National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Integrated Monitoring Protocol for Cave Entrance Communities and Cave Environments in the Klamath Network

Narrative, Version 1.0

Natural Resource Report NPS/KLMN/NRR—2017/1400

ON THE COVER
Caldwell Ice Cave, Lava Beds National Monument
Photograph by: Jean K. Krejca

Integrated Monitoring Protocol for Cave Entrance Communities and Cave Environments in the Klamath Network

Narrative, Version 1.0

Natural Resource Report NPS/KLMN/NRR—2017/1400

Jean K. Krejca[1], G. Robert Myers III[1], Alice Chung-MacCoubrey[2], Eric C. Dinger[2], Sean Mohren[2,4], David Riggs[3], Daniel Sarr[2,†], Katrina Smith[3], Allison Snyder[2], and Shawn Thomas[5]

Edited by Sonya Daw[2]

[1]Zara Environmental LLC
Manchaca, Texas 78610

[2]National Park Service
Klamath Network Inventory and Monitoring Program
Ashland, Oregon

[3]NPS Lava Beds National Monument
Tule Lake Unit, WWII Valor in the Pacific NM
Tulelake, California 96134

[4]Crater Lake National Park (current affiliation)
Crater Lake, Oregon

[5]Bat Conservation International (current location)
Flagstaff, Arizona

March 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal, high-level peer review based on the importance of its content, or its potentially controversial or precedent-setting nature. Peer review was conducted by highly qualified individuals with subject area technical expertise and was overseen by a peer review manager. Standard operating procedures associated with this protocol received the same level of review as the protocol narrative but are stored as unpublished documents on the National Park Service Integrated Resources Management Applications web portal.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the Klamath Inventory and Monitoring Network website and the Natural Resource Publications Management website. To receive this report in a format optimized for screen readers, please email irma@nps.gov.

Please cite this publication as:

Krejca, J. K., G. R. Myers III, A. Chung-MacCoubrey, E. C. Dinger, S. Mohren, D. Riggs, D. Sarr, K. Smith, A. Snyder, and S. Thomas. 2017. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network: Narrative, Version 1.0. Natural Resource Report NPS/KLMN/NRR—2017/1400. National Park Service, Fort Collins, Colorado.

NPS 963/136789, March 2017

Contents

Contents (continued)

Contents (continued)

Page

Figures

Tables

Appendices

Revision History Log

Version 1.0

To create a new version of this narrative, carefully follow the instructions in SOP #18: Revising the Protocol (https://irma.nps.gov/DataStore/Reference/Profile/2238840). Be sure to update Table 18-1 in SOP #18, which tracks the current combination of all documents in the protocol. Use the Revision History Log below to describe the revisions:

- Populate the top table of the revision history log, providing the previous version number, revision date, author of the change, a specific but concise description of the changes made, the footnote number associated with change details, and a new version number.
- In the bottom table, add a footnote and as much text as needed to describe in detail the reasons for and implications of the change.

Previous Version #	Revision Date	Author of Change	Changes Made	Footnote #	New Version #

Footnote #	Detailed Reasons for and Implications of the Changes

Version numbers will be incremented by a whole number (e.g., Version 1.3 to Version 2.0) when a change is made that significantly affects requirements or procedures. Version numbers will be incremented by decimals (e.g., Version 1.6 to Version 1.7) when there are minor modifications that do not affect requirements or procedures for publication in the series.

Standard Operating Procedures

Eighteen standard operating procedures are associated with the Klamath Network cave monitoring protocol. To accommodate frequent changes, each standard operating procedure (SOP) is informally published online through the National Park Service Integrated Resources Management Applications (IRMA) portal (https://irma.nps.gov/Portal). The SOPs can be retrieved from IRMA using the citation or the hyperlinked record number, below. Versioning tools in IRMA will offer the most current version from these links.

Title	Citation	IRMA record number
SOP #1: Training	Krejca, J. K., and others. 2017. Standard Operating Procedure 1: Training. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239162
SOP #2: Scheduling	Krejca, J. K., and others. 2017. Standard Operating Procedure 2: Scheduling. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239163
SOP #3: Site Selection and Marking	Krejca, J. K., and others. 2017. Standard Operating Procedure 3: Site Selection and Marking. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239164
SOP #4: Water	Krejca, J. K., and others. 2017. Standard Operating Procedure 4: Water. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239165
SOP #5: Climate	Krejca, J. K., and others. 2017. Standard Operating Procedure 5: Climate. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239166
SOP #6: Ice	Krejca, J. K., and others. 2017. Standard Operating Procedure 6: Ice. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239167
SOP #7: Visitation	Krejca, J. K., and others. 2017. Standard Operating Procedure 7: Visitation. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239168
SOP #8: Bats	Krejca, J. K., and others. 2017. Standard Operating Procedure 8: Bats. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239169

Title	Citation	IRMA record number
SOP #9: Cave Entrance Vegetation	Krejca, J. K., and others. 2017. Standard Operating Procedure 9: Cave Entrance Vegetation. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239170
SOP #10: Scat and Visible Organics	Krejca, J. K., and others. 2017. Standard Operating Procedure 10: Scat and Visible Organics. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239171
SOP #11: Invertebrates	Krejca, J. K., and others. 2017. Standard Operating Procedure 11: Invertebrates. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239173
SOP #12: Cave Database	Krejca, J. K., and others. 2017. Standard Operating Procedure 12: Cave Database. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239175
SOP #13: Data Entry	Krejca, J. K., and others. 2017. Standard Operating Procedure 13: Data Entry. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239176
SOP #14: Photograph Management	Krejca, J. K., and others. 2017. Standard Operating Procedure 14: Photograph Management. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239177
SOP #15: Data Transfer, Storage, and Archiving	Krejca, J. K., and others. 2017. Standard Operating Procedure 15: Data Transfer, Storage, and Archiving. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239178
SOP #16: Protected Data	Krejca, J. K., and others. 2017. Standard Operating Procedure 16: Protected Data. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239180
SOP #17: Data Analysis and Reporting	Krejca, J. K., and others. 2017. Standard Operating Procedure 17: Data Analysis and Reporting. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2239182
SOP #18: Revising the Protocol	Krejca, J. K., and others. 2017. Standard Operating Procedure 18: Revising the Protocol. Version 2017Feb10. Integrated monitoring protocol for cave entrance communities and cave environments in the Klamath Network. Unpublished National Park Service Report, Klamath Inventory and Monitoring Network, Ashland, Oregon.	2238840

Executive Summary

The National Park Service Klamath Network Inventory and Monitoring Program (KLMN) monitors status and trends of ecosystem components and processes in 7 national park units in northern California and southern Oregon. KLMN monitors ecosystem components and processes (or "vital signs") within each of 4 domains: terrestrial, subterranean, freshwater, and marine (Sarr et al. 2007). This protocol addresses long-term monitoring of the network's subterranean vital sign, Cave Environment and Cave Communities, by integrating monitoring of 4 physical (climate, ice, pool water levels, and visitation) and 4 biological (invertebrates, bats, organic inputs, and entrance vegetation) elements of subterranean (cave) ecosystems. This monitoring will occur at 2 KLMN park units with significant cave resources, Lava Beds National Monument (LABE, "Lava Beds") and Oregon Caves National Monument and Preserve (ORCA, "Oregon Caves"). Located near Tulelake, California, Lava Beds contains over 700 documented caves, most ranging from 15 to 500 m in length. In contrast, Oregon Caves (near Cave Junction, Oregon) is 1/10th the size of Lava Beds and contains 1 major cave, named Oregon Caves ("The Cave"). This cave is the park's prime attraction, has multiple entrances, and contains ~ 5.6 km of mapped passage. The park also contains a handful of smaller caves, such as Blind Leads Cave, which barely have a dark zone.

The objectives of this monitoring protocol are to monitor status and trends in physical and biotic parameters within 1) a random sample of deep caves and a nonrandom set of bat and ice caves at Lava Beds, and 2) The Cave and a randomly selected small cave, Blind Leads Cave, at Oregon Caves. Specifically, this protocol is designed to detect changes in cave climate (temperature and humidity), water levels in subterranean pools (Oregon Caves only), elevation and surface area of cave ice (Lava Beds only), invertebrate community composition, hibernating bat populations, and entrance vegetation communities. The presence or absence of scat and other visible organic material will also be noted and quantified, when possible, for management purposes. Where appropriate, parameters are monitored within entrance, middle, and deep zones within each cave. Lastly we also monitor human visitation as a potential covariate to explain any observed variation in the above parameters. In addition to providing status and trend information on individual parameters, the integrated sampling of these abiotic and biotic parameters allows us to explore potential causal relationships.

Each park required a different sampling design due to the different number and type of cave resources at each park. At Lava Beds, we will monitor a randomly selected, spatially balanced sample of 30 caves from our deep cave sampling frame, which consists of 114 caves over 91 m (~300 ft.) in length. We will also monitor an additional 3 bat caves and 4 ice caves, selected nonrandomly because they contain significant bat and ice resources, at Lava Beds (judgment sample). At Oregon Caves, we focus on The Cave with intensive sampling, plus 1 randomly selected cave (Blind Leads Cave), which will be sampled similarly to the randomly selected caves at Lava Beds.

We monitor climate with data loggers; vegetation with line-transect, point-intercept methods and photographs; ice surface area and water levels with photographs and measurements relative to fixed points; invertebrates with bait stations; visitation through each park’s respective methods for tracking visitor use; and bats and scat through timed visual surveys. Methods are described briefly in chapter 3 and in greater detail in individual Standard Operating Procedures (SOPs).

A KLMN Project Lead provides general oversight. The Lava Beds Natural Resource Program Manager addresses across-park coordination, logistics, seasonal hiring, written performance evaluations, and training for the safe and effective implementation by park staff of the protocol methods. Five parameters (climate, bats, ice, subterranean pool water levels, and visitation) are monitored annually and 3 parameters (scat, vegetation, and invertebrates) are monitored every other year (in even years). KLMN provides funding during even years when the additional parameters add a significant amount of summer field work. Annual effort reports are prepared by the park Field Leads, whereas Biennial reports and Analysis and Synthesis reports are produced collaboratively by the Lava Beds Natural Resource Program Manager, the park Field Leads, and the KLMN Project Lead.

This protocol consists of a descriptive narrative, including appendices with relevant information, and Standard Operating Procedures for various tasks. 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.

Acknowledgments

Park staff contributed greatly to this protocol, including Lava Beds resource managers David Larson and Nancy Nordensten, and their staffmember, Shane Fryer, and the Oregon Caves resource manager John Roth and associated staff, Elizabeth Hale and Ivan Yates. We would especially like to thank Shawn Thomas and Ivan Yates for their help in implementing the pilot study, providing extensive reviews of this protocol, and contributing significantly during scoping meetings and subsequent fieldwork. Other contributors included Jason Mateljak (LABE), Jason Walz (ORCA), Dennis Odion (Southern Oregon University), and Elizabeth (Bess) Perry (KLMN). We would also like to thank Kathi Irvine (Montana State University) and Leigh Ann Starcevich (West Inc.) for their statistical support and comments. Dale Pate was extremely helpful for maintaining a national perspective on cave resource monitoring objectives. Two regional NPS Inventory and Monitoring Program coordinators have also helped shape this protocol during its development and deserve special acknowledgements: Dr. Penelope Latham and Lisa Garrett.

Lastly, although a co-author on this protocol, we want to especially acknowledge the leadership and scientific foresight of the late Daniel Sarr, who provided leadership during the formative years of this network, including scoping and development of selected Vital Signs into long-term monitoring protocols. The network and this protocol greatly benefitted from his expertise, foresight, and passion for science, inventory and monitoring, and the Klamath Region.

1 Background and Objectives

1.1 Introduction

This protocol narrative outlines the rationale, sampling design, and methods for monitoring cave environments in the Klamath Inventory and Monitoring Network (KLMN) of the National Park Service (NPS). It has been prepared in accordance with NPS guidance and standards (Oakley et al. 2003, Mohren 2007, Sarr et al. 2007). A glossary of terms used in this protocol is provided in chapter 7.

KLMN includes 7 park units, 2 of which have significant cave resources and are the subject of this document: Lava Beds National Monument (LABE, “Lava Beds”) and Oregon Caves National Monument and Preserve (ORCA, “Oregon Caves”). These 2 monuments are located in northern California and southern Oregon, respectively, and have caves with endemic species, flowing underground streams, permanent ice, cultural artifacts, and many other special features.

With an area of approximately 188 km^2, Lava Beds is located south of Tulelake, California. As of August 2016, Lava Beds contains 779 documented caves representing more than 53 km of surveyed cave passage. Catacombs Cave is the longest cave at Lava Beds, with 2.6 km of surveyed passage; however, most documented caves at Lava Beds range from approximately 12 to 250 m in length, with just 4 caves of at least 1 km in length. Most of the caves at Lava Beds are lava tubes formed from eruptions through vents along the northern flank of Medicine Lake Volcano. Oregon Caves, located east of Cave Junction, Oregon, is approximately 18.5 km^2. With approximately 5.6 km of mapped passage and multiple entrances, the main cave (named “Oregon Caves”; hereafter “The Cave”) is the prime attraction at Oregon Caves National Monument and Preserve; however, the monument does contain some smaller caves, including Blind Leads Cave. Oregon Caves is primarily known for its marble caves, which are less common than limestone caves.

The Klamath Network monitors status and trends of ecosystem components and processes in each of 4 domains: terrestrial, subterranean, freshwater, and marine (Sarr et al. 2007). This protocol addresses the network’s Cave Environment and Cave Communities vital signs and integrates monitoring of 4 physical (climate, ice, subterranean pool water levels, visitation) and 4 biological (invertebrates, bats, scat/organic inputs, and entrance vegetation) elements of subterranean (cave) ecosystems. Tracking the selected parameters will provide many potential benefits, including the ability to provide management a baseline to evaluate future change against, understand the role of natural and anthropogenic changes, identify needed research, and lastly, provide educational and outreach material that will further the understanding and protection of the parks’ caves.

Data collection methods for biotic and abiotic cave parameters vary among management plans and monitoring activities at different caves across the country. This protocol follows some existing methods to the extent they are applicable to Oregon Caves and Lava Beds (e.g., invertebrate searches described by Helf et al. 2005), or where continuing previous methods used in KLMN allows comparisons with historical monitoring (e.g., bat monitoring at Lava Beds and Oregon Caves). In some cases, no adequate methods existed (e.g., scat monitoring to track use of cave by birds and small to medium-sized mammals), so methods were developed based on literature reviews, existing protocols for similar parameters in other types of habitats, and comments by subject-matter experts.

Some sampling approaches vary slightly at the 2 parks due to differences in the number and size of caves, mode of formation or speleogenesis (lava tube vs. marble dissolution), and visitation levels. Data collection, recording, and analysis were standardized to allow spatial and temporal comparisons between caves within a single park and limited comparisons between caves in Lava Beds and Oregon Caves.

Caves and their biotic and abiotic parameters are relatively understudied. We acknowledge that our efforts to create monitoring protocols for these environments are somewhat experimental compared to other natural resources (e.g., birds and water quality monitoring) for which the effectiveness, efficiency, and statistical power of standard monitoring methods have been well documented (e.g., USEPA 2013). We also recognize that this lack of baseline data from these caves and other caves around the world means that we may spend many years attempting to differentiate the background noise from real trends in condition. However, the protocols herein were designed based on a large pool of experience, and we anticipate this regular data collection will assist to "prime the pump" for more basic research and inventory that is clearly needed in the cave sciences. For example, the detection of changing ice levels could inspire funding of research on airflow patterns in caves, or research on measuring humidity levels to a higher accuracy. The observations of invertebrate distribution through a cave may spur research on microhabitat preferences of geographically restricted or rare species, as well as common, more widespread species. Clearly the parameters we chose to measure are not well-established metrics yet and may be refined over time with the help of future research and inventory projects.

