

NATIONAL PARK SERVICE CAVE ECOLOGY INVENTORY AND MONITORING FRAMEWORK

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Abstract

A team developed the *Cave Ecology Inventory and Monitoring Framework* for National Park Service (NPS) units. It contains information for NPS cave managers across the United States to determine how to inventory and monitor cave ecology. Due to the wide geographical scope of NPS caves and their many different types, the document does not prescribe exact protocols. Instead, it provides 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 NPS cave parks.

Introduction

In late 2008 a meeting was held in Lakewood, Colorado to discuss how national protocols could be written to

address a variety of National Park Service (NPS) units containing cave resources. It was decided to divide into smaller groups to focus on cave paleontology, cave inventory, cave air quality, cave water quality, and cave ecology. This document is the product of the cave ecology group, which has communicated intermittently by email and teleconference over the past five years.

Cave biological and ecological 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 (I&M) Framework* is intended to assist NPS cave managers to better understand what lives in the caves that they are responsible for managing. 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.

Methods

The *Cave Ecology I&M Framework* was developed by a multidisciplinary group via conference calls and emails. Specialists led calls, during which notes were taken and then incorporated into the document. Numerous drafts were circulated with the authors clarifying and expounding on the document.

Results

A 100+ page document resulted from five years of work. Excerpts from the sections are presented below. At the time of submission, the *Cave Ecology I&M Framework*

was still undergoing internal review prior to peer review. The final document may differ slightly from what is presented here.

NPS Cave Resources and Policies

NPS sites contain a wide variety of cave types, and not all are part of a karst system. Nonkarst caves include lava tubes, erosion caves, tectonic caves, talus caves, ice caves, and sea caves.

NPS Management Policies (2006) 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.”

Why Caves Are Important

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.

Karst makes up about 40% of the land east of the Mississippi and 20% of land worldwide (White et al. 1995) and provides a critical source of water in many of these areas. Caves are found in many areas of the United States, with notable high concentrations in Kentucky, Indiana, Tennessee, Alabama, Georgia, Missouri, Arkansas, Pennsylvania, Florida, Texas, California, and New Mexico. Cave and karst resources occur in over 125 NPS units, most of which are within the contiguous U.S. (Figure 1). Only a small proportion of these units, though, are considered true “cave parks” in which caves and karst constitute the dominant resources. Caves and karst are also present in NPS units of Alaska, Hawaii, and the U.S. territories.

