taylor et al. 2003b). Thus, with modification, this monitoring protocol could be adapted for use in any government land holding with significant cave cricket populations of either genera.
http://www1.nrintra.nps.gov/im/units/CUPN/monitor/cavecrickets/cavecrickets.cfm (access to NPS only)

SOP: Cave Invertebrates

Integrated Cave Entrance Community and Cave Environment Long-Term Monitoring Protocol, Klamath I&M Network

This SOP gives step-by-step instructions for surveying invertebrates bait stations. To find this file, go to: http://science.nature.nps.gov/im/units/klmn/publications.cfm?tab=3

Click on 2010 Draft integrated cave entrance community and cave environment long-term monitoring protocol *Multiple Files (Zip).* Scroll down to SOP11_Invertebrates_V1.00_DRAFT_20100624.pdf

SOP: Cave Swallow (*Petrochelidon fulva*) Banding Project,
Carlsbad Caverns National Park, Eddy County, New Mexico

The Cave Swallow (*Petrochelidon fulva*) banding project has been conducted for over 20 years at the entrance of Carlsbad Caverns National Park. The main objective is to band Cave Swallows to study their winter range. During handling, the birds are also weighed, wings and tail are measured, and checked if brood patch is present, for maturity status, ectoparasites, and more. Over the years, additional data has been taken on birds handled and the data set for this population is very large.

Standard mist nets are used, about 3 m tall and 12 m long. Volunteers hold the nets in place, and the net covers about 40% of the cave entrance. Up to 14 volunteers help at any one time.

As of 31 December 2011, 21,049 Cave Swallows have been banded at the entrance to Carlsbad Cavern and 17,111 retraps have been handled. Retraps are birds that have already been banded previously. To date, no birds have been captured with bands placed there by other banders. Fewer than 25 of these retraps have been banded at other locations by this project.

<u>Protocol: Integrated Cave Entrance Community and Cave Environment Long-Term Monitoring Protocol,</u> Klamath I&M Network
This long-term cave monitoring protocol was created according to NPS and Klamath Inventory and Monitoring Network (KLMN) guidance and standards. It concerns two parks, Lava Beds National Monument (LABE) and Oregon Caves National Monument (ORCA), and provides the rationale and methods for monitoring cave climate; ice and water levels; human visitation; coverage of ferns, mosses, and lichen; bat colonies; scat deposition; and invertebrate communities in caves. The protocol consists of a descriptive narrative, Standard Operating Procedures (SOPs) for various tasks, and appendices of relevant information. These procedures were designed for long-term use by each park so that data could be collected consistently and provide defensible results for management of park resources, public interpretation, and scientific research. To find this publication, go to:
http://science.nature.nps.gov/im/units/klmn/publications.cfm?tab=3

Click on 2010 Draft integrated cave entrance community and cave environment long-term monitoring protocol *Multiple Files (Zip).*

<u>Protocol: Cave Aquatic Ecosystem Monitoring Protocol</u>, Mammoth Cave National Park Cumberland Piedmont Network
The overriding question addressed by this protocol is: Are biological communities within Mammoth Cave's aquatic ecosystem impaired by any biotic or abiotic stressor arising from within or beyond park boundaries?

Stressor effects that could be detected by this protocol are acute or chronic exposure to toxins, low level to extreme organic enrichment, mild to severe siltation, plus introduction and/or establishment of either exotic (such as rainbow trout) or epigean species.
http://www1.nrintra.nps.gov/im/units/CUPN/monitor/aquaticfauna/aquaticfauna.cfm (access to NPS only)

SOP: Cave Entrance Vegetation

Integrated Cave Entrance Community and Cave Environment Long-Term Monitoring Protocol, Klamath I&M Network

Plant communities near caves can be distinctive, due to the unique environment offered by a cave entrance. For instance, some ferns at cave entrances in Lava Beds are biologically unique for being disjunct from the rest of the species' range. Mosses and lichen that grow at many cave entrances in Lava Beds are an interesting and appreciated park resource but are vulnerable to human impacts. This SOP is intended to quantitatively describe the flora at cave entrances so that impacts can be detected.

The methods in this SOP are designed to be implemented in less than 1 hour per cave. It is, therefore, a rapid assessment approach that outlines simple vegetation classes and employs a quick, repeatable means of gaining accurate abundance information.