1.2 Monitoring History

Monitoring histories for Lava Beds and Oregon Caves were prepared by park personnel and are presented here to provide some background on previous inventory and monitoring efforts.

1.2.1 Monitoring History in Lava Beds

Bats: Lava Beds currently protects 14 documented species of bats and monitors significant maternity roosts for Townsend's Big-eared Bats (*Corynorhinus townsendii*), Pallid Bats (*Antrozous pallidus*), and Brazilian Free-tailed Bats (*Tadarida brasiliensis*). Bats are a critical component of cave ecology because they transport nutrients into the subterranean system; they also generate substantial visitor interest. The park first began documenting bat use in caves in 1962 and has conducted intensive monitoring since 1985.

Stephen Cross of Southern Oregon University in Ashland, Oregon, completed an analysis of Brazilian Free-tailed Bat populations in Lava Beds in 1988. He established a protocol (Cross 1989) that monitored the outflights, behavior, and associated environmental influences on a yearly basis during the summer maternity colony period, here defined as mid-June to mid-September. In addition, Cross collected core samples of guano deposits and analyzed bat corpses, finding evidence of pesticide and contaminant presence (Cross 1989). From 1988 to 2011, park staff have continued photographic monitoring per Cross's methods of selected outflights during the summer maternity period. This monitoring has revealed annual fluctuations in colony size (Purinton 2004, Fuhrmann 1997, Pleszewski 2005, Mateljak et al. 2006, Tobin 2009a).

Pallid Bat monitoring consists of annual in-roost surveys of 2 maternity colonies in backcountry caves within the monument. Both colonies were observed in different locations on the same day in 2012. Each colony consists of approximately 25–150 individuals with high fidelity to 3 total known sites. No further environmental or other monitoring has been done at these sites.

Townsend's Big-eared Bat monitoring and management at Lava Beds has varied through time. Before 1988 there was no active management, and monitoring did not exist beyond occasional observations made by visitors and staff. Between 1988 and 1995, summer interns began to assess colony locations and sizes and established a database for bat observations. Cave closures to reduce human disturbance of bats began in 1993. In 1996, a seasonal "bat specialist" was hired to create survey and monitoring protocols and to devote an entire field season to bat management projects. Between 1997 and 1999, the bat management program was expanded to include an active survey and monitoring program (focusing on population dynamics), monitoring of bat roosts, and surveys of nighttime flying insects. Cave closures were enacted to protect newly identified roosts and surveillance equipment was installed to detect unauthorized human access at certain caves. Cave gating projects were also initiated and foraging surveys were completed in 1997 using radio telemetry. By 2011, 3 Townsend's Big-eared Bat maternity colonies were known in the park, along with the largest known hibernating population in California (approximately 1,100 bats). Summer exit counts were conducted regularly from 1989 to present (e.g., Dunne 2002; Tobin 2009b; Thomas 2011). Further details about previous and existing bat monitoring at Lava Beds are in Appendix A: Other Bat Surveys and Monitoring at Lava Beds and Oregon Caves.

Ice Resources: Since 1990, resource management volunteers have monitored 16 caves that historically contained substantial ice resources. None of these caves have substantial liquid water resources. As of 2016, there has been a dramatic loss of ice in 12 of the monitored caves, with the near total loss of ice in 7 caves. Only 4 are stable or growing, and 19 more have no record of monitoring (Smith 2014). The loss of ice is suspected to be caused by a 0.5 ºC rise in the mean monthly low surface temperature and nearly 1.5 ºC rise in the mean monthly high surface temperature observed over the past 60 years (Lava Beds National Monument, Weather Dataset, 2011).

In an attempt to quantify and monitor changes in ice volume, Devereaux (2009) began a study in 1988 that measured the distance from permanent stations affixed on the wall or ceiling above the ice to the frozen surface below. With the exception of Merrill Ice Cave, which had a large breach open in the ice floor, most ice floors graded up and down with accretion and ablation. This study has allowed Lava Beds to monitor ice levels from a 0 datum (the initial measurement) and gives a reasonable estimate of elevational loss or gain at study sites.

Visitation: For purposes of tracking visitor use in caves, Lava Beds installed voluntary cave registers at 20 backcountry caves from 1995 to 2002 and pressure plate trail counters in 11 frontcountry caves in 2002. As technology improved, infrared trail counters replaced pressure plates by 2010. During the setup of this protocol in 2012, infrared counters were placed at additional frontcountry caves selected for monitoring. Infrared counters continued to collect visitation data at caves not selected for monitoring by this protocol for purposes of reporting to the NPS Visitor Use Statistics Database.

As of 2016, infrared counters are used at 10 frontcountry caves selected for monitoring by this protocol, and 7 additional frontcountry caves for reporting to the NPS Visitor Use Statistics Database. Voluntary cave registers report visitation from the remaining 27 caves selected by this protocol.

Photo Monitoring: Photo monitoring can document speleothem breakage, litter accumulation, ice level variability, and structural impacts. Cave Research Foundation members Bill and Perri Frantz, with the support of Lava Beds, developed an undocumented photo monitoring protocol for 16 caves, some of which had more than 1 site, resulting in a total of 37 monitoring sites (Frantz and Frantz, personal communication to K. Smith). Between 1990 and 2008, the protocol was implemented 5 times.

Human Impact Inventory: In 2008, the first human impact inventory of frontcountry caves in Lava Beds was completed (Rogers 2008). This inventory gives resource staff a baseline and planning tool for future restorative efforts. The inventory was proposed to be developed into an impact monitoring protocol.

Invertebrates: In 2006, an invertebrate inventory of 29 caves was performed. It highlighted the presence of 2 common terrestrial troglobites (a millipede and a dipluran; troglobites are confined to caves or similar habitats), as well as 2 troglobites that may be new, park endemic species (an isopod and a pseudoscorpion) (Taylor and Krejca 2006). They also reviewed the results of several less formal invertebrate sampling efforts performed at the park and in Siskiyou County, California.

1.2.2 Monitoring History in Oregon Caves

The Cave at Oregon Caves has a longer period of cave inventory and monitoring than Lava Beds, and a wider array of parameters measured, but most efforts have been sporadic and/or short in duration. Temperature and humidity in various parts of The Cave were initially recorded during the last major exploration and survey in the late 1960s and early 1970s (Halliday 1963, Eide 1972, Knutson 1973, Sims 1980, Aley and Aley 1987a, 1987b, Aley 1988).

Water Resources: Hygrothermographs (to monitor humidity and temperature) were deployed in The Cave in 1988–1989 to assess whether additional doors in constructed tunnels were needed for airflow restoration; the results indicated that additional doors were not needed (unpublished park data). Onset Computer HOBO data loggers have been recording temperature and humidity throughout the cave since 2005; data show inner cave temperatures range from 6.6 to 7.2 ºC (unpublished park data). Humidity data from the HOBOs have been unreliable, especially at the high humidity levels common in lower parts of The Cave year-round. A carbon dioxide meter has been used to measure monthly carbon dioxide levels throughout The Cave sporadically since 2007 (unpublished park data). A doctoral dissertation was completed by an Oregon State University student (Ersek 2008) that provided a high resolution (to 50 yr intervals), long-term cave climate baseline that used oxygen and carbon isotopes from a stalagmite as temperature and precipitation proxies, respectively, for most of the last 330,000 years.

In 1991, a weir was placed on the subterranean River Styx, close to where it exits the cave and transitions into Lower Cave Creek. Monthly discharge readings were made in 1992. In 2007, a WaterLOG pressure transducer and a staff gauge were installed about 15 m upstream to record stream depth and water temperature. Starting in 2008, the water level in seasonal cave pools has been measured. Ice is known to form in the cave entrance and Watson's Grotto in winter, but it has not previously been monitored. No significant permanent cave ice has been reported in the park.

Drip-water infiltration at 1 to 3 points in the cave has been recorded by tipping buckets and data loggers since 1998 (Salinas 1999a, 1999b, 2000, 2001, 2002a, 2002b, 2004). A 1992–1993 monthly synoptic baseline recorded major ions, pH, conductivity, dissolved carbon, and temperature of various cave and surface waters (archived unpublished park data). A 1994 inspection showed some leaching of hydrocarbons from asphalt trails into underlying sediment (John Roth, personal communication). The asphalt was replaced by concrete and fiberglass. Dissolved zinc indicated leaching of galvanized steel handrails, which were subsequently replaced by dense fiberglass and stainless steel (Miller et al. 1998, Schubert 2007). Water quality measurements have been performed by the US Geological Survey (USGS) in 1997 (Miller et al. 1998), a park contractor in 1999–2004 (Salinas 1999a, 1999b, 2000, 2001, 2002a, 2002b, 2004), and a KLMN water inventory crew in 2003 (Currens et al. 2006).

Speleothem Resources: In 2007, blocks of marble were strategically placed in the cave water bodies (drip, pool, and stream areas) and have been dried and weighed on a monthly basis to determine calcite dissolution rates. The pH and conductivity of the associated cave waters are also measured to determine if they match calcite solubility indices measured during a 1992–1993 study. Generally, all measured sites in The Cave show neither a gain nor a loss of limestone except for 1 stream block that is dissolving due to an input of solutional aggressive water from the Upper River Styx and a passageway at the end of a long bedding plane pathway in which limestone is being deposited by water dripping on the block (unpublished park data).

Significant lint buildup has been observed in The Cave. Cave and park visitation records go back as far as 1910, with peak visitation occurring in the late 1970s (Hoger et al. 2003). Attempts to monitor lint deposition have been confounded by rapid bacterial decomposition, but some lint collected during cave clean-ups has been weighed and recorded since 2007.

In the early 1990s, a room-by-room inventory of most of The Cave established baselines for speleothem breakage, direction of airflow, and dozens of other parameters (unpublished park data). An inventory of broken speleothems was conducted in 1991 and 1995, and broken formations were marked with a grease pencil to monitor for vandalism. However, vandalism rates could not be determined in 2006 due to lack of prior documentation because cave water washed off some of the grease pencil markings. In 2007, efforts were made to re-mark broken formations with UV inks and mixtures of clear paint with UV powders, but those substances underperformed in certain very wet and very dry parts of the cave and many of the marks dried white instead of clear. Fixed-point photo monitoring stations were established in 2003 and will yield some data on breakage rates, but there are not enough sampling points for the data to be representative. Sites along the tour route are photo monitored every 3 years (Yates 2007).

Biological Resources: The room-by-room inventory also recorded several biotic parameters, including visible macroinvertebrates and the presence of microbes on cave walls that are potentially correlated with deposits including moonmilk, limestone crusts, and vermiculations.

The results of bat tagging in the late 1950s showed high fidelity of cave exit and entrance flight patterns at The Cave (Cross 1976, 1977, 1986, 1987). Recaptures from harp traps suggested fairly stable populations of bats using The Cave during nighttime fall swarming from the early 1970s into 2015 (Cross 1997; Kerwin 2016). A study in 1995 showed a substantial decline in the bat population that was originally attributed to changes in airflow caused by airflow restoration efforts (Cross 1997). However, a study in 2002 found the decline appeared to be a sampling artifact due to changes in entrance/exit usage (Cross and Waldien 2002). Studies of summer activity using radio transmitters in the late 1970s and Anabat II bat detectors and mist netting in the early 2000s indicate that most bats do not spend much time at The Cave once they leave it (Cross 1976, 1977, 1986, 1987, 1989, 1997; Whiteman 1997; Cross and Waldien 2002, 2003). The most recent cave entrance net survey and acoustical monitoring gave a range of bat population between 800 and 1000, which is taken as evidence of at least a stable population (and even slightly increasing) compared to previous monitoring (Kerwin 2016). Further details about previous and existing bat monitoring at Oregon Caves is in Appendix A: Other Bat Surveys and Monitoring at Lava Beds and Oregon Caves.

Other systematic taxa surveys involved the coverage and taxonomic identification of lampenflora (mostly diatoms and cyanobacteria) near electric lights in the mid and late 1980s (Aley and Aley 1987a, 1987b; Aley 1988). Control by bleach was initiated and wall coverage was monitored thereafter. Reduced lighting and supplemental use of hydrogen peroxide further reduced the impacts of these invasive species by the mid-1990s.

In the early 1990s, a 15-month pit trapping study in Oregon Caves yielded over 100 species of macroinvertebrates (Crawford 1994, 1996). The study also established that invasive species and/or other human-introduced organics, like clothing lint, were increasing near the paved trail. Synoptic counts of bats and large macroinvertebrates along the tour path began in 2001. A macroinvertebrate biodiversity study with nonlethal passive pit traps, along with “Critter Counts,” was started in 2007 (Hale 2007). Analysis of the first series of data collection, using the Shannon-Weaver biodiversity index of richness and evenness, was performed by Iskali (2008) to investigate whether removing human-caused organics helped improve habitat quality.

A 1991 dissolved oxygen study suggested that initial fall rains moved dissolved organics into cave pools. The pools then showed increased microbial activity as measured by biological oxygen demand before slowing down from dilution after big rains and spring melt, and then slowly declining as summer progressed and less water and organics entered the cave (Bratvold 1995). Comparisons between cave microbial wall coverage, biofilms, and dissolved organic inputs suggested that fewer dissolved organics entered The Cave compared to many eastern US caves. This may be due to greater summer drought and more oxidation during longer soil storage at Oregon Caves. Cave fungi and bacteria were sampled, cultured, and identified, generally down to genus level, in 2003 and 2004 (Carpenter 2003, 2004). DNA analyses of fungi, archaea, and bacteria (both chemo-organotrophs and chemotrophs) were registered in GenBank. The data suggested that anthropogenic effects did not extend to such taxa along less traveled routes in the cave (Fuller 2006).

1.3 Integration of Cave Environment and Entrance Community Vital Signs

Sarr et al. (2007) and Odion et al. (2005) describe the process by which cave environments and cave entrance communities became selected as 2 of the top 10 vital signs to be monitored within KLMN. The process involved creating a large set of candidate monitoring subjects that panels of experts ranked based on 5 management criteria (i.e., provides an early warning of loss of ecological integrity that can be addressed through management actions) and 5 ecological criteria (i.e., addresses changes to ecosystem structure, composition, and function that may occur). Then experts considered the legal/policy mandate and cost/feasibility of candidates and chose cave environments and entrance communities as important vital signs to be monitored.

Within KLMN parks, subterranean ecosystems were 1 of the 4 essential ecosystem domains for which long-term monitoring information was needed. Cave entrance communities and cave environmental conditions were chosen as the best vital signs for the subterranean domain (Sarr et al. 2007). Figure 1 illustrates the relationships between near- and far-field human influences and the focal communities and ecosystem parameters selected for monitoring.