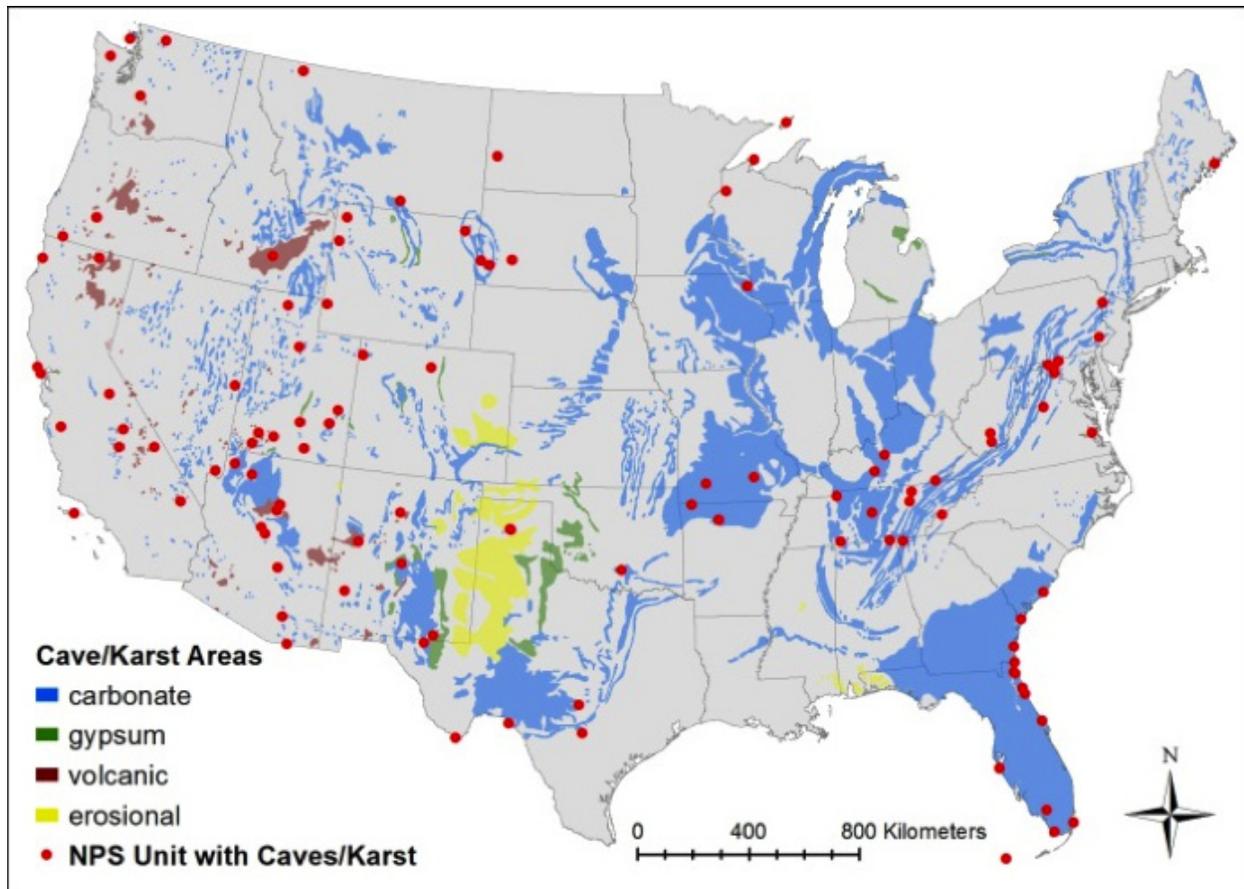


Figure 1. Cave/karst areas and NPS units with cave/karst resources in the contiguous U.S. Adapted from Croskrey, 2012 and Tobin and Weary, 2004.

Many of these caves contain cave-obligate biota, and without caves, these species would cease to exist. In North America there are over 1,100 known troglobites and stygobites (Culver et al. 2003), with many more likely present in other subterranean environments, like aquifers and the epikarst. Most cave species are largely unknown; they have small populations and low rates of reproduction, making field studies difficult, and few can be raised successfully in the lab.

Introduction to Cave Ecology

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 1).

Typical cave ecosystems are decomposer ecosystems (Figure 2). In the absence of solar energy, these ecosystems depend upon organic materials which fall,

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. Larger organisms – invertebrates – also may consume this surface-derived organic material, such as when a larger vertebrate falls into a pit entrance or is washed into a stream cave. 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. In most cave settings, larger animals that live exclusively in the caves to form still higher trophic levels do not exist. It should be emphasized that compared to surface habitats, caves have low biodiversity.

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

Accidentals	Accidentals are animals 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 <i>Ceuthophilus</i> that 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 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 <i>Hadenoeus</i> , are troglophiles. They reproduce entirely within the cave, but leave at night to feed on the surface.
Troglobites	Troglobites 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.