To find this publication, go to:

http://science.nature.nps.gov/im/units/klmn/publications.cfm?tab=3

Click on 2010 Draft integrated cave entrance community and cave environment long-term monitoring protocol *Multiple Files (Zip).* Scroll down to SOP09_Cave_Entrance_Vegetation_Monitoring_v1.00_DRAFT_20100608.pdf

Appendix E: Job Hazard Analysis

<table>
<tr><td colspan="6">JOB HAZARD ANALYSIS</td></tr>
<tr><td colspan="5">Job Description:
Caving for the purposes of monitoring</td><td>Date of last update:
April 2013</td></tr>
<tr><td colspan="3">NPS Division with primary responsibility for this JHA:</td><td>Last updated by:</td><td>Reviewed by:</td><td>Approved by:</td></tr>
<tr><td>Required standards & general notes:</td><td colspan="5">Cave entry permits must be obtained and approved prior to any caving activity. Surface watch and call-in time must also be established prior to the trip; surface watch should be informed of party exiting cave ASAP (e.g., via cell phone or radio). LE informed of trip plan when conducting surveys in remote sections of cave. Trip leaders must be appropriately trained and prepared for the type of trip they are leading. Each team member must be prepared for the type of trip and familiar with first aid kit locations along the nearest travel route. All PPE will be inspected and tested prior to using, and all equipment will be adequate for the type of trip. Always cave with an appropriate party size for activity and cave area; caving alone is usually not appropriate.</td></tr>
<tr><td>Personal protective equipment:</td><td colspan="5">UIAA approved helmet with four-point suspension chin strap, three reliable independent light sources, knee-pads (as needed), elbow-pads (as needed), gloves, treaded boots with good soles and ankle support, sufficiently warm clothing, chemical heat pack, compact first aid kit.</td></tr>
<tr><td>Typical tools, equipment & supplies:</td><td colspan="5">Side-mounted pack, adequate drinking water, adequate quick-energy food supply, extra batteries, watch, cave maps, compass, hand-line.</td></tr>
<tr><td colspan="2">Activity</td><td colspan="2">Potential Hazards</td><td colspan="2">Safe Action or Procedure</td></tr>
<tr><td colspan="2">Planning Cave Trip</td><td colspan="2">Lack of leadership, and communication, or training. Failing to establish a reliable surface watch and reasonable call-in time.
Planning a caving trip that will exceed the abilities of any team member. These abilities include physical condition, technical skills</td><td colspan="2">One person for each trip will be designated as the trip leader. This person is responsible for providing leadership and clear communication concerning safety, minimizing impact to the cave resource and achieving the trip goals. Ensure that trip plans are within the range of all team members.
Discuss trip plans with team members and make sure each member understands the trip plans, is prepared to meet the challenges of the trip in terms of physical condition, technical skills and psychological</td></tr>
</table>

	and psychological aspects.	aspects. Establish a reliable surface contact person and reasonable call-in time. Ensure designated surface watch and LE informed when conducting surveys in remote sections of cave and/or backcountry caves.
Preparing Equipment	Not bringing proper equipment to achieve the planned objectives.	Trip members will make sure they have the proper personal equipment for the trip. Trip leader will supply protocol-specific checklist of necessary equipment.
	Equipment worn, broken or inoperable due to lack of proper maintenance.	Each trip member is responsible for regularly checking, cleaning and ensuring their caving equipment is in proper working order. Each trip leader is responsible for verifying that equipment is in working order.
	Team member not knowing how to properly use caving equipment.	All team members will have the training and knowledge as to proper usage of each piece of equipment used for their specific trip.
Activity	**Potential Hazards**	**Safe Action or Procedure**
Entering Cave	Entrance Zone Animals	While in the entrance area of a cave all team members should be alert and aware that skunks, venomous snakes, spiders, and other potentially hazardous animals may be found. Avoid treading on accumulated guano or middens.
	Rock fall	Due to high fluctuation in temperature and moisture near cave entrances, some entrances areas can be particularly prone to loose rocks. Move carefully and thoughtfully so as not to dislodge rocks.
Horizontal Caving (general)	Exposed climbs	Always use three points of body contact on cave surfaces to minimize risk of falling. Where feasible, use a hand-line or belay.
	Slippery surfaces / Falling	Everyone will wear footwear with good traction and a caving helmet with a chinstrap. Everyone should move in a careful, controlled manner to avoid falling. When climbing, test all holds to ensure that they can withstand the force being placed upon them.
	Low/small areas	Trip leaders should ensure all members are able to negotiate low/small areas on caving route. Remaining calm and thinking