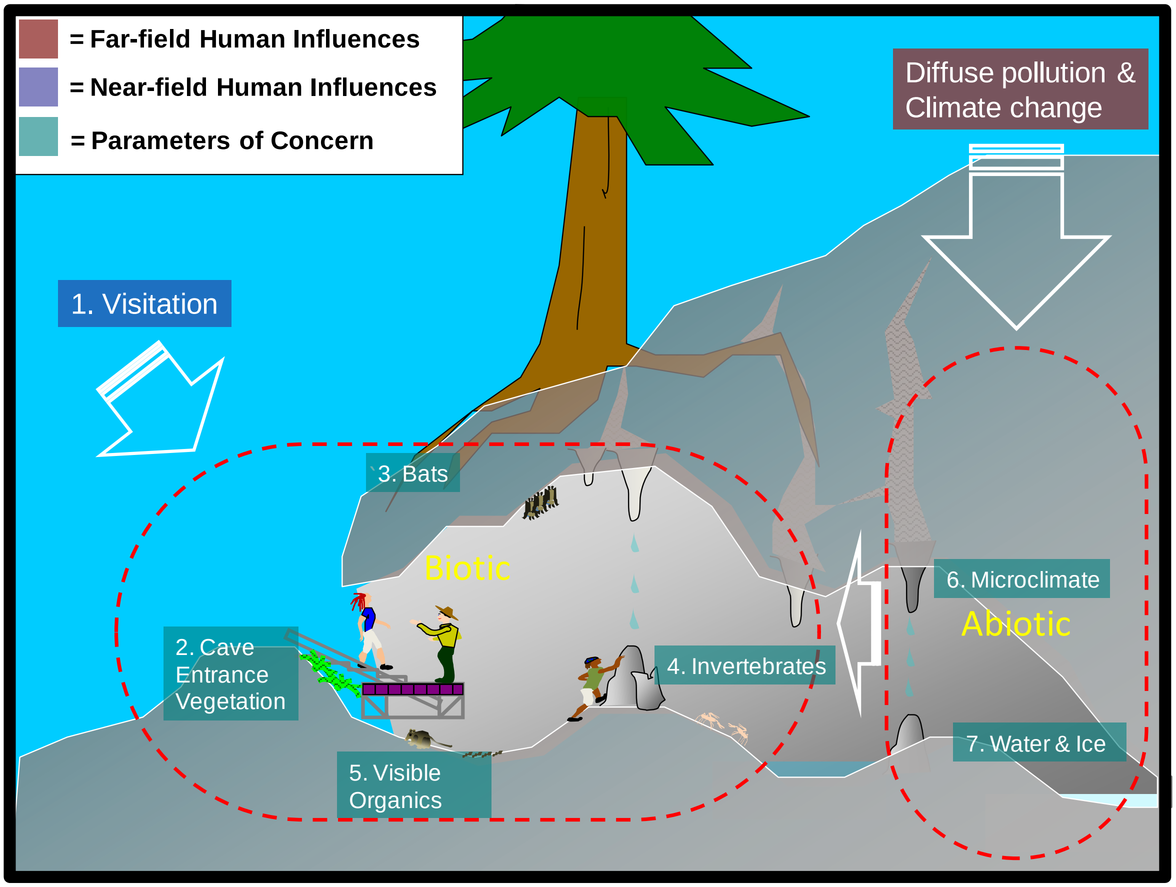


Figure 1. A conceptual model of the cave ecosystem, biotic and abiotic parameters to be monitored (numbers 1-7), and relevant human influences. Number 7 includes two separate metrics: subterranean pool water levels and ice.

1.4 Vital Signs Monitoring Objectives

This protocol monitors status and trends in abiotic (nonliving chemical and physical factors) and biotic parameters within 1) a random sample of deep caves and a nonrandom set of bat and ice caves at Lava Beds, and 2) the main cave ("The Cave") and a randomly selected small cave, Blind Leads Cave, at Oregon Caves. Specific objectives are as follows:

1. *Monitor the status and trends of cave climate (temperature and relative humidity)*. Specific climate regimes (e.g., stable temperatures and high humidity) are critical to maintaining physical cave resources, such as cave ice, processes, and the biotic communities that inhabit these caves, such as hibernating bats or rare and endemic fauna.
2. *Monitor the status and trends in water level in subterranean pools and elevation and surface area of ice.* Measuring pool levels (The Cave) and ice surface area (Lava Beds) will quantify the loss or gain of water and ice. By monitoring surface area and elevation changes, we will estimate the approximate ice volume loss/gain. These resources are intrinsically valuable and provide a link between large-scale climatic changes (e.g., warming and drying trends) and cave-specific changes (e.g., changes in entrance morphology and gates that impact airflow through caves).

3. *Monitor the status and trends of focal species and communities.* This involves various techniques for measuring hibernating populations of Townsend’s Big-eared Bats (*Corynorhinus townsendii*), invertebrates, and plants. The monitoring techniques for cave bats and cave invertebrates match those used in other parks, including the inventory and monitoring protocol at Mammoth Cave National Park (Helf et al. 2005), making it possible to make biological comparisons between widely separated and climatically distinct park units.
4. *Monitor the status and trends in human visitation.* These data may serve as potential covariates that help explain observed variation in other measured parameters. For example, a negative correlation between human visitation and bat use may prompt park staff to adjust seasonality of public access, volume of visitation, and/or cave signage.

To address the above objectives, this protocol will monitor 4 abiotic (Cave Climate, Ice, Subterranean Pool Water Levels, and Visitation) and 4 biotic (Cave Invertebrates, Bats, Scat and Visible Organics, and Entrance Vegetation) parameters that target important resources or potential sources of impact and disturbance. Monitoring should detect significant changes in valued resources, including increases in disturbance or shifts from historical levels. As parameters co-vary (e.g., climate and ice, or pool water and invertebrates), potential causal relationships can be hypothesized.

1.5 Management Actions

Monitoring data may be used to detect when parameters exceed baseline variation and to alert park staff as to when management action may be needed. After approximately 8–12 years of this regimented data collection and analysis, we will have established a baseline of the means, range, and variance from which to compare future values. Generally, we expect abiotic parameters to vary less than biotic parameters, and consequently, fewer years may be needed to establish a baseline, partly because the abiotic parameters are monitored more frequently. Significant changes in the annual means for biotic or abiotic parameters should trigger a discussion about what the park can do to better understand, or if necessary, mitigate the change. Both Oregon Caves and Lava Beds have cave management plans that will guide potential management changes based on detections of significant changes in each of these parameters.

2 Parameter Selection and Sampling Design

To most effectively address monitoring objectives, cave monitoring parameters were selected in consultation with NPS and inventory and monitoring professionals. A spatial sampling design was created to ensure field data are statistically robust and could be collected safely and feasibly by seasonal field crews. The sampling focuses on 4 abiotic parameters and 4 biotic parameters, whose populations vary throughout the sampling frame.

2.1 Selected Parameters

This list of abiotic and biotic parameters was selected by park staff, with input from KLMN monitoring specialists and cave scientists at Zara Environmental in a series of scoping meetings held from 2007 to 2009. The original list of parameters was then refined based on a pilot study (Thomas 2010). The cave entrance community and cave environment vital signs will be sampled and analyzed together. Hereafter, we refer to the selected parameters for these vital signs as simply abiotic and biotic parameters. The following parameters will be monitored under this protocol:

2.1.1 Abiotic Parameters

1. Cave Climate: Annual and seasonal temperature and relative humidity at 3 zones (entrance, middle, and deep) within each cave, and on the surface near cave entrances for reference (SOP #5: Climate)
2. Cave Ice (LABE only): Surface area and level (SOP #6: Ice)
3. Subterranean Pools (ORCA only): Water level of pools (SOP #4: Water)
4. Human Visitation: Number of visitors and park staff entering cave per year (SOP #7: Visitation)

2.1.2 Biotic Parameters

1. Cave Entrance Vegetation: Percent cover by group (vascular plants, bryophytes, and lichens) and by plant growth form (graminoid, fern, herb, shrub) (SOP #9: Cave Entrance Vegetation)
2. Bat Populations: Relative abundance of hibernating bats (primarily *Corynorhinus townsendii*) per cave, i.e., total number observed during winter survey (SOP #8: Bats)
3. Scat and Organic Material: Count of observed fresh scat (ORCA) or presence/absence of scat and other organic material (LABE) (SOP #10: Scat and Visible Organics)
4. Cave Invertebrate Community: Taxa richness, evenness, composition, and other community metrics (SOP #11: Invertebrates)

These parameters will be measured over different seasons through a partnership between Lava Beds, Oregon Caves, and KLMN. Data on visitation, bats, ice, subterranean pool water levels, and climate will be collected annually. Data on scat, invertebrates, and cave entrance vegetation will be collected during even years only (see sampling frequency section for more details).

2.1.3 Rationale for Selected Parameters

Climate Monitoring: Temperature and relative humidity are monitored because diurnal and/or seasonal changes in climate can set off a cascade of changes in other parameters and affect other resources. For example, changes in these climate conditions can affect the quantity and persistence of ice and/or the suitability of cave environments for bat hibernacula, microbial communities, or invertebrate species.

Water and Ice Monitoring: Water and ice levels affect biotic and abiotic systems in caves and these resources may be threatened by rising atmospheric, surface, and near-surface temperatures. Some caves have permanent ice or water features, while others experience seasonal melting/freezing. It is important to monitor ice in caves because the energy required to melt ice, or conversely, the energy liberated when water freezes, serves to buffer cave temperatures. With less ice in the summer, the maximum in-cave temperature may increase, and more remote or deeper ice might melt, creating a positive feedback loop.

Human Visitation Monitoring: Human visitation can have major impacts on caves. Visitation likely creates the largest impacts in parks where hundreds or thousands of visitors traverse small areas in caves. Monitoring visitation is critical for detecting correlations between visitation and other parameters. If visitation is shown to correlate with negative impacts observed in a cave ecosystem, adaptive management techniques (e.g., changing trail routes) can be employed to mitigate the impacts.

Cave Entrance Vegetation Monitoring: Cave entrances provide unique conditions for plant life. Some species in and around Lava Beds cave entrances are locally rare and disjunct from the rest of their established ranges. They compose a unique component of Lava Bed’s biodiversity and the importance of these communities was recognized and described in the vital signs scoping process for the Klamath Network Inventory and Monitoring Program (Sarr et al. 2007).

Some caves draw human visitors who may impact the vegetation around entrances. Impacts at these sites can be minimized through appropriate management strategies, and monitoring can provide feedback on the effectiveness of those management strategies. Visitation likely affects all vegetation types. Although the role of vascular plants, bryophytes, and lichen in cave entrance ecology is unclear, these cave entrance biota are unique and vulnerable to human impacts and were consequently deemed important to monitor.

Bat Monitoring: Bats are a high profile park resource that generate visitor interest and are an important part of cave ecosystems. Lava Beds and Oregon Caves combined provide habitat for 14 species of bats, including Townsend’s Big-eared Bats, a California Species of Special Concern. In California, the largest known population of hibernating Townsend’s Big-eared Bats are found in caves at Lava Beds. Several of the parks’ known bat species are susceptible or likely susceptible to a condition called White Nose Syndrome (WNS), which is characterized by a fungus, *Pseudogymnoascus destructans*, that grows on the nose, wings, ears, and tail. The fungus infects the skin and membranes of bats, likely causing death by increasing the frequency of arousal during hibernation (thereby depleting energy reserves), damaging wing membranes (leading to dehydration from fluid loss), and disrupting other critical physiological functions (Blehert et al. 2011). Because of this fungus, many large populations of bats have declined or become locally extinct in northeastern and midwestern states (https://www.whitenosesyndrome.org/resources/map).

Although Lava Beds tracks known maternity colonies of several bat species (Townsend's Big-eared Bats, Pallid Bats, and Brazilian Free-tailed Bats) for cave management purposes (e.g., closures from visitors), this protocol focuses on winter hibernation counts within 6 caves that support a significant proportion of the park's hibernating Townsend's Big-eared Bat population and within which other bat species (usually *Myotis* and *Eptesicus*) have been incidentally observed. Long-term monitoring of bats and detecting change in bat populations are best accomplished by monitoring in the winter when sampling variability is reduced; summer maternity colonies are extremely active, switching caves or locations within caves weekly, and are therefore very difficult to track. Collecting baseline information on Townsend's Big-eared Bats and other hibernating bat populations is critical, given the westward spread of WNS. With our concurrent collection of other cave parameters, such as climate and visitation levels, we will also model characteristics of suitable winter hibernacula.

Scat and Visible Organics Monitoring: Park managers are interested in knowing the nature and general level of cave use by rodents and other animals, which are capable of introducing substantial amounts of energy into cave ecosystems via scat, food items, bones, detritus, nesting materials, and other inputs. Scat can be used as an indicator of this use by mammals and birds. We will record the presence or absence of scat and visible organic material in caves at each park, and at Oregon Caves only, we will also note quantities of scat not present during the previous inventory (as identified by the presence of hyphomycetes). Presence and absence of scat and organic material will be used as a covariate in analyses and to explore relationships with other monitored parameters (e.g., invertebrates).

Invertebrate Monitoring: One truly unique aspect of park caves is the incidence of rare invertebrates found deep within. Some are park-endemic species and could be candidates for Threatened and Endangered (T&E) listing because of their extremely restricted ranges. Cave invertebrates form decomposer communities that perform an important cave ecosystem function. Beyond their biological uniqueness and ecological function, they are interesting to visitors because of their unusual morphology and "otherworldly" habitat. Monitoring can serve a dual purpose by detecting changes in distributional patterns and allowing NPS staff to familiarize themselves with species inhabiting deep cave environments, increasing the likelihood that new species are encountered and range extensions (geographic and elevation) are recorded. Additionally, monitoring may uncover possible correlations with other parameters, such as climate or visitation.

2.1.4 Alternative Parameters Considered

During the initial cave scoping meetings that evaluated potential parameters, hydrology and water quality ranked very high. Cave-specific methods (e.g., constant monitoring or flood pulse monitoring) are important given the complex and flashy nature of contaminant flow through karst (White 1988), but were judged too labor intensive for this protocol. These parameters would require an extensive pilot study to determine the best methods. Given the nascent state of knowledge on water chemistry, water quality, and cave characteristics, it was also decided that such water quality work is more closely aligned to research than monitoring.

Other high-ranking abiotic parameters included measures of visitation impacts, such as broken formations and ground compaction and disturbance. Monitoring ground compaction and disturbance are important because they can reflect when cave entrance vegetation is destroyed or when important microhabitats for deep cave invertebrates (e.g., spaces underneath rocks and interstitial voids) are lost. However, deep cave microhabitat disturbance ultimately fell lower in the ranking because it is difficult to measure, there were no standard procedures readily available, and there is little information to support a relevant threshold of impact to species. Oregon Caves staff suggested using their existing methods to monitor formation breakage (e.g., photograph stations and paint dot inventories), but these methods were not reliable or robust. Formations are difficult to mark permanently due to moisture, and it is difficult to attribute documented breakage to natural breakage or vandalism. Ultimately, vandalism of formations was identified as a management issue and was deemed unsuitable for this monitoring protocol (section 1.2.2: Monitoring History in Oregon Caves).

Monitoring dust and lint accumulation was given serious consideration and field tested. During the pilot study, it became apparent that dust and lint quickly absorbed moisture, became wet in the hyper-humid cave environment, and subsequently underwent rapid microbial degradation, which prevented accurate measurements or monitoring (Thomas 2010).

Microbes were a high-ranking biotic parameter considered for measurement. Microbial diversity in caves is known to be significant both in terms of globally rare species, colony fragility, microbe position at the base of the food chain, and universal distribution on the planet (e.g., Arrigo 2005; Bond-Lamberty and Thomson 2010). Direct biodiversity measurement requires specialized methods such as genetic analysis; we determined that an indirect measure of microbial activity, Biological Oxygen Demand of pools and soil, would be more efficient and a better fit with our evaluation criteria. This parameter, however, ranked lower than the selected 8 parameters.

We considered monitoring various aspects of the surface environment over the cave. Since the subsurface ecosystems rely on energy brought in from the surface, activities in the cave drainage basins (e.g., road building and surfacing, water quality degradation) and in the area where trogloxenes forage (e.g., changes in land use where bats or pack rats forage; trogloxenes enter but do not live permanently in caves) are likely to influence the cave ecosystem. We determined that the vegetation and land cover monitoring planned as part of the KLMN Inventory and Monitoring Program (Odion et al. 2011) was sufficient to detect major changes in vegetation regime in the park boundaries, and that large-scale land use changes were beyond the scope of this project to monitor.