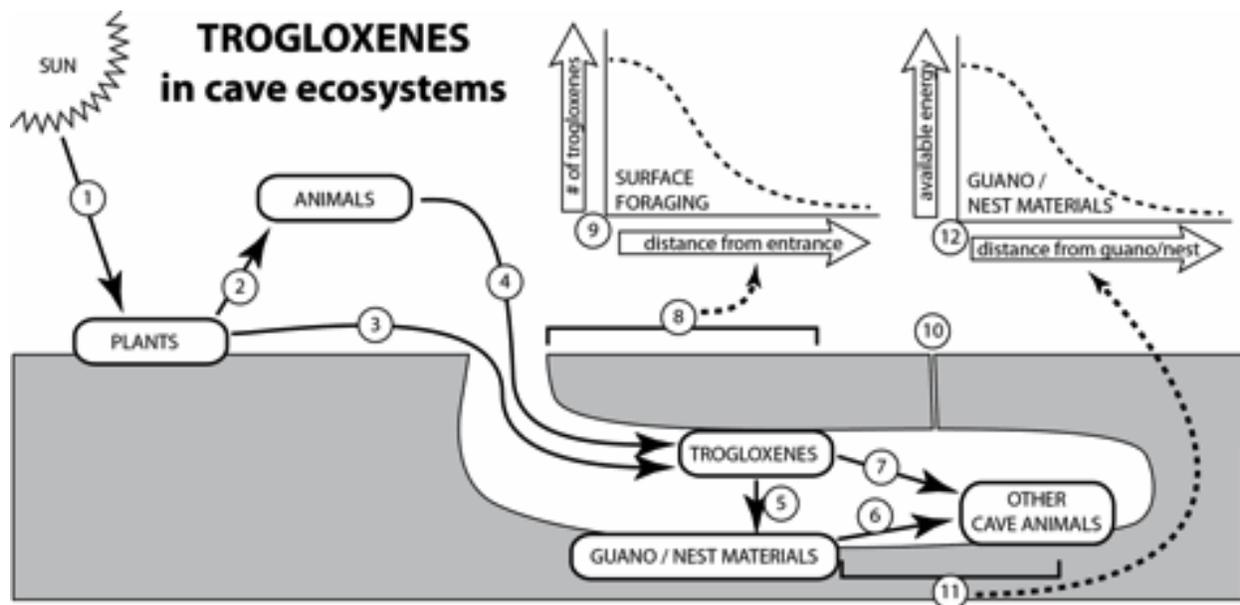


Figure 2. Energy entering cave by action of trogloxenes.

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.

The above paragraph describes a typical trophic structure, but there are many variations. A few caves have very 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 invertebrates can graze upon these microbes as an energy source, forming an ecosystem based on an energy source other than sunlight.

General Considerations for Cave 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 found in caves (99.99%) 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:

- 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;
- tracks metrics that are of interest to the general public; and,
- creates ground-breaking, publishable ecological data.

A primary objective of this *Cave Ecology Inventory and Monitoring Framework* (Framework) is to

determine variability and long-term trends in cave biota using summaries of descriptive statistics for selected parameters. 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 primary 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.