		through what one must do to get through low/small areas is key. Team members will not travel head-first through low/small areas that slope steeply downward.
	Exertion / Exhaustion	Each team member should have adequate knowledge of the length and duration of trip prior to heading into the cave, and should have cave-specific physical conditioning. People in good physical condition need less water and are less prone to injury. Push your endurance limit in gradual increments. Avoid overloading your pack; be creative to reduce weight and bulk. Prior to the trip, the trip leader should inquire about people with known physical conditions and treatment needs. Groups should avoid overexertion, and should stop at least every hour to eat and drink. Group speed should be tailored to the slowest person on the team. Should the trip become too much for one trip member, the whole trip plan will be modified to achieve a safe trip.
	Temperature related issues	Ensure team members are appropriately dressed for continued movement – a lightweight long-sleeved shirt and lightweight, durable pants are usually sufficient and prevent overheating.
		Ensure team members have adequate cold-weather clothing in their packs if needed, such as a balaclava and long-sleeved polypropylene shirt. Explain to team members about the colder temps while not moving and the necessity of wearing these items to prevent hypothermia. Keeping clothing dry is important.
	Overdue party	Trip leaders should always establish a reliable surface watch prior to embarking on a trip. This person should be briefed on what time to expect the team to return (or call-in) and whom to contact in the event the team does not exit on time. Location of the team, number of participants and travel route description or maps will be made available to the surface watch. Trip leaders will allow a reasonable

		amount of time for the team to exit the cave. If the team becomes lost, they will remain where they are and wait for the surface watch to notify search & rescue.
	Dehydration	All team members will be properly hydrated before entering the cave and drink sufficient water or electrolyte replacement drinks during the trip to maintain a proper hydration and avoid cramps.
	Minor injuries	Self-rescue using compact first aid kit in pack or in caches.
	Major injuries	When possible, at least one team member stays with injured party while other team member(s) goes for help. When surveying remote locations the contact info of LE Ranger on duty should be known beforehand.
	Rock fall	Cavers should locate themselves in places where they will not be exposed to rockfall from team members above them. Cavers will move carefully and thoughtfully so as not to dislodge rocks. Should a team member accidentally dislodge a rock or drop equipment they will clearly yell “Rock!” to inform team members below of the impending danger. Team members below should be alert and step away (not look up). All team members will wear a UIAA approved helmet with four-point suspension chin strap caving helmet with a chinstrap. This helmet should not be removed when in an area with a potential for rockfall.
Activity	**Potential Hazards**	**Safe Action or Procedure**
Wading	Total submersion	When possible, monitoring in cave streams and rivers should be performed during the dry season so that water levels and flooding potential are low (and visibility high). Always check weather reports before performing monitoring in cave streams or rivers. Be aware of antecedent conditions: consider current soil saturation. If there is a high chance of heavy rain in the surrounding area the trip should be

		postponed. Always work in areas with adequate air space between the water surface and the cave ceiling. Know alternative exit routes.
	Hypothermia	When wading use neoprene socks and shorts to keep warmed film of water in contact with skin. Chemical heaters that last for 8-10 hours are highly recommended to deal with hypothermia. They can be wrapped in a rag and inserted into the exposure suit to supply heat to the person's snorkeler's core. A heat tab stove can be used to heat up a hot meal (e.g., beef stew) for energy and warmth. Performing physical exercise, e.g., hands and knees crawling, is a good way to warm someone up.
Vertical Caving Additional required equipment: Rope of adequate length, harness outfitted with standard (or preferred) ascending and descending gear, and Quick Attachment	Miscommunication resulting in someone entering the rockfall zone while another team member is in a position to dislodge rocks or while another team member is still on rope.	Clear signals will be used to avoid miscommunications. "On Rope!" will be clearly shouted when entering the rockfall zone with the intent to rappel or ascend a rope. "Off Rope!" will be clearly shouted after getting off rope and exiting the rockfall zone. A clearly shouted "OK!" from the other team members should acknowledge either of these commands.
	Ropes and or rigging materials worn or damaged.	All ropes and rigging materials will be inspected for wear or damage before use. If necessary damaged or worn materials will be retired.