2.2 Sampling Frame and Site Selection

This section defines the pool of possible sites from which different methods were used to select sites for sampling. The 2 parks are very different in terms of types and numbers of caves, their distribution, lengths, and uses. Not every cave has every resource monitored by this protocol (e.g., bats are not present in all caves); thus, the appropriate subset of parameters will be measured at each cave.

2.2.1 Oregon Caves

At Oregon Caves, there is 1 main cave and a handful of small caves <30 m in length. The 1 main cave, “The Cave,” is 5.6 km long, has multiple resources (invertebrates, subterranean pools, etc.), and has sections that are heavily used by visitors. The remaining shorter caves barely qualify for having a dark zone. Due to the small number of caves at this park and the park's specific focus on the main cave, we chose to monitor only 2 caves: The Cave and Blind Leads Cave. Blind Leads Cave was randomly selected from among 5 potentially sampled small caves (Blind Leads Cave, Icebox Cave, High and Low Hopes Caves, Cave Next Door).

Within The Cave at Oregon Caves, climate will be monitored at 23 sites that are relatively evenly distributed throughout the cave (Figure 2). Some of these sites have been monitored with HOBO data loggers since as far back as 2005, and others were judgment-selected (nonrandom). Invertebrates and scat are also surveyed around these 23 sites. Blind Leads Cave will be sampled similarly to caves at Lava Beds (see below). Bats will be monitored in The Cave only, the only known cave at the park with visible hibernating bats. Subterranean pools are present only in The Cave at Oregon Caves. The park will monitor water depth at a judgment sample of 5 subterranean drip pools in The Cave. Results from future analyses will be pool-specific.

2.2.2 Lava Beds

At Lava Beds, there are presently 779 documented caves of varying length, resources, and levels of visitation. We selected caves to be monitored for all relevant parameters using a combination of random and judgment sampling. Five parameters (invertebrates, scat, climate, visitation, and vegetation) will be monitored at all caves, regardless of sampling method (random or judgment). The remaining 2 parameters (bats and ice) will be monitored in the nonrandom set of caves where these resources are present (i.e., judgment samples). Based on logistics and funding constraints (Thomas 2010), we projected being able to sample a total of 31 caves per year (combined total of random and judgment sites), but field testing suggests that monitoring the 37 caves identified below in a year is possible.

2.2.2.1 Random sample of caves with entrance, middle, and deep zones

In addition to cave entrance communities and environment, parks are interested in monitoring the unusual conditions and resources (e.g., ice, microbial and invertebrate communities) found within the deep zones of their caves. Thus, we devised a sampling frame consisting of all caves $\geq$91 m long that are most likely to have the 3 desired zones: entrance, middle, and deep zones. See section 2.3 for zone definitions.

After the park reviewed their cave database (for accuracy of cave length, ensuring caves with multiple entrances were represented only once, etc.), we filtered the then-current list of 775 known caves by our length criteria and identified our sample frame of 114 caves $\geq$91 m long. We are interested in visitation as an explanatory covariate and thus did not use visitation as a factor in the design. We did not exclude multilevel caves or caves with fragile resources, nor did we filter based on proximity to roads and trails. We used the Generalized Random Tesselation Stratified (GRTS) approach to draw an unweighted, spatially-balanced, ordered, and random sample of 30 caves to be monitored from this sample frame, and an oversample of 30 caves (Appendix B). Upon implementation, 10 caves (8 main sample; 2 oversample) were rejected either because they did not meet the deep zone definition (5 caves) or because they contained fragile resources specifically in the travel/access path (5 caves). We replaced these caves with the next caves in the ordered GRTS oversample. In summary, a total of 30 spatially-balanced, randomly-selected caves ≥91 m long will be monitored for invertebrates, scat, climate, visitation, and vegetation.

2.2.2.2 Judgment sites for bat and ice monitoring

Six caves at Lava Beds are believed to contain approximately 70% of the known population of Townsend's Big-eared Bats in the park and will be monitored annually for bats. Three of these caves were randomly selected via the GRTS draw described in section 2.2.2.1 and the remaining 3 were nonrandomly selected as judgment sites. Because the bat monitoring sites were largely hand-picked, monitoring results will be cave-specific. The full set of parameters will be monitored at the 3 randomly selected bat caves, but only bats, climate, and visitation will be monitored at the 3 judgment bat caves. Reduced sampling at the hand-picked bat caves focuses efforts in these caves on primary parameters of interest and reduces overall sampling time and cost.

Five caves contain the most significant ice resources in the park. A cave is considered to contain significant ice resources if a large, perennial ice floor is present (versus an ephemeral flow or stalactites and stalagmites of ice). These latter formations will not be monitored because they are non-level and transient in nature, making their volume and area difficult to quantify and long-term sampling from monumented stations difficult. One of the 5 caves was selected randomly for monitoring via the GRTS draw described in section 2.2.2.1, and the remaining 4 were nonrandomly selected as judgment sites. The full set of parameters will be monitored at the 1 randomly selected ice cave, and all parameters but scat will be monitored at the 4 nonrandomly selected ice caves. Reduced sampling at the judgment ice caves is intended to focus efforts on primary parameters of interest and reduce overall sampling time and cost. Because ice caves were largely hand-picked, results will be cave-specific.

The complete list of the 37 caves to be monitored at Lava Beds (30 random, 3 nonrandomly selected bat caves, 4 nonrandomly selected ice caves) is found in Table 1. Throughout this protocol and the SOPs, caves are represented either by their full name or a cave code, depending on their classification in the LABE Cave Management Plan. Class I caves are those made accessible to the public (i.e., caves are identified in the park brochures and have signage and trails leading to them). We identify Class I caves in this protocol by name because they are public knowledge. Class II to Class IV cave names are represented by 4-letter codes because they are not intended for public knowledge. Appendices C (Examples of Cave Site Dossier Materials) and D (Restrictions for Cave Information at Lava Beds National Monument) exclude protected cave information but point to the location of documents containing the identities of the Class II to Class IV caves in Table 1 (e.g., EMST, RALO). For resource protection purposes, only individuals associated with implementation of this protocol will have access to the protected location information. Specific coordinates and narrative instructions are available in the cave database for park staff implementing the protocol. FOIA requests for protected information such as cave locations will be denied as this information is exempt from FOIA under the Federal Cave Resources Protection Act.

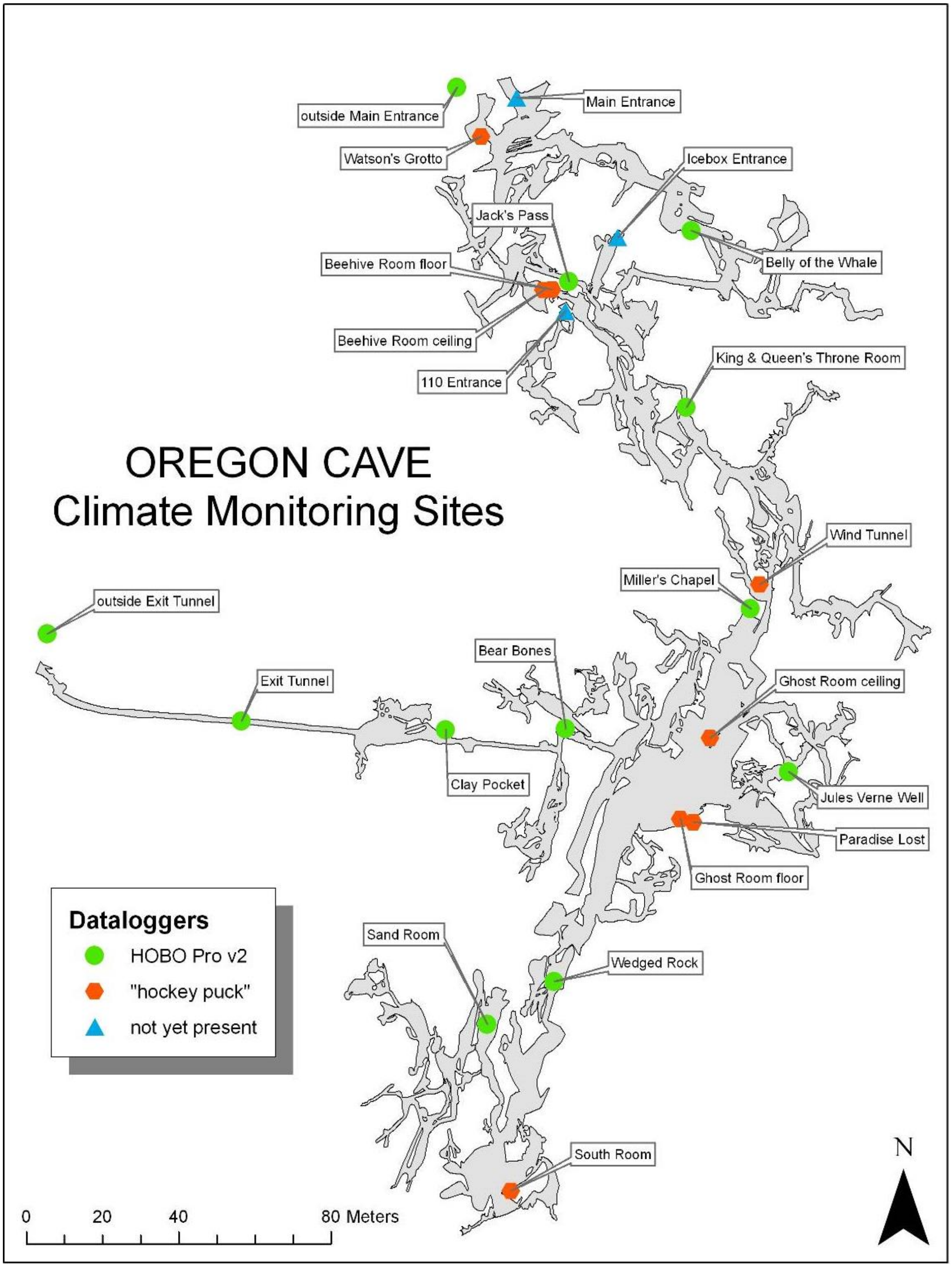


Figure 2. Monitoring sites inside Oregon Cave.

Table 1. List of caves to be monitored at Lava Beds and Oregon Caves, including method of selection (random versus judgment/nonrandom) and significant resources at each cave, if any. Full cave names are provided for LABE Class I caves. Four letter codes are used for LABE Class II to IV caves, the full names of which are not intended for public knowledge. An asterisk marks caves that were established and monitored starting in 2012.

		Monitored Parameters						
		Every Year				Alternating (Even) Years		
Selection Method	**Cave Name or Code**	**Bats**	**Ice or Pools**	**Climate**	**Visitation**	**Scat**	**Veg**	**Invert**
Oregon Caves: Nonrandom (N=2)	Oregon Caves (The Cave)	X	Pools	X	X	X	X	X
	Blind Leads Cave	-	-	X	X	X	X	X
Lava Beds: Nonrandom (N=7)	BEAC*	X	-	X	X	-	-	-
	DRHE*	X	-	X	X	-	-	-
	SENT- Sentinel Cave*	X	-	X	X	-	-	-
	BIPA- Big Painted Cave*	-	Ice	X	X	-	X	X
	CAIC*	-	Ice	X	X	-	X	X
	COIC*	-	Ice	X	X	-	X	X
	SKIC- Skull Ice Cave*	-	Ice	X	X	-	X	X
Lava Beds: Random (N=30)	ANGL*	X	-	X	X	X	X	X
	BLGR- Blue Grotto Cave	-	-	X	X	X	X	X
	CGCA*	X	-	X	X	X	X	X
	CRCA	-	-	X	X	X	X	X
	CRIC- Crystal Ice Cave*	-	Ice	X	X	X	X	X
	DECA	-	-	X	X	X	X	X
	EMST	-	-	X	X	X	X	X
	FOCA	-	-	X	X	X	X	X
	HIMM	-	-	X	X	X	X	X
	ICEB	-	-	X	X	X	X	X
	IDWL- Indian Well Cave	-	-	X	X	X	X	X
	INCA*	X	-	X	X	X	X	X
	JUHE- Juniper - Hercules Leg Cave*	-	-	X	X	X	X	X
	JUPO	-	-	X	X	X	X	X
	JURI	-	-	X	X	X	X	X
	LALA- Labyrinth - Lava Brook Cave	-	-	X	X	X	X	X
	LOPI*	-	-	X	X	X	X	X
	MEIC- Merrill Ice Cave	-	-	X	X	X	X	X
	NOBE	-	-	X	X	X	X	X
	PEAR	-	-	X	X	X	X	X
	RALO	-	-	X	X	X	X	X

Table 1 (continued). List of caves to be monitored at Lava Beds and Oregon Caves, including method of selection (random versus judgment/nonrandom) and significant resources at each cave, if any. Full cave names are provided for LABE Class I caves. Four letter codes are used for LABE Class II to IV caves, the full names of which are not intended for public knowledge. An asterisk marks caves that were established and monitored starting in 2012.

		Monitored Parameters						
		Every Year				Alternating (Even) Years		
Selection Method	**Cave Name or Code**	**Bats**	**Ice or Pools**	**Climate**	**Visitation**	**Scat**	**Veg**	**Invert**
Lava Beds: Random (N=30) (*continued*)	ROCO*	-	-	X	X	X	X	X
	SEAN*	-	-	X	X	X	X	X
	SKYL	-	-	X	X	X	X	X
	SOLA- South Labyrinth Cave*	-	-	X	X	X	X	X
	SPID	-	-	X	X	X	X	X
	SYMB	-	-	X	X	X	X	X
	THDB- Thunderbolt Cave	-	-	X	X	X	X	X
	VALE- Valentine Cave*	-	-	X	X	X	X	X
	YELL*	-	-	X	X	X	X	X
Total across both parks		**7**	**6**	**39**	**39**	**32**	**36**	**36**

2.2.3 Protocol Development History

Development of this protocol was initiated in 2009 and submitted to peer review in 2010. Pilot testing and the installation of sampling locations began in 2012. By 2014, original authors of the protocol were no longer at KLMN and new KLMN staff took on completion of the protocol. The sample frame at Lava Beds originally included single-level caves ≥152 m (~500 ft) long that were within 1 km of a road (i.e., 55 out of 700+ caves), and the process for developing this sample frame was identified to be flawed. Discussions with Lava Beds staff led to revision of the sampling frame (to that which is described in 2.2.2 above), a new GRTS draw, and minor revisions to SOPs based on experience and data from the pilot testing. Approximately one-third of caves from the original sampling frame were randomly selected for the new sample frame; thus, these caves have monitoring data dating back to 2012. The full history of protocol development is detailed in Appendix E.

2.3 Delineating Zones and Marking Sites

Cave zones are a useful generalization intended to simplify the location of sampling areas, as well as to allow comparisons among zones with differing conditions (e.g., light, temperature, wind speed, humidity). The gradient of conditions used to define zones is critical to our understanding of the cave environment. Three parameters (climate, scat, and invertebrates) will be monitored in the entrance, middle, and deep zones of each cave. Two additional parameters (vegetation and visitation) will be monitored at the entrance of each cave. The remaining parameters (bats, ice, and subterranean pools) will be monitored at selected sites where applicable.

For all caves monitored at Lava Beds and for Blind Leads Cave at Oregon Caves, 3 zones (entrance, middle, and deep) were delineated based on descriptions modified from Poulson and White (1969) and Culver (1982) to fit field conditions at Lava Beds and Oregon Caves. The Cave has multiple entrance, middle, and deep zones identified along the main and off-trail tour routes for more thorough monitoring of this extensive cave system (Table 2).

Flexibility in selecting the zones allows for elimination of the need for permanent marking. Changes in cave morphology such as rooms, tunnels, and constrictions or other obvious cave features (i.e., unique boulders, benches, aprons) exist sufficiently enough to mark zone boundaries when needed. If a cave has multiple entrances, the entrance with the highest diversity or abundance of vegetation will be selected, while also considering the likelihood of vegetative trampling due to visitor use. In such situations where field personnel identified the lack of a deep zone as defined here, the cave was rejected for monitoring and the next potential cave drawn from the oversample list.

The 3 zones are defined to encompass the following biophysical gradient:

Entrance: Light present; active air exchange with exterior; temperature and relative humidity are most variable on daily and seasonal time scales; frequent use by opportunistic surface wildlife species that leave organic material or potentially consume cave biota; includes the more commonly described twilight zone.

Middle: Beyond the zone of visible light; less air exchange with the outside and greater use by both cave obligates (troglomorphs [species with morphologic and occasionally physiological cave adaptations] and troglobites), and certain nonobligates (troglophiles and trogloxenes); intermediate variability in temperature and relative humidity.

Deep: Nonbioluminescent light absent; relatively stable temperature and relative humidity; minimal surface wildlife usage; conditions most favorable for cave obligate species but other species occur as well..

The method for marking field sites is best determined by park personnel on a site-by-site basis and should minimize resource damage and be as inconspicuous as possible. For this reason, some general guidelines are provided in SOP #3: Site Selection and Marking, but the exact method used can be determined at the park level. It is important that the location of cave zones, survey/monitoring stations, and monitoring equipment (e.g., HOBO data loggers) be marked and numbered on maps (Appendix C: Examples of Cave Site Dossier Materials) and in the caves where necessary. This ensures that a permanent record of monitoring locations is preserved and personnel in caves can easily determine where to collect data and if equipment has been removed or disturbed. When a permanent marker is required, a small stainless steel screw can be inserted into the rock with a small wire tag affixed with the station number. Dyes, markers, and flagging were judged too ephemeral to be reliable position markers given the long monitoring timeline and the sometimes high humidity and human disturbance of the cave environment.

SOP #3: Site Selection and Marking provides guidance on how to select/mark sites and monitoring stations at sites. SOPs give more detailed information on site selection relative to each monitored parameter.

2.4 Sampling Frequency

To meet the desired sampling regime under the current budgetary and logistical constraints, the workload and funding associated with this protocol will be divided between Lava Beds, Oregon Caves and KLMN. During even years (e.g., 2016, 2018…), KLMN will provide supplemental funding to perform the additional summer monitoring at both parks (scat, vegetation, invertebrates). In the odd years (e.g., 2015, 2017…), the parks will fund the sampling of the 5 annual parameters (bats, ice, subterranean pool water levels, visitation, and climate). Table 2 summarizes when each parameter will be sampled during a given field season in odd or even years.

Table 2. General implementation schedule for monitoring all cave parameters, including those only sampled during even years. Time periods when parameters will be sampled are highlighted, or in the case of climate and visitation, highlighting shows when data will be downloaded.

Years	Parameter	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
All Years	Water (ORCA)	Winter		-	-	Spring	-	-	Summer	-	-	Fall	Winter
	Ice (LABE)	-	-	Spring	-	-	-	-	-	-	Fall	-	-
	Climate	-		-		Summer download				-	-	-	Winter download
	Visitation	Collected year-round, entered into database by January 31 for previous calendar year											
	Bats			-	-	-	-	-	-	-	-	-	Winter
Even Years Only	Vegetation	-	-	-	One survey				-	-	-	-	
	Scat	-	-	-		One survey					-	-	-
	Invertebrates	-	-	-		One survey					-	-	-

2.5 Statistical Power

Power analyses are a useful tool for determining whether a monitoring project will have adequate statistical power to meet planned objectives and provide relevant and timely information for management of natural resources. These analyses determine whether the proposed sampling effort (i.e., number of caves sampled) is sufficient to detect long-term trends in environmental and ecological indicators. Power is determined by sample size, number of years of sampling, variance in the parameter of interest, magnitude of trend, and Type 1 error. The variance of a parameter is typically unknown and is usually estimated from available pilot data. Pilot data and historical data collected by the parks using similar methods were used for our power analyses, which were performed by statistics contractors. Appendix F: Power Analyses for Cave Monitoring Parameters provides a full overview of power analyses performed and includes reports from 3 independent sets of analyses conducted from 2010 to 2016. A summary of these analyses are provided below.

2.5.1 Climate Power Analysis

We used power analyses to address the following questions and inform the sampling design for monitoring annual relative humidity (%) and temperature (Celsius) in The Cave at ORCA and the randomly selected caves at LABE:

1. Are 23 data loggers in The Cave adequate for detecting trends in temperature and relative humidity? How many years are needed to detect trends in both parameters?
2. How many randomly selected caves at Lava Beds should be monitored to detect trends in temperature and relative humidity in the entrance and deep zones of deep caves (cave >91 m)? How many years are needed to detect trends in both parameters?

At Oregon Caves, the desired 80% power to detect an annual change of 0.50% in relative humidity (or 5% net change over 10 years) will be reached in approximately 7 years for a sample size of 23 HOBO loggers with Type 1 error of 10% (Appendix F, section 1). To detect a 2% annual change in temperature (i.e., 2.78 °C change over 20 years), the desired 80% power will be achieved after approximately 8 years of sampling with 23 loggers. We conclude that 23 HOBOs are sufficient to monitor climate throughout the cave for our purposes.

For Lava Beds, power to detect change was calculated for multiple sample sizes (20, 30, and 40 caves) using a 10% Type 1 error rate. For temperature, a one-sided test for an increase in mean temperature was performed. For the proposed sample size of 30 caves, power over a 10 year sampling period (2.5% annual change) was 100% for both monthly mean temperature and mean monthly temperature range (max-min) at both the entrance and deep zones. For mean monthly relative humidity, a one-sided test for a decrease in humidity was performed. Power to detect a 2.5% annual decline was 100% for the deep zone and 98% in the entrance zone in a 10 year span. Given these results, we will proceed with our proposed sample size of 30 randomly selected deep caves at LABE.

2.5.2 Bat Power Analysis

This section reports on power for detecting annual trends in hibernacula counts of the Townsend's Big-eared Bat. The 6 monitored bat caves are a mixture of randomly and nonrandomly selected caves that collectively support ~70% of the hibernating Townsend's Big-eared Bat population. We will restrict inferences about annual trends in bat hibernacula counts to the 6 monitored caves; we will not assume the same patterns exist in unsampled caves, which may have dramatically different bat habitat. Given that the majority of the bats are thought to be present in these sampled caves, this is a reasonable choice for sampling bats in Lava Beds due to budget and time constraints (section 2.2 details site selection for bat hibernacula counts).

A power analysis of 12 years of bat hibernacula count data (1998–2010) determined that the ability to detect an annual trend of 5% in the median bat counts (with Type 1 error of 10% and 80% power) will be achieved after 12 years of sampling at 6 caves (Appendix F, section 2). For a more subtle 2% annual decline, more than 20 years is needed to reach 80% power (both using 10% Type 1 error). Of note, power to detect population declines was higher in the 6-cave sampling scenario than sampling 10 or 12 caves. This counter-intuitive result is due to the fact that expanding the sample size from the

6 main "bat caves" to include more sparsely/infrequently populated caves increases the site variation, so that power is actually reduced at a larger sample size.

2.5.3 Vegetation and Invertebrate Power Analyses

Given that vegetation and invertebrates are sampled every other year, power analyses for these parameters were examined over a longer (20-year) time span. Vegetation was analyzed using a metric of biodiversity, essentially taxa group richness along with bare ground. For a two-sided test (allowing increasing or decreasing trends) on a 2% annual trend, power was 60% in the inner vegetation zone and 77% in the outer zone for a sample size of 30 caves (see SOP #9: Cave Entrance Vegetation for description of inner versus outer zone). For invertebrate taxa richness per cave, a two-sided test on 1% annual trend found that a power of 73% was achieved after 20 years for 30 caves monitored. Both vegetation and invertebrate communities will also be analyzed for community composition change using nonparametric multivariate based trend tests tests (such as the index of multivariate seriation), which are not suitable to power analysis. These tests have been generally more sensitive than the univariate techniques used here (Somerfield et al. 2002). Hence, these power results should be seen as conservative estimates of the more robust multivariate methods.

3 Methods

3.1 Schedule

An annual calendar of events is provided in SOP #2: Scheduling, which also offers guidance on necessary personnel, equipment preparation, and reporting. Given that most of the resources monitored are underground, their monitoring schedules are not seasonally driven. For example, climate and human visitation data will be collected on a monthly and ongoing basis. Nonetheless, some resources will be monitored during specific seasons, either due to seasonality in the resource (e.g., bat hibernation periods) or in the availability of field staff.

The majority of monitoring will occur between April and September, with seasonal technician support during even years. Seasonal technicians will require training in safety, caving techniques, equipment use, and data collection. SOP #1: Training provides information on the necessary qualifications, skills, and training requirements for technicians. Hiring of seasonal workers should begin the winter prior to each field season. During the spring, the Lava Beds Natural Resource Program Manager and/or park Field Leads should develop a field schedule detailing upcoming training and monitoring activities, technician roles and responsibilities (SOP #1: Training, and section 5.1 in this narrative), and calendar of monitoring events. Much of this scheduling can be borrowed from the calendar provided in SOP #2: Scheduling. It is important that the schedule include time for cave safety, travel, and navigation training and in the specific SOPs that the seasonal technicians will operate under. The schedule must also allow enough flexibility to account for staff interruptions, equipment problems, and other unforeseen complications. Before the start of work, the park Field Leads should provide seasonal technicians with the relevant methods SOPs so that they can become familiar with them. Some monitoring will occur monthly or otherwise outside of the summer season and will be the responsibility of the park Field Lead (section 5.1). The post field season activities include equipment inventory, writing of reports, and coordination between the parks and network. SOP #2: Scheduling lists those activities, the requisite skills, and a schedule of events.

3.2 Facilities and Equipment

All activities will require support facilities and equipment. Equipment specific to monitoring each parameter is described in the SOPs. Basic office facilities such as storage space, a work station with a computer, and access to a server and database will be needed. Technicians will need standard caving gear, including knee and elbow pads, helmets, lights, batteries, and vehicles to travel to field sites, along with housing/camping sites at the parks. It is the responsibility of the park Field Lead to ensure that necessary equipment is available and in working order.

3.3 Field Methods

Field methods specific to each parameter are provided in the SOPs and summarized briefly in this chapter. Training is briefly discussed in chapter 5 and in greater detail in SOP #1: Training. As noted above, SOP #2: Scheduling describes timing, frequency, and coordination of monitoring activities and includes a calendar to assist in scheduling field activities. SOP #3: Site Selection and Marking offers guidance on establishing field sites. SOPs #4–11 articulate procedures for collecting data on all monitored parameters, and a brief summary of each is below.

3.3.1 Cave Climate (SOP #5)

Temperature and humidity are recorded every hour at all caves and the level of detectible significant change will depend on the natural variation within caves (Appendix F: Power Analyses for Cave Monitoring Parameters, sections 1, 3). Onset Computer HOBO loggers have a resolution of 0.21 ºC in temperature, and a 2.5% resolution in relative humidity, although this resolution might not be possible at extremely high humidity. HOBO data loggers are capable of storing many months of readings before a data download is required; however, data will be downloaded more frequently to minimize losses due to equipment malfunction and to discover problems that might interfere with data analysis. The equipment and methods for monitoring climate are detailed in SOP #5: Climate.

For this protocol, HOBO Pro v2 data loggers were chosen for their reliability, ease of use, and cost effectiveness. These data loggers are effective at recording natural daily and seasonal variation in temperature and humidity and will also indicate major climatic changes in the cave environment. The use of multiple loggers per cave will provide a spatial dataset that can be used to compare climate between caves and among zones within and between caves. A fault of these loggers is that they are known to lose resolution of humidity data when relative humidity levels exceed 95%—a common situation in deep cave environments. We determined that the use of these loggers is justified because they balance cost effectiveness and performance. As this protocol requires deployment of over 120 data loggers, cost effectiveness is paramount to monitoring all sites. Furthermore, obtaining accurate humidity data above 95% saturation is not necessary for meeting this protocol's goal of detecting major climatic changes in caves; park staff are primarily interested in knowing when humidity drops below 95%.

Temperature and humidity will be measured in each cave using HOBO data loggers according to the instructions in SOP #5: Climate. All monitored caves at Lava Beds and Blind Leads Cave at Oregon Caves will contain 3 HOBO data loggers: 1 in each of the zones (entrance, middle, and deep). In The Cave at ORCA, HOBO data loggers will be placed at 23 locations throughout the main cave and on the surface near 2 entrances. Additionally, in 2016, Lava Beds has installed 12 surface data loggers placed inside solar radiation shields (painted light green to camouflage visual disturbance) mounted on 4-foot-tall poles located throughout the monument. Placement locations are such that no surface data logger is more than 1.2 km from any monitored cave entrance, and 2 are located in the headquarters weather station (1 painted, 1 white). Secure placement of climate measurement devices at valuable locations (e.g., near bat colonies, away from disturbance) is considered in SOP #5: Climate. Devices will be labeled and their location and recorded data will be stored in a database.

3.3.2 Water Levels in Subterranean Pools at ORCA (SOP #4)

In Oregon Cave, water is present in a stream and in seasonal pools that occasionally dry during warmer months. We evaluated only simple, easily implemented measurement techniques for water. SOP #4: Water describes the methods for measuring water elevation. Water levels in pools in The Cave will be measured 4 times per year using staff gauges by park staff. Where a gauge cannot be permanently installed, a secure footing will be installed so the gauge can be repeatedly placed in the same location and allow consistent measurements.

3.3.3 Ice Levels in Ice Caves at LABE (SOP #6)

Ice measurements include the elevation and condition of the ice surface and the ice surface area. In SOP #6: Ice, we describe monitoring of ice at caves in Lava Beds using measurements from fixed stations above the ice as well as a method for calculating the top surface area using a laser distometer. Survey methods provide quantitative changes in ice elevation and surface area extent and these two together can be used to gauge volume change.

3.3.4 Human Visitation (SOP #7)

SOP #7: Visitation describes the equipment and methods (ticket sale records, infrared counters, and cave registers) for counting the number of human visitors to each cave. Methods for counting visitation differ among parks because the type, frequency, and nature of visitation, the number of caves at each park, and the visitor-related infrastructure differ among parks. Lava Beds contains hundreds of caves with wide variation in the type and intensity of visitation, whereas The Cave is the main focus of most visitation at ORCA. Thus The Cave is gated and visitors purchase tickets before entering. Tickets sales are managed by the Crater Lake Natural History Association (CLNHA), an officially recognized National Park Service 501(c) (3) nonprofit company. Monthly ticket sales data are included in monthly reports that are sent to the NPS office in Washington, DC, and copies of these reports are ideal for capturing most of the visitation to The Cave. Nonticketed visits by staff and researchers are tracked via a visitation log.

At Lava Beds, it is more challenging to gauge human visitation because the caves are numerous (over 700 have been identified) and often ungated. At sites that receive tourist visitors, LABE currently uses 3 methods of gauging visitor numbers: cave registers (backcountry caves), infrared trip-beam counters (frontcountry caves), and a visitation log (Crystal Ice Cave only). SOP #7: Visitation provides instructions for gauging visitation and storing the information with references to the specific site and source.

3.3.5 Entrance Vegetation Monitoring (SOP #9)

SOP #9: Cave Entrance Vegetation describes the methods for cave entrance vegetation monitoring. Klamath Network vegetation ecologists discussed multiple methodologies and selected the line-transect, point-intercept method described in SOP #9 to rapidly estimate cover by group and growth form within group (i.e., shrub, fern, herb, or graminoid, for vascular plants). This method will allow a crew with little training in vegetation monitoring techniques or identification to quickly assess vegetation cover at cave entrances. This method, in addition to being easy to implement, is highly effective for monitoring changes in percent cover (Elzinga et al. 2001). Under a separate monitoring program (Odion et al. 2011), KLMN monitors terrestrial vegetation throughout both parks, which can provide important context for the cave entrance findings.

Only a handful of caves in Lava Beds have rare fern populations. Moss and lichen grow near the entrance of many more caves, though this is also variable from one site to another. Despite providing visually impressive displays of color and texture, little is known about the importance of ferns, moss, lichen and other plants to cave ecosystems or what factors affect their distribution and abundance.

Identifying vascular and nonvascular plant species and determining their abundance requires specialized expertise that is beyond the ability of most cave field technicians. Therefore, vegetation will be grouped by growth form into 3 categories: vascular plants, bryophytes, or lichens. A simple photographic identification guide is included in SOP #9: Cave Entrance Vegetation to help with identification. Vegetative cover will be measured using the line-transect, point-intercept method (Elzinga et al. 2001). Two transects will be placed parallel to the cave entrance and perpendicular to the passage orientation at 0.5–1.0 m apart. Twenty sampling points will be measured along each transect and growth forms will be recorded.

3.3.6 Bat Monitoring (SOP #8)

Both parks have independent programs (i.e., not associated with this protocol) for monitoring summer use of caves by bats for management purposes. This summer monitoring is very flexible, allowing for staff availability and immediate responses when, for example, a large colony moves into a tourist cave that needs to be temporarily closed. This protocol focuses on winter hibernation counts within 7 caves that support a significant proportion of each park's hibernating Townsend's Big-eared Bat (*Corynorhinus townsendii*) population and within which other bat species (usually *Myotis* and *Eptesicus*) have been incidentally observed. Long-term monitoring of bats and detecting change in bat populations is best accomplished by monitoring in the winter when sampling variability is reduced; summer colonies are extremely active, switching caves or locations within caves weekly. Bats composing a single colony on one day may disperse to multiple different caves the next day. Winter colonies tend to be more stationary throughout the season, decreasing the likelihood of double-counting or missing the counts of some individuals due to surveyor effort being spread over multiple days. SOP #8: Bats describes bat monitoring that will be implemented during the winter hibernation season at the parks. Bats, climate, and visitation will be monitored at bat caves to deepen our understanding of the interrelatedness of these parameters.

Many methods exist to monitor bats, including but not limited to visual counts, acoustic recordings, emergence counts, disturbance counts, mark-recapture, mist netting, still and motion picture photography, extrapolation of numbers based on density and area covered, guano deposition, and infrared photography and videography. The USGS (2003) provides an excellent overview of available techniques. We chose in-cave visual counts to ensure consistency with existing protocols already implemented at Lava Beds and Oregon Caves. This method is widely used for measuring colonies of less than 1,000 individuals, making the data gathered in this park easily comparable to data collected in other geographic areas (some colonies in the winter can be over 1,000 individuals, but always below 1,500). In nearly all instances, the only genera ever documented in caves of the area are *Corynorhinus*, *Myotis*, and *Eptesicus.* These 3 genera are easily distinguishable from one another by ear size and facial features; therefore, technicians can be quickly trained to differentiate the species. In-cave visual counts will also minimize the need for special training, techniques, and analysis while increasing staff safety and minimizing bat stress by avoiding handling bats.

Because of the possibility that a pathogen could be transferred by humans (and their gear and clothes), all work in caves will follow the parks' WNS protocol, which will be based on the national-level decontamination protocol, found at (https://www.whitenosesyndrome.org/topics/decontamination). These procedures require the use of dedicated field equipment (i.e., gear and clothing used only within the park) or decontaminated equipment from areas not affected by WNS. The latest map of WNS spread may be found at https://www.whitenosesyndrome.org/resources/map. In some cases, procedures may include skipping bat surveys at times or places that resource managers deem are most critical for bat survival.

Instructions for winter bat monitoring at 6 Lava Beds caves (Table 1) and at The Cave in Oregon Caves can be found in SOP #8: Bats. The bat monitoring protocol requires little specialized equipment. However, training is extremely important so that researchers strictly follow the latest WNS cave entry procedures (see also section 2.1.4 and many available external sources for more on WNS) and can confidently identify bats to the appropriate level for analysis and avoid disturbing them or inciting unnatural behaviors (such as premature cessation of hibernation). Bat identification (and analysis) is simplified to only differentiate the 3 common genera, *Corynorhinus*, *Eptesicus* and *Myotis*, based on the obvious external characteristic of ear size. Depending on bat viewing conditions, expertise in differentiating these species can be achieved in 1–5 visits to bat caves with all 3 genera. It is important to protect bat colonies by not publicizing the names of bat colony caves; therefore, in this protocol, sensitive Lava Beds bat caves are assigned codes. Appendix D lists bat cave names or codes, as appropriate, and describes how to access the full list of cave names. Park documents with sensitive bat cave names should not be made available to the public and it will be the responsibility of the park staff to address approved requests for this information.

During the winter months (December to March), each cave will be visited once and a complete visual count of the number and type of bats hibernating in each cave will be recorded. Each cave will be divided into zones in order to provide spatial data and 2 or more surveyors will record temperature data and count the number of bats per zone. In order to reduce the likelihood of double-counting or undercounting, all sites at Lava Beds will be visited as close together as possible, preferably within 1 week.

The methods described herein pertain to small colonies (<1,000 individuals, or in some cases up to 1,500 individuals) of the Townsend’s Big-eared Bat and other species, and assume colony fidelity to a particular area. This fidelity is not independently verified, and therefore variation in point counts across caves may not reflect population variation but may instead reflect the use of other unmonitored roosts. Verification of colony identity at Lava Beds is a priority for future investigations, and, as time permits, Lava Beds staff will survey additional caves in an effort to determine all known bat sites. If a site is used consistently, it may be incorporated into this protocol, assuming funding and time are available.

3.3.7 Scat and Visible Organics (SOP #10)

SOP #10 will identify the movement of surface nutrients into caves via presence of plants, animal food, nesting materials, waste, detritus, and human introduced organic material. Surveys will record the presence or absence of several different types of scat and organic material (e.g., bones, owl pellets, bird waste, bat guano, etc.) in each zone of the cave. While these data will not be analyzed quantitatively, they are important in supporting general cave management. At Oregon Caves, we will collect additional information on recent scat deposition by counting the number of rodent scat pieces with fungal hyphomycetes (see figures in SOP #10) and the total number in each zone. In humid environments, these fungal hyphomycetes are relatively good indicators of recent scat because they persist for less than 2 years (John Roth, personal communication). Little training is required to implement this protocol. Additional details are described in SOP #10: Scat and Visible Organics, which will be performed in even years.

3.3.8 Invertebrate Monitoring (SOP #11)

Cave invertebrates are often sparsely distributed and difficult to detect, making monitoring difficult, yet they represent an important source of biodiversity. The low detectability of these species means that significant changes in distributional patterns may take a long time to detect. The limitations of this protocol are severe, considering that invertebrate sampling will only take place every other year and the variance in natural systems such as invertebrate populations is large. This monitoring is not a replacement for the more basic level research that is needed on these rare species, but rather a method for gathering baseline data that may prompt research questions. When selecting an appropriate method for monitoring invertebrates, we considered detectability, distributional patterns throughout the cave, training of field staff, observer bias, replication, and data analysis. We determined that bait stations were the most effective protocol, given our constraints. Our experience with bait stations in Carlsbad Caverns National Park and Great Basin National Park (Krejca and Myers 2005, Taylor et al. 2008) indicates that baits increase detectability in a small area and increase the number of organisms seen, both of which help detect patterns. The baited methods are also similar to cave invertebrate monitoring in Mammoth Cave National Park (Helf et al. 2005) and have already been in use at Oregon Caves. The use of consistent methods across multiple parks will help make biological comparisons nationwide.

SOP #11: Invertebrates describes a method using bait stations to increase the likelihood of detecting some species. To monitor for invertebrates, technicians will place 3 artificial substrates with bait in each zone of a cave and then return in 14–16 days with a quadrat to count all taxa in a 1 × 1 m area around the bait card.

Identification of invertebrates is a highly specialized field; therefore our methods will identify invertebrates only to the most practical taxonomic level. In many cases we may only identify to taxonomic order (e.g., millipede, spider, fly). Deep cave environments have fewer species, and a photographic identification guide for the most common taxa is available for each park (see SOP #11). These guides are intended to help a crew of nonspecialists identify organisms in the field to the most reasonable taxonomic level (often only order), not to identify each organism to species level.

4 Data Management

Data management for a monitoring project is a cyclic process that begins during the planning phase and continues until the close-out of each season. This process is then repeated each year the project is implemented and includes planning; training; data collection and entry, verification, and validation processes; documentation; distribution of project products; storage; and archiving (Mohren 2007). This section provides an overview of data handling, analysis, and report development, with details in SOPs #12–17. 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. SOP #15: Data Transfer, Storage, and Archiving, lists the target dates and responsibilities for each individual and product.

4.1 Preparation

Preparation involves ensuring that field datasheets and databases are up-to-date and available, and that all involved staff members have folder and file access. Field datasheet examples are provided in the relevant SOPs. Field datasheets and maps are printed for all caves that will be visited during the field season. Sheets are organized to facilitate sampling and tracking of parameters to be measured through the field season. If a GPS is needed to locate a cave, the Field Lead will ensure that cave coordinates and a GPS unit are available to properly trained technicians.

4.2 Data Collection and Entry

Some data are recorded on paper datasheets. Before leaving a site, the field crew is responsible for ensuring that all datasheets have been filled out completely and that the information on each datasheet is logical and legible. Upon returning from each sampling trip, datasheets should be scanned to PDF files. If changes are subsequently made to paper datasheets, they should be rescanned. Field datasheets are part of the permanent record and are discussed in SOP #15: Data Transfer, Storage, and Archiving. Hard copies will be stored at the KLMN office until transferred to an archival facility.

Data are managed in a relational cave database. A “working database” is used for entering, editing, and error-checking data for the current season. The “master database” contains the complete set of certified data for the monitoring project. The working database will be provided to each crew (one database for each park) at the beginning of each field season (SOP #12: Cave Database); this will be used for entering and editing data for the current field season. SOP #13: Data Entry details the procedures for entering data into the databases. It is the responsibility of the technicians to enter data into the project database as soon as possible following field work.

Temperature and humidity data are collected by data loggers at regular intervals; this type of continuous data is not appropriate for an MS Access database. However, information about the loggers (e.g., deployment dates, locations) will be maintained in the database and Aquarius Time Series software by Aquatics Informatics will be used to manage the continuous data in accordance with upcoming guidance on using Aquarius from NPS Water Resources Division.

Lava Beds, working with the USDA Forest Service Pacific Southwest Research Station (PSW), developed a database to house all historical and current bat monitoring and inventory data (see description in SOP #12: Cave Database). The staff at Lava Beds use this database to store bat data collected as part of this protocol. After entry of seasonal bat data is complete, a copy of this database is delivered to KLMN and the Data Manager will upload the data to the master Cave Database (SOP #13: Data Entry).

4.3 Data Verification and Validation

Data will undergo 2 rounds of initial review by the technicians. The first review occurs in the field after each survey when the observer checks the datasheets (SOP #13: Data Entry). This involves searching for errors or missing data. There should be no blank fields (except possibly the "notes" section) without an accompanying explanation. The technician will initial the bottom of each field datasheet after it is proofread.

The second round of review occurs when entering the data into a database. The person entering the data can correct minor errors, such as misspellings, with a red pencil. Because the database has built-in domain values, only acceptable values can be entered for many of the fields. Unresolved issues should be noted and forwarded to the Field Lead. Once data entry is complete, a copy of the database should be sent to the KLMN Data Manager for archiving (this is the raw, working database copy).

The Project Lead, or someone familiar with the data, should verify the data by comparing hard copy datasheets to the database. Once verification is complete, a copy of the database should be sent to the KLMN Data Manager for archiving (this is the verified, working database copy).

The Project Lead will work with the Data Manager to validate the data, checking it for completeness, integrity, and logical consistency. The Data Manager will provide any needed database queries, reports, graphs, or export file formats to assist with the overall validation.

Details about any all-record review and the resulting actions taken (e.g., nature of the errors) are documented in the dataset metadata.

Once validation is complete, the database should be sent to the KLMN Data Manager. The Data Manager will do a final check on the data and when complete, will merge the ORCA and LABE database. A copy of the merged validated database will be moved to the archive. Then the working database will be uploaded to the master database. KLMN will maintain the final copies of the database.

4.4 Photographic Data

Care should be taken to distinguish data photos from incidental or opportunistic photos. Data photos are those taken for at least one of the following reasons:

1. To document a particular feature or perspective for the purpose of site relocation.
2. To capture site habitat characteristics and to indicate gross structural changes over time.
3. To document species detection.

It is the responsibility of the Project Lead to ensure images are properly named and stored in the correct location, along with the image metadata as described in SOP #14: Photograph Management. Information about data images are entered into the project database.

4.5 Site Dossiers

Site dossiers provide cave-specific information including descriptions, directions, maps, and photos. Cave maps show the location of monitoring stations, survey zones, and monitoring equipment (including the number of each transect or station). Outdated versions of dossiers will be saved for reference by future researchers. Future maps should use standard methods and symbols described in Dasher (1994). The Project Lead should ensure that all dossiers, and the files used to create them, are transferred to the KLMN Data Manager for archiving.

4.6 Data Certification

Data certification is a benchmark in the project information management process that indicates the following:

1. The data are complete for the period of record.
2. The data have undergone and passed quality assurance checks.
3. The data are appropriately documented and in a condition for archiving, posting, and distributing as appropriate.

Certification is not intended to imply that the data are completely free of errors or inconsistencies. Rather, it describes a formal and standardized process to track and minimize errors.

To ensure that only quality data are included in reports and other project deliverables, the data certification step is an annual requirement for all data. The Field Lead is primarily responsible for completing the Data Delivery form (SOP #15), which, along with the database, is reviewed by the Data Manager. This brief form should be submitted with the certified data according to the timeline in SOP #15: Data Transfer, Storage, and Archiving.

4.7 Data Backup and Storage

All data will be stored on network servers (versus local hard drives). While the data are at the parks, they will be backed up regularly to ensure that data and information are recoverable in the event that data are accidentally deleted, hardware or software fails, or edits from previous versions become questionable. At LABE, incremental backups of the main server are run every night. At ORCA, incremental backups are run during the week and full backups are run periodically (typically weekends). After files are transferred to the KLMN Data Manager, they will be managed on the KLMN server, which is backed up nightly. This includes, but is not limited to, data and information related to field data, images, administrative records, and planning documents.

Metadata are updated annually for tabular data and as needed for spatial data. Once the master project dataset and metadata are considered final, the Data Manager will place a copy of the dataset and the metadata record into the appropriate folder within the archive directory on the network server. These archived files will be stored in read-only format. Any subsequent changes made to this database must be documented in an edit log.

Any digital files associated with data analysis products and project reporting are to be archived in a similar fashion.

Hard copy materials (e.g., datasheets, field notebooks, and reports) are currently stored in the network office but will be moved to an NPS-approved repository for permanent storage.

4.8 Data Maintenance

Any editing of certified data must be documented in an edit log and accompanied by an explanation that includes pre-and post-edit data descriptions. Datasheets can be reconciled to the database through the use of the edit log. If park staff find an error in the database, they should communicate the error to the Data Manager, who will edit the data in the master database.

Prior to any major changes of a dataset, a copy is stored with the appropriate version number to allow for tracking changes over time. Each additional version will be assigned a sequentially higher number.

Full metadata records and databases are available through the NPS Integrated Resource Management Applications portal (IRMA). Records for reports and other publications are created in the Data Store section (https://irma.nps.gov/DataStore/) of IRMA. Digital report files, in PDF format, are then uploaded and linked to the IRMA record. Species observations are extracted from the database and entered into the NPSpecies section of IRMA, which is the NPS database and application for maintaining park-specific species lists and observation data (https://irma.nps.gov/NPSpecies/).

4.9 Protected Information

Some project information (e.g., the specific locations of rare or threatened taxa) should not be shared outside NPS, except where a written confidentiality agreement is in place. Before preparing data in any format for sharing outside NPS, including in presentations, reports, and publications, data users should refer to the guidance in SOP #16: Protected Data. Information that may reveal the specific location of sensitive resources or treatments should be screened or redacted from products meant for public consumption prior to release. All official Freedom of Information Act (FOIA) requests will be handled according to NPS policy. The Project Lead will work with the Data Manager and the FOIA representative(s) of the park(s) for which the request applies. FOIA requests for certain protected information such as cave locations will be denied as this information is exempted from FOIA under the Federal Cave Resources Protection Act.

4.10 Analysis and Reporting

Analysis and reporting procedures are described in SOP #17: Data Analysis and Reporting. Reporting is the collective responsibility of the park Field Lead, Lava Beds Natural Resource Program Manager, and KLMN staff (see chapter 5). Four types of reports will be developed as part of this monitoring effort:

1. Annual Effort reports - an internal report documenting basic information about each year’s monitoring activities; individual park reports are prepared by each park’s Field Lead)
2. Biennial reports - published report summarizing the past two years’ monitoring activities at both parks; collaboratively prepared by the NRPM, KLMN Project Lead, and park Field Leads

3. Resource Briefs
4. Analysis and Synthesis reports

In addition to these reports, described in more detail below, journal publications related to the objectives of this protocol are anticipated as opportunity allows (e.g., relevant findings, staff time, analytical assistance, etc.). Guidance on data analysis, including methodology for using community composition to detect trends, is given in SOP#17: Data Analysis and Reporting.

4.10.1 Annual Effort Report

The Annual Effort report is an internal document provided by each of the Field Leads to the NRPM and KLMN office summarizing monitoring *efforts* for the year. This report is due on March 1st of the year following the sampling year (e.g., March 1, 2018, for CY 2017 efforts). It will provide a concise summary of the year's efforts, highlights, notable deviations from standard sampling plans, and any insights that will aid in preparation of subsequent Biennial reports. In addition, it should include the following information:

1. An introduction referencing the protocol.
2. A summary of the current year's monitoring efforts, including time frame, caves visited, parameters measured at each cave, names of participating staff, etc.
3. Any anomalies, departures from SOPs, issues addressed, problems encountered, etc., that were incurred.
4. Public interest highlights, if any.
5. Recommended changes to the protocol.

The Annual Effort report should adequately document the season's activities so that future Field Leads, Project Leads, NPS specialists, research scientists, and other personnel fully understand the location and types of data collected.

4.10.2 Biennial Reports

Each Biennial report will provide a summary of monitoring efforts and general findings for the preceding 2 years at both parks. The report will be formatted for the NPS Natural Resource Publication Management series, either as a Natural Resources Data Series or Natural Resources Report, as appropriate. Summary data and supporting materials for this report are due from the park Field Leads to the KLMN Project Lead on March 1st of the year following sampling (e.g., March 1, 2017, for calendar year 2015–16 efforts). The final report is a collaborative effort among the park Field Leads, the LABE Natural Resource Program Manager (NRPM), and the KLMN Project Lead and is due on June 15th. All 8 parameters (e.g., Bats, Invertebrates, Vegetation, Climate, Vegetation, Scat, etc.) will be included in the Biennial reports, and examples of analyses and trigger points for management actions are described in SOP #17: Data Analysis and Reporting. The report lead writing the report must be able to operate basic computer software (including graphical data display), must have spent a significant amount of time performing monitoring of at least half of the parameters, and must have consulted with other data collectors and upper-level resource managers about the discussion and conclusions. The initial 2-year report should follow the templates provided in other

KLMN monitoring protocols and the future reports should use this initial report as a standard template. Biennial reports will include the following:

1. Abstract or Executive Summary. Include a summary of findings as well as highlights of the conclusions.
2. Introduction. A short summary of background, goals and objectives, and the context of the reported years relative to all years collected for this protocol and other related cave monitoring in the parks.
3. Methods. A summary of methods, the survey effort, any departures from SOPs, and a reference to the published protocol.
4. Results. The results of monitoring efforts. This section can be organized by site or otherwise, as fitting..
5. Discussion. This will not be extensive but can offer interesting or anomalous findings from the results. It is also a venue for expressing observations outside of the normal parameters, including identifying information gaps that, if filled by research, may help future monitoring efforts. Note that the inclusion of a lengthy discussion may change the report to a Natural Resource Report. Refer to guidelines available online from the Natural Resource Publication Management office (http://www.nature.nps.gov/publications/NRPM/) to distinguish NRDS from NRR reports
6. Logistical Challenges, Protocol Review Recommendations, and Expected Equipment Needs.
7. Key Accomplishments and Seasonal Highlights.

4.10.3 Resource Briefs

Resource briefs are 1 to 2 page summaries of monitoring efforts, usually assembled by the KLMN Science Communication Specialist with support from the park Field Leads and the KLMN Project Lead. These reports are designed to quickly inform resource managers about the work that has been completed and any significant results. In addition, these reports will be written in a nontechnical manner to be accessible to all interested park staff or the general public.

4.10.4 Analysis and Synthesis Reports

Analysis and Synthesis reports will be completed every fourth year as a collaborative effort between the park Field Leads, the Lava Beds NRPM, and the KLMN Project Lead. Summary data and supporting information will be due from the Field Leads to the KLMN Project Lead on March 31st of the following year, and the final Analysis and Synthesis report will be due on June 15th. For example, a 2020 Analysis and Synthesis report will be due June 15th, 2021.

The Analysis and Synthesis report is a detailed investigation into particular aspects of cave biology or environment, either through hypothesis testing or detailed descriptive work. The Analysis and Synthesis reports will 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. These reports are not intended to be exhaustive, and by design do not report on every monitored parameter; they are more likely to explore 1 parameter at a time. Eventually, the Analysis and Synthesis reports will focus on trend detection, but we acknowledge that the monitoring design will require 10 or 20 years, depending on the parameter, to accumulate enough observations to differentiate between noise and real trends. For these reasons we designed Analysis and Synthesis reports to be a deeper exploration of a limited number of parameters that provide information about an important dimension of cave ecosystems for the initial reports. SOP #17: Data Analysis and Reporting suggests topics for early Analysis and Synthesis reports, and brief descriptions are provided below. As topics of management concern evolve or change, the Analysis and Synthesis reports should likewise be flexible to accommodate emerging concerns or statistical advances.

Analysis and Synthesis Report 1: A Gradients Analysis and Typology of Cave Environments in Lava Beds National Monument and Oregon Caves National Monument and Preserve: After 4 years of data have been collected at Lava Beds and Oregon Caves, the first report will summarize the general patterns and types of cave environments in the parks. The specific parameters to be analyzed include cave microclimate, ice and subterranean pool water resources, and visitation patterns. To the degree possible, the efforts will attempt to elucidate spatial patterns in each of the parameters across each park sampling frame, and describe the general types of cave environments and biological communities found. The report will likely have broad relevance to general management and interpretive planning at each park, as well as general interest to the public.

Analysis and Synthesis Report 2: A Gradient Analysis and Typology of Cave Communities in Lava Beds National Monument and Oregon Caves National Monument and Preserve: After 8 years of data have been collected at Lava Beds and Oregon Caves, the second report will follow the format of the first, but could be focused on the cave communities: entrance vegetation, invertebrates, and bats.

Analysis and Synthesis Report 3: Status, Trends, and Dynamics in Cave Environmental Conditions: This report may analyze and synthesize cave environmental data from the first 12 years of monitoring, augmented with comparisons to longer term measurements undertaken by the parks. Specific parameters will include visitation, cave microclimate, ice (at Lava Beds), and water (at Oregon Caves). The focus will be to summarize trends in the potential human stressors and abiotic environments.

Analysis and Synthesis Report 4: Status, Trends, and Dynamics in Cave Communities: This Analysis and Synthesis report may summarize and analyze cave community data from the first 16 years of monitoring, with comparisons to longer term time series based on park sampling as feasible (e.g., for bats). Specific parameters will include cave invertebrates, bats, and cave entrance vegetation. Our general aim in this report will be to summarize the trends and dynamics in the diversity, distribution, and compositional changes in cave biological communities over time.

4.10.5 Report Format

Reports will be formatted using the NPS Natural Resource Publications Management report series templates, which are preformatted Microsoft Word documents based on current NPS formatting. Biennial reports will likely be formatted using the Natural Resource Data Series template whereas Analysis and Synthesis reports and other peer-reviewed technical reports will likely be formatted using the Natural Resource Report template. These templates and documentation of the NPS publication standards are available at: http://www.nature.nps.gov/publications/NRPM/index.cfm.

5 Personnel Requirements and Training

5.1 Roles and Responsibilities

These protocols were designed to maintain continuity of data collection by seasonal staff over multiple years. A Project Lead, who is a KLMN employee and who is, or is appointed by, the Network Program Manager, will be in charge of project oversight. In addition, the KLMN Data Manager will be responsible for the long-term management and maintenance of the project deliverables. The Lava Beds Natural Resource Program Manager (NRPM) will serve as the primary coordinator for project implementation among parks. This role is particularly important during even years for hiring and coordinating the shared technician between parks and training the combined park staff on methods. Each park will have a Field Lead (term or permanent) who will ensure all aspects of implementation at the Field Lead’s respective park, including any tasks related to scheduling, hiring, training, and equipment management not addressed by the Lava Beds NRPM. The park Field Lead will implement climate, bat, ice/water, and visitation SOPs during odd years, with the support of other park staff, technicians, or interns, as needed. In even years, the additional summer work load (scat, vegetation, and invertebrates) will be performed primarily by a seasonal technician who will be hired to support both parks. Ideally, this technician will be initially trained and duty stationed at ORCA, will conduct summer cave monitoring at ORCA for 3–4 weeks, and then be will be duty stationed at Lava Beds to conduct summer cave monitoring at Lava Beds for the remainder of the season. When a second individual is needed for field work, the shared seasonal technician will be assisted by another technician, intern, or other park staff (e.g., Field Lead, NRPM). Most of the activities covered by the SOPs do not require extensive expertise or experience and can be completed by well-trained seasonal technicians. For some field operations, such as bat monitoring, where sensitive resources are involved, the Field Lead and/or Lava Beds NRPM will provide field leadership and coordination. The SOPs provide more detail on what will be expected of field personnel. The park Field Leads will support the Lava Beds NRPM and KLMN Project Lead on development of reports.

5.2 Qualifications, Hiring, and Training

With the exception of report writing, seasonal technicians or park staff should be able to carry out the instructions in the SOPs. For Annual Effort reports, the Field Lead, or whoever is assigned by the Field Lead, must have highly developed written communication skills and firsthand knowledge of the caves and monitoring parameters. For the Biennial and Analysis and Synthesis reports, the author(s) must collectively possess a familiarity with the caves, parks, and monitored parameters as well as some knowledge of biostatistics, including standard univariate and multivariate analyses. Co-authors will include the park Field Leads, the Lava Beds NRPM, the KLMN Project Lead, and others as needed.

Seasonal field support should have university-level knowledge or experience in the natural sciences, geography, or environmental resource management fields. They should be in excellent physical condition and be able to safely traverse uneven ground and negotiate all caves where work will be performed. They should also be able to work independently with little direct supervision and also able to work well within a team. They must be comfortable working in caves and remote areas of the parks. It is extremely important that they understand how to collect and record accurate data for scientific investigations and know when to ask for assistance. This is best demonstrated by some research or field work experience, but can also be demonstrated by coursework that requires data collection and management.

Park Field Leads and the Lava Beds NRPM have responsibility for recruitment and selection of summer seasonal workers. Hiring of seasonal employees should follow standard procedures for federal employment. It is also possible to supplement the field crew with staff from regional universities, Geologists-in-Parks program, and the Student Conservation Association, as needed.

Once technicians are hired, it is the responsibility of the park Field Lead to send them the protocol and SOPs that they will be implementing. Park staff will provide an orientation to the park and its staff, living and working conditions, hours, residency information, park-specific and general safety, rules/restrictions, and area maps. This information will help these technicians plan their stay and understand what is expected of them. They may have basic questions and concerns about day to day operations and living, managing workloads, and conducting themselves in a professional field environment. Technicians generally arrive at the park 1 to 2 weeks before they are expected to begin their seasonal monitoring duties. This orientation period, organized and performed or overseen by the Field Lead, will be devoted to an introduction to the park and its operations and to training. All seasonal workers in the parks generally receive training in safe caving techniques, radio communication, backcountry travel, minimizing impacts, navigating in the parks (including reading cave maps and using a GPS unit), and dealing with emergencies.

5.3 Safety

Safety is the first priority. Anyone entering a cave should have at least 3 independent sources of light and a contact on the surface should be aware of what caves the field personnel will visit, in what order they will be visited, and when they are expected to return. All safety gear and clothes must comply with WNS prevention policies as well as the latest park protocols, which require dedicated gear acquired in new condition and used only at the park, or decontaminated gear from areas not affected by WNS. Field crews will be trained by their respective parks on park check-in and check-out processes, job hazards, and risk management. The Field Lead will verify that seasonal field crew members are safely out of the caves by the end of the day and will follow park check in/out procedures when in the field alone, without coworkers. It is especially important to train seasonal personnel in safe caving and hiking techniques. All field personnel should know who to contact in the case of a medical emergency and field personnel should be asked this information periodically to ensure that they remember it. In odd years, periodic bat and ice monitoring and climate/visitation logger downloads are integrated into the Field Lead’s year-round activities and combined with research or monitoring that falls outside of the scope of these protocols, such as collecting data on the percentage of hibernating bats. Per discussion with the park Chiefs of Resources, a protocol readiness review will be conducted in even years in advance of the summer monitoring work. The protocol readiness review is a document that facilitates cooperation and co-management of the risks associated with protocol implementation. It is signed and agreed upon by the KLMN Program Manager, the Project Lead, and the Superintendent at each park.

5.4 Workload

The annual workload is laid out in SOP #2: Scheduling, and individual SOPs detail the work involved in monitoring each environmental parameter. To conduct even-year monitoring, the hiring process will begin in the previous December, training will occur in early April, and field work will begin in April at ORCA and May at LABE and continue until September. Full-time park staff (e.g., Field Leads) will perform field work for some parameters (climate, visitation, bats, ice) that can be integrated into other year-round field activities. This monitoring should occur according to the schedule in SOP #2.

During the field season, data management is as important as data collection and should follow the guidelines laid out in SOPs #13–17. The KLMN Data Manager should be in close contact with the Field Lead regarding data management issues. The Field Lead and some park staff should be familiar with the database and architecture of the data storage file structure and programs that will house information collected under these protocols. It is important that multiple park staff be familiar with the data management procedures so that they can answer questions from seasonal technicians and proper data management can continue in the event of staff turnover. Basic data entry will often be performed by seasonal technicians. Data entry should be demonstrated and written instructions are provided in SOP #13 for future reference. It is the duty of the Field Lead to provide these instructions and ensure technicians are properly trained.

6 Operational Requirements

6.1 Annual Activities and Schedule

Activities related to cave monitoring will take place throughout the year, but scat, vegetation, and invertebrate monitoring will be concentrated between April and September of even years. Park staff have created datasheets for each parameter that is sampled, annotated cave maps with established survey zones and sampling stations, and installed climate measuring devices, cave registers, and visitor counters. Regular maintenance of equipment, hiring and training, and data collection will all be performed as described in various SOPs as well as in Table 2. A calendar of events is provided in SOP #3: Scheduling, to aid in planning upcoming activities.

Data will be recorded on hard copy field datasheets (examples are provided in individual SOPs), validated while on-site, and then entered into the database according to SOP #13: Data Entry. Once entered, the data will be validated according to SOP #15: Data Transfer, Storage, and Archive. Once validated, the data will be reported and then archived.

Annual Effort reports, Biennial reports, Analysis and Synthesis reports, and Resource Briefs will be the primary tools for disseminating the findings from this protocol. Report preparation occurs after data are collected, entered, validated and certified. Instructions on data reporting are included in SOP #17: Data Analysis and Reporting. To make reporting as streamlined as possible, the authors of this monitoring protocol will work with the KLMN Data Manager to design a database conducive to searching, analyzing, and reporting data in the format that reports are likely to take. Reports will be generated by NPS staff who should be trained in database use and be familiar with related SOPs.

6.2 Facilities and Special Tools

This project does not require any special facilities; however, some specialized equipment (such as data loggers) will be necessary. Equipment specific to each parameter is listed in the respective SOP. Access to computers and servers, some basic lab equipment, and storage for equipment will be necessary. Basic caving gear will also be required, as will vehicles to reach field sites. Housing for field crews might also be necessary. The Lava Beds NRPM will coordinate with each park Field Lead to ensure that all equipment needs are met at least 1 month before sampling occurs, and, during even years, will work with the KLMN Project Lead to purchase any necessary equipment.

6.3 Budget

Based on implementation costs during pilot years (2012–2016), we estimate a budget of approximately $26,591 to implement monitoring during odd years and $46,448 during even years (Table 3). The difference between odd and even year budgets results from the summer field work associated with scat, vegetation, and invertebrate monitoring in even years. Protocol implementation costs during odd years is primarily for salary of existing park staff and will be covered by these employees' respective parks ($7,875 at ORCA; $18,716 at LABE). In even years, KLMN will provide funding as identified in Table 3, subject to approval of the network's annual workplan and budget by the KLMN Board of Directors. Note that values in Table 3 reflect actual monitoring costs and exclude the initial startup costs/time associated with setup of caves for long-term monitoring, and protocol development. Klamath Network staff contributions are identified in Table 3, but are not included in the annual total costs because network salaries are accounted for in the network’s core expenses.

During odd years, expenses are primarily salary for the Lava Beds NRPM (project coordination/reporting, occasional field work), each park’s Field Lead, occasional technician support when a second person is required, and minor amounts of equipment and vehicle costs. During even years, a shared seasonal technician performs the bulk of the seasonal field work at both parks and is accompanied as needed by a second seasonal technician at LABE. With spring and summer field work, data entry, and gear management addressed by these individuals, work load for the LABE Field Lead is lessened in even years. Other park staff funded during even years include the LABE NRPM and the ORCA Field Lead. The even year budget also includes vehicle costs at LABE, equipment, and a small amount of travel for group training at ORCA.

Data management activities comprise at least 30% of all hours by the Lava Beds NRPM, Field Leads, and technicians (Table 3). In addition, the KLMN Data Manager dedicates 100% effort to data management duties. Thus data management related activities consume at least 30% of the total budget provided by KLMN. Costs are incorporated into the odd and even year budgets for Annual Effort and Biennial reports, which are prepared as a collaborative effort among the Field Leads, Lava Beds NRPM, and KLMN Project Lead. The first Analysis and Synthesis (A&S) report will be developed in 2020, by which time we will have completed 2 full cycles of sampling (odd and even years) at caves in the Lava Beds random sampling design (section 2.2.2). A&S reports will be produced roughly every 4 years thereafter. The KLMN Project Lead will likely coordinate and lead development of this report, which will be started late in FY 2019. We estimate roughly 4 pay periods of the KLMN Project Lead time, augmented by 2 pay periods each from the Lava Beds NRPM and the ORCA Field Lead. Given salaries cited in Table 3, one A&S report would cost approximately $32,918 in FY16 dollars.

Table 3. Estimated costs for implementing the KLMN cave protocol in odd and even years (in FY16 dollars). KLMN staff salaries (gray shaded cells) are not included in data management calculations or total project budget (because they are already included in the network's core expenses).

		Odd Years				**Even Years**				**Data Management**	
Description	**Rate/PP**	**Quantity**	**LABE**	**ORCA**	**KLMN**	**Quantity**	**LABE**	**ORCA**	**KLMN**	**% time**	**$ allocated**
KLMN Project Lead- GS-13	$5,221	2	-	-	$15,663	2	-	-	$15,663	30	$4,699
KLMN Data Manager- GS-12	$4,209	1	-	-	$6,314	1	-	-	$6,314	100	$6,314
LABE Nat. Res. Prog. Mgr. GS-09/11	$2,967	2.5	$7,418	-	-	2.5	-	-	$7,418	30	$2,967
LABE Field Lead GS-07	$2,085	3.5	$7,298	-	-	3	-	-	$6,255	30	$1,877
LABE seasonal technician GS-05	$1,500	2	$3,000	-	-	5	-	-	$7,500	30	$2,250
ORCA Field Lead GS-09	$3,050	2.5	-	$7,625	-	2.5	-	-	$7,625	30	$2,288
Shared seasonal technician GS-05	$1,500	-	-	-	-	10	-	-	$15,000	30	$4,500
Travel (camping per diem)		-	-	-	-	-	-	-	$150	-	-
Vehicle		-	$500	-	-	-	-	-	$1,000	-	-
Field equipment		-	$500	$250	-	-	-	-	$1,500	-	-
Total (not including KLMN staff)			**$18,716**	**$7,875**					**$46,448**	**30%**	**$13,882**

7 Glossary of Terms

abiotic—nonliving chemical and physical factors in the environment.

ablation—the melting or wearing away of rock or ice.

accretion—increase in size by external addition, fusion, or inclusion.

anthropogenic—caused by humans.

archaea—microorganisms resembling bacteria but certain aspects of their chemical structure, such as the composition of their cell walls, is different; typically live in extreme environments.

biodiversity—the variety of lifeforms.

biofilms – a coating on rock or other materials (especially organics) that organisms produce, and particles (sediments, organics, or minerals) that are trapped by or precipitated within the film; usually composed of bacteria, fungi, diatoms and/or protists.

biological oxygen demand—amount of dissolved oxygen that is consumed by aquatic species in a volume of water per some unit of time.

biotic—relating to, produced by, or caused by living organisms.

bryophyte—all embryophytes (land plants) that have tissues and enclosed reproductive systems, lack vascular tissue, and do not produce flowers or seeds.

calcite—$CaCO_3$, dominant mineral in limestones; the same chemical composition as aragonite and vaterite but of a different molecular arrangement expressed in different crystal forms.

carbon dioxide—CO_2, a gas usually elevated in caves compared to the surface.

cave—1. Any natural cavity in the earth in which the long dimension (length or depth) is greater than the cross-sectional dimensions at an actual or eventual entrance and which is large enough for humans to enter. 2. Any naturally occurring void, cavity, recess, or system of interconnected passages under the earth's surface or within a cliff or ledge, but not any vug, mine, tunnel, aqueduct or other man-made excavation. Must be large enough for entry of humans, whether or not the entrance is naturally formed or man-made. Generally excludes riverbank undercuts but usually includes rock shelters.

chemo-organotroph—organism that gets its energy by oxidizing organic compounds; includes decomposers.

chemotroph—organism which gets metabolic energy from chemical reduction or oxidation of inorganics, such as sulphur or iron.

conductivity—the ability of a substance to conduct an electric current.

culture—the cultivation of microorganisms, bacteria, or tissues for scientific study.

The Cave—Refers to Oregon Caves, the main cave at Oregon Caves National Monument and Preserve.

data logger—an electronic device that records information over time.

Decomposer—chemo-organotroph, usually a microbe, that breaks down organic matter.

dissolved oxygen—the amount of oxygen that is dissolved or in a given medium, usually water.

ecology—science of the relationships between organisms and their environments.

endemic—population only from a particular area.

FOIA—Freedom of Information Act.

foraging—wandering in search of food.

formation—in a cave, refers to any form created by deposition or erosion.

fungi—eukaryotic single-celled or multinucleate organisms that decompose and absorb organic material in which they grow.

genus—subdivision of a family or subfamily in the classification of organisms; usually consists of more than 1species.

graminoid—grasses and grass-like plants.

guano—scat piles from bats, birds, and crickets; the most important organics in many caves are bat guano and carrion, cricket guano and eggs, or pack rat nest litter and feces.

herb—flowering plant that does not produce woody tissue and generally dies at the end of each growing season.

hibernaculum—location chosen by animals to hibernate. Plural: hibernacula.

humidity (relative)—water-vapor in air at a given temperature, expressed as a ratio of vapor content needed for saturation.

hydrocarbon—an organic compound consisting entirely of hydrogen and carbon.

hygrothermograph—instrument that measures and records atmospheric humidity and temperature.

ice (cave)—often near bottom of cave; can be primary (glacier) or secondary deposits.

invasive species—nonindigenous species that negatively affect the habitats they invade.

invertebrates—animals without backbones. Commonly includes insects, worms, and arachnids.

Ion—atom or molecule where the number of protons and electrons are not equal, giving it a positive or negative charge.

Isotope—an atom that contains the same number of protons but a different number of neutrons than other atoms of the same element.

KLMN—Klamath Network Inventory & Monitoring Program

LABE—Lava Beds National Monument

lampenflora—plants growing around lights in show caves.

leaching—separation or dissolving out of soluble constituents from a porous medium by the percolation of water.

lichen—a fungus that grows symbiotically with algae, forming a composite organism that often encrusts rocks and trees.

limestone—carbonate made up almost entirely of calcite and/or aragonite ($CaCO_3$).

macroinvertebrate—invertebrates larger than meiobenthos and which are retained on coarse sieves with a mesh size greater than or equal to 2 mm; usually visible to the naked eye from 1 foot away or closer.

marble—metamorphosed limestone and/or dolomite; usually calcite recrystallized as coarser grained than crystals in limestone and of lower porosity, averaging less than 1%.

microbe—microscopic species. Usually archaea, bacteria, protists (single cell eukaryotes), fungi, fungi-like (e.g., oomycetes). Often filamentous in U-loops, moonmilk.

microhabitat – a restricted, definable space where environmental conditions differ from those in surrounding area.

moonmilk—white clay, often carbonates and rarely sulfates; consistency similar to creamy cottage cheese when wet, and dried milk when dry.

morphology—the form and structure of individuals, excluding anatomy.

mosses– see bryophytes.

NPS—National Park Service.

NRPM—Natural Resource Program Manager.

ORCA—Oregon Caves National Monument and Preserve.

Oregon Caves—Oregon Caves National Monument and Preserve.

oxidation—the combining of an element with oxygen, as in the formation of silicates and iron and manganese oxides.

pH—the concentration of hydrogen ions in water in moles per liter, defined on a logarithmic scale; greatly affected by amount of dissolved CO_2 and calcium and adjacent hard rock mining. Shows weak inverse relationship to discharge. Low pH can mobilize toxic heavy metals that can injure species.

positive feedback loop—in a system, when a perturbation acts to increase the magnitude of the system's response to that perturbation. Melting cave ice creates a positive feedback that accelerates cave warming and increases melting rates.

pressure transducer—a sensor that measures pressure, typically of gasses or liquids.

range—the geographic area in which a species can be found.

roost—where bats or birds sleep or rest. Incl. deserted, distribution (ceiling, crevice, single, groups of 2–10, groups >10, wall), hibernaculum, migratory, moth wings, night, nursery, occasional, scratches, summer, & transitory.

scat—excrement, dung.

shrub—woody plants less than 8 m in height; usually have many stems arising at or near the base.

solubility—the total amount of solutes that will remain indefinitely in a solution maintained at a constant temperature and pressure in contact with the solid crystals from which the solutes were derived.

species—the basic taxonomic unit in bio-classification; usually based on evolutionary kinship (phylogenetic) or the potential for natural interbreeding.

speleothem—any secondary and natural mineral deposit formed in a cave by the direct action of water.

staff gauge—a graduated scale anchored in water so that it can be read by observing where the water surface contacts the scale.

troglobite—species confined to caves or similar habitats.

troglomorph—species with morphologic and occasionally physiological cave adaptations.

trogloxene—animal entering cave but not living there permanently.

vascular plant—plant with lignified tissues for conducting water, minerals, and photosynthetic products through its body; includes ferns, clubmosses, flowering plants, conifers and other gymnosperms.

vermiculation—thin, irregular, discontinuous sediment usually of clay, sometimes of silt, but may be composed of hydrated iron and aluminum oxides, and soot.

weir—a small dam in a stream, designed to raise the water level or to divert its flow through a desired channel for discharge measurement (e.g., cubic feet per second).

8 Literature Cited

Aley, C. 1988. Restoration of natural microclimate in Oregon Caves National Monument, Final Report. Ozark Underground Laboratory, Protem, Missouri.

Aley, T. J., and C. L. Aley. 1987a. Airflow investigations. Pages 75-76 *in* R. Hyra and N. Knowles, editors. 1986 Annual science report. National Park Service, Pacific Northwest Region, Seattle, Washington.

Aley, T. J., and C. L. Aley. 1987b. Restoration of natural cave features, Oregon Caves National Monument, Oregon. Ozark Underground Laboratory, Protem, Missouri.

Arrigo, K. R. 2005. Marine microorganisms and global nutrient cycles. Nature 437:349-355.

Blehert, D. S., J. M. Lorch, A. E. Ballmann, P. M. Cryan, and C. U. Meteyer. 2011. Bat White-nose Syndrome in North America. Microbe 6: 267-273.

Bond-Lamberty, B., and A. Thomson. 2010. Temperature-associated increases in the global soil respiration record. Nature 464:579-582.

Bratvold, D. 1995. Oregon Caves microbial ecology project report. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Carpenter, S. E. 2003. Report of fungal samples. Submitted by John E. Roth, Oregon Caves National Monument. Abbey Lane Laboratory LLC, Philomath, Oregon. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Carpenter, S. E. 2004. Report of fungal samples. Submitted by John E. Roth, Oregon Caves National Monument. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Crawford, R. 1994. Cave invertebrates of Oregon Caves National Monument, Josephine County, Oregon: Initial species list and progress report. Unpublished contract report by the Burke Museum, University of Washington, Seattle, to Oregon Caves National Monument, Cave Junction, Oregon.

Crawford, R. 1996. Specimens from Oregon Cave identified and labeled in 1995-6. Unpublished contract report to John Roth, Oregon Caves National Monument, Cave Junction, Oregon.

Cross, S. P. 1976. Investigator’s annual report: The bats of Oregon Caves. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Cross, S. R. 1977. A survey of the bats of Oregon Caves National Monument. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Cross, S. 1986. Investigator’s annual report: Bats of Oregon Caves. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Cross, S. P. 1987. Bats of Oregon Caves. Page 76 *in* R. Hyra and N. Knowles, editors. 1986 Annual science report. National Park Service, Pacific Northwest Region, Seattle, Washington.

Cross, S. P. 1989. Studies of the Brazilian Free-Tailed Bat, Bat Cave, Lava Beds National Monument: Measuring population levels and influencing factors. Unpublished report. Lava