Deciding What to Monitor

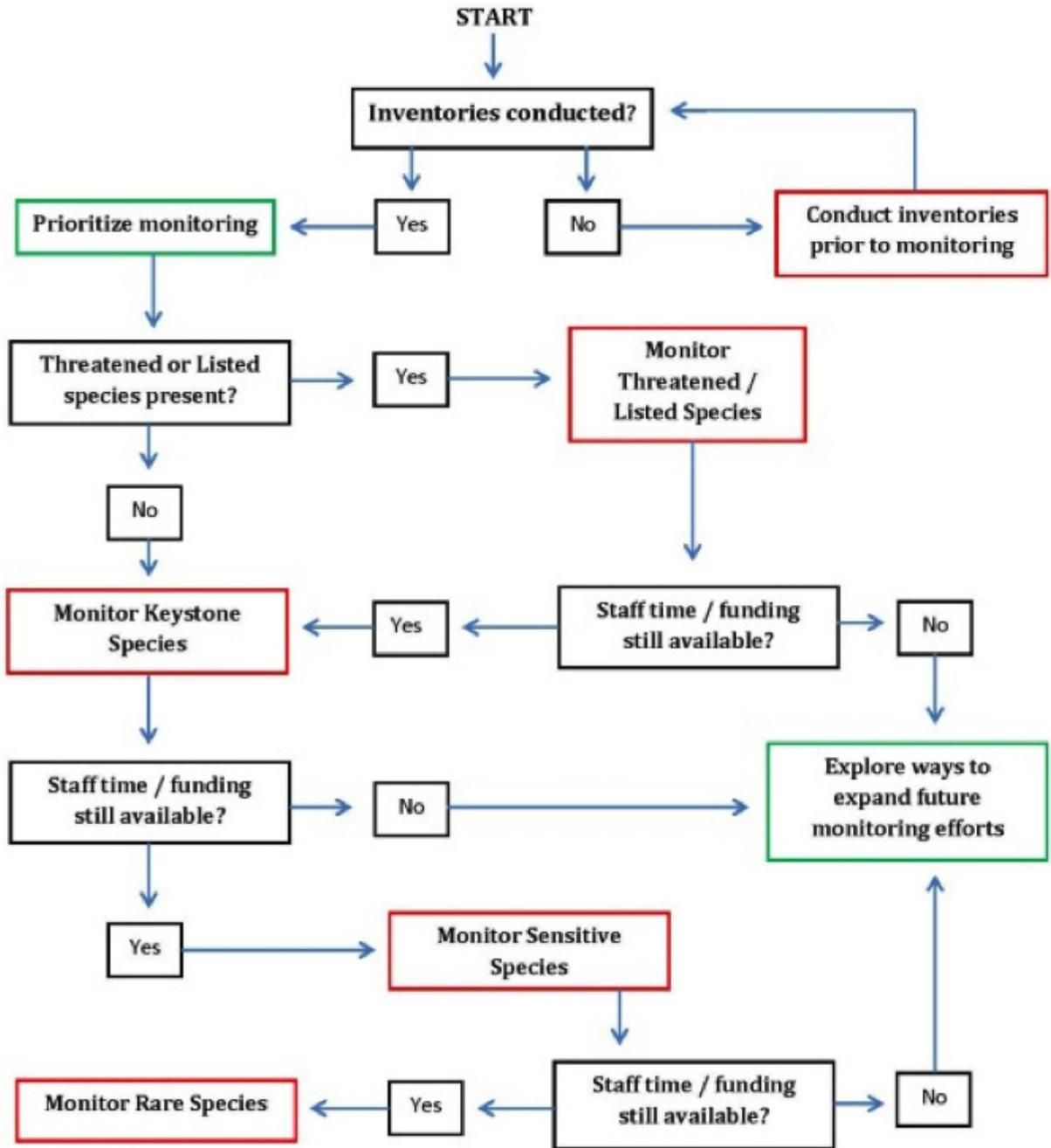
Park managers must decide what to monitor given a limited budget and limited staffing. In this section, a decision flowchart (Figure 3) with considerations about what to monitor is offered to help managers decide what cave habitats and communities are the highest priority to inventory and monitor.

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. Are the caves wet, dry, vertical, horizontal? Do they contain ice, bad air, or any other special features that could affect the cave ecology? 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

Figure 3. Decision Flowchart for Managers to Decide What Cave Ecology to Monitor. Black boxes indicate questions for managers, Green boxes indicate decision-making exercises, Red boxes indicate activity to be undertaken.



their population levels could be an early indicator of a problem with overall ecosystem health.

- **Keystone Species** - Species which has a disproportionately large effect relative to its abundance. Plays a critical role in determining and maintaining community structure of an ecosystem.
- **Representative Species** - Species can be representative of all or a portion of a cave ecosystem and are cost-effective targets.
- **Sensitive Species** - Species 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, e.g., wildfires, climate change, changing vegetation structure, new construction, changing hydrological regimes, or oil and gas prospecting?
- **Rare Species** - Rare and unique species are vulnerable, and thus awareness of their condition is important.
- **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.

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.

Potential Monitoring Targets for Cave Ecology Inventory and Monitoring

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.

Terrestrial Cave Ecosystems

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, cave crickets, birds, and cave obligate invertebrates. We also consider other wildlife use of caves, detritivores and predators linked to keystone species, and listed or other special interest species.

Aquatic Cave Ecosystems

Aquatic cave ecosystems can vary considerably from one cave to the next. Some include one river that sinks into a cave and later reemerges. Others could include multiple inputs from numerous streams and sinkholes. Aquatic cave ecosystems are not limited to surface water. Groundwater can play a large part, 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.

Aquatic cave ecosystems are vulnerable to threats from sinkhole inputs up-gradient and from surface streams that can back-flood into cave streams through springs. They may also include threatened, endangered, or endemic species.

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.

Microbes

Microorganisms (microbes) are ubiquitous in caves, although their small size means they are often overlooked despite their important role in nutrient recycling, decomposition, and primary productivity. Microorganisms 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. In some caves, the presence of microbes is displayed through geomicrobial processes that cause bedrock alteration

(e.g., corrosion residue) or contribute to formation of secondary deposits (e.g., weblites, pool fingers). Routine monitoring of water quality by monitoring coliforms can indicate potential problems.

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 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. 2013) for specifics in data management with regards to a cave ecology program.

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.

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 determine the sample size needed to determine an effect of a given size with a specified level of confidence.

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.

Roles and Responsibilities

Parks have the primary responsibilities for determining what the needs are for their parks 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.

The NPS Cave and Karst Program is part of the Geological Resources Division based out of Lakewood, Colorado. This program offers support to all the NPS units with cave and karst resources. Information can be found on the program's website: <http://nature.nps.gov/geology/caves/index.cfm>. The program may provide advice or referrals for simple requests or may suggest routing requests through the Technical Assistance Call (TAC) if more complex support is required. More information about the TAC can be found on the NPS Natural Resource Stewardship and Science (NRSS) website: <http://inside.nps.gov/waso/waso.cfm?prg=4&lv=1>.

The National I&M Program is centered nearby in Fort Collins, Colorado. I&M regional and network offices are scattered throughout the country. Managers and ecologists have a great deal of knowledge about inventory and monitoring techniques. 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/>.

NPS regions may have natural resource specialists, ecologists, geologists, and/or hydrologists who are able to assist with cave monitoring questions. Many regions also have funding available for park-sponsored projects.

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 and/or private landowners in the management and monitoring of cave resources. Additionally, the NPS can seek help from other groups that specialize in cave-related work, including the National Cave and Karst Research Institute (NCKRI) and the National Speleological Society (NSS).

Operational Requirements

This Framework offers many ideas for managers of cave resources to pursue. However, 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.

Discussion

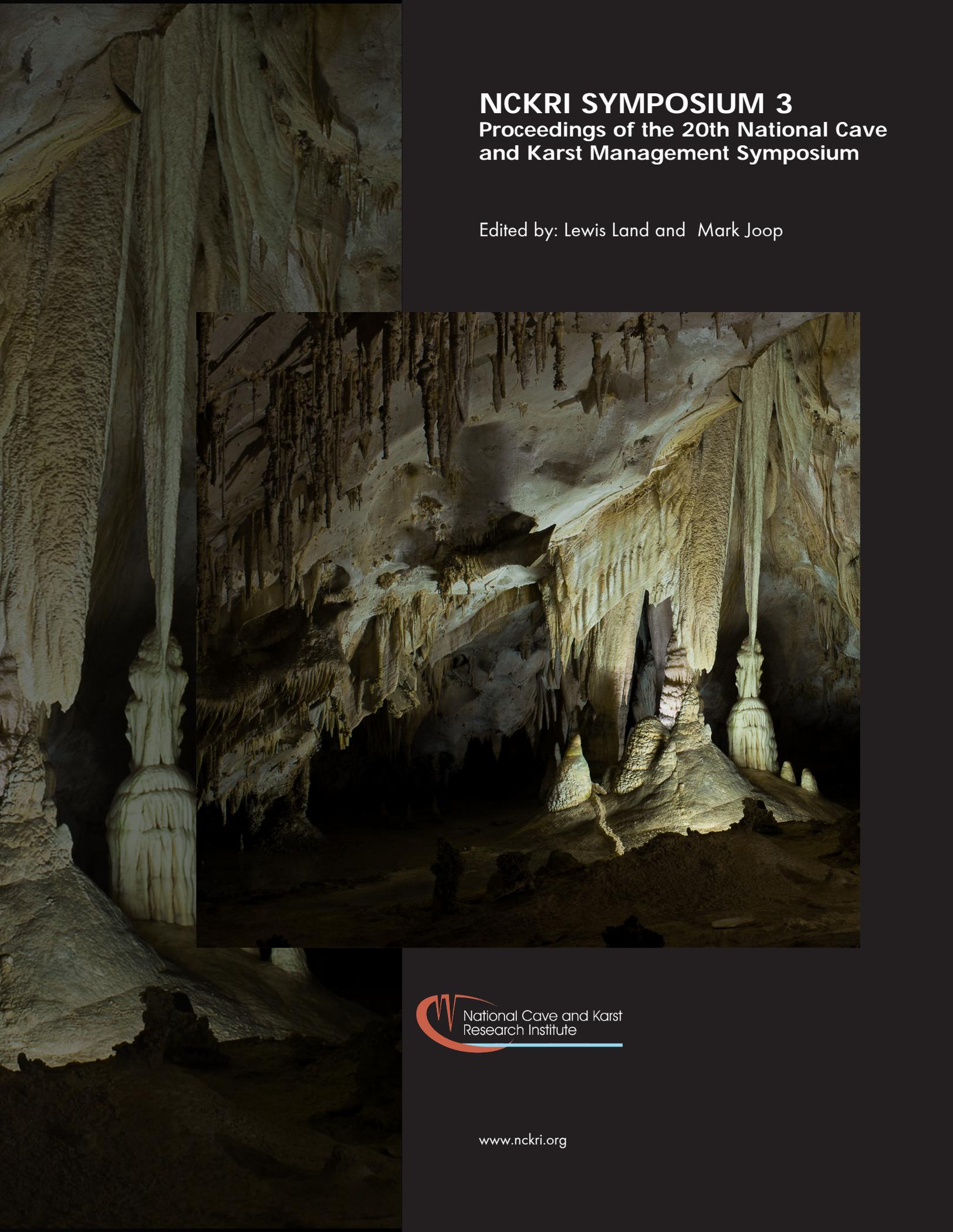
It has taken nearly five years to complete the Framework in preparation for peer review. It certainly could have been completed faster if it had a budget so that preparers could meet in person. However, given that no travel was expended on this project, it is remarkable what has been completed.

The ultimate product will be an NPS publication available to anyone.

The desire of the authors is that the Cave Ecology Inventory and Monitoring Framework will be a guiding document for those undertaking cave ecology studies at their management area.

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Cover Photo: A testimony to “A Changing Climate” frozen in time, the Witch’s Broom, a column in the Papoose Room of Carlsbad Cavern, formed during two different climatic conditions on the surface: the drapery formed by a slow drip rate under drier conditions, perhaps during a glacial period when vast quantities of the water supply were locked in ice; and the stalagmite formed by a faster drip rate under wetter conditions, during an interglacial period when the ice caps were melting. Note the challenge of getting artificial lighting to the Witch’s Broom on a flowstone-covered floor. Concealed electrical wiring is visible at the base of the stalagmite in the lower right corner of the image. Photo by Dianne Joop.