	Unsafe Rigging.	All rigging will be inspected before use to ensure that it is safe. If determined not to be safe, the rigging will be modified if possible or the trip halted until the rigging can be made safe. During rigging, a figure eight knot will be tied at the end of the rope prior to the first rappel to prevent accidental "short-roping".
	Not conducting a thorough check prior to rappelling.	All vertical caving participants will go through a pre-rappel checklist; often called "Checking the Chain".
	Rope damage encountered while on rope.	A butterfly knot will be used to eliminate the damaged section of rope from the life supporting rope. A note will be left both at the top and bottom of the rope informing cavers of the situation.
	Incident occurs where caver is forced to change over to ascent while descending or to descent while ascending.	Everyone participating in vertical caving will be required to have the equipment, training and knowledge to perform changeovers from ascent to descent and descent to ascent.
	Object becomes jammed in rappel device.	Everyone participating in vertical caving will be required to have the equipment, training and knowledge to safely lock off their rappel device and remove the jammed object without using a knife.
	Difficulty in passing a rebelay, traverse or other complex rigging situation.	All persons traveling to sections of cave with complex riggings will be required to have the equipment, training and knowledge to safely negotiate these complex riggings.
	Caver becomes exhausted, unconscious or injured resulting in immobilization on rope.	When someone becomes immobilized on rope, it is critical to remove that person from rope as soon as possible, usually by talking them through the problem, or lowering them to the ground. Ideally every trip should have at least one person knowledgeable of small-party vertical rescue techniques. Single-rope pickoffs are a last resort.

JHA Instructions

The JHA shall identify the location of the work project or activity, the name of employee(s) involved in the process, the date(s) of acknowledgment, and the name of the appropriate supervisor approving the JHA. The supervisor acknowledges that employees have read and understand the contents, have received the required training, and are qualified to perform the work project or activity. Identify all tasks and procedures associated with the work project or activity that have potential to cause injury or illness to personnel and damage to property or material. Include emergency evacuation procedures (EEP). Identify all known or suspect hazards associated with each respective task/procedure listed.

For example:

a. Research past accidents/incidents.
b. Research the Health and Safety Code, or other appropriate literature.
c. Discuss the work project/activity with participants.
d. Observe the work project/activity.
e. A combination of the above.

Identify appropriate actions to reduce or eliminate the hazards identified.
Abatement measures listed below are in the order of the preferred abatement method:

a. Engineering Controls (the most desirable method of abatement). For example, ergonomically designed tools, equipment, and furniture.
b. Substitution. For example, switching to high flash point, non-toxic solvents.
c. Administrative Controls. For example, limiting exposure by reducing the work schedule; establishing appropriate procedures and practices.
d. PPE (least desirable method of abatement). For example, using hearing protection when working with or close to portable machines (chain saws, rock drills, and portable water pumps).
e. A combination of the above.

Emergency Evacuation Instructions

Work supervisors and crewmembers are responsible for developing and discussing field emergency evacuation procedures (EEP) and alternatives in the event a person(s) becomes seriously ill or injured at the worksite. The items listed above serve only as guidelines for the development of emergency evacuation procedures.

Be prepared to provide the following information:

a. Nature of the accident or injury (avoid using victim's name).
b. Type of assistance needed, if any (ground, air, or water evacuation).
c. Location of accident or injury, best access route into the worksite (road name/number), Identifiable ground/air landmarks.
d. Radio frequencies.
e. Contact person.
f. Local hazards to ground vehicles or aviation.
g. Weather conditions (wind speed & direction, visibility, temperature).
h. Topography.
i. Number of individuals to be transported.
j. Estimated weight of individuals for air/water evacuation.

	PRINT NAME	SIGNATURE	DATE
JHA and Emergency Evacuation Procedures Acknowledgment We, the undersigned work leader and crewmembers, acknowledge participation in the development of this JHA (as applicable) and accompanying emergency evacuation procedures. We have thoroughly discussed and understand the provisions of each of these documents:	____________________ ____________________ ____________________ ____________________ ____________________ ____________________ ____________________ ____________________ ____________________	____________________ ____________________ ____________________ ____________________ ____________________ ____________________ ____________________ ____________________ ____________________	__________ __________ __________ __________ __________ __________ __________ __________ __________

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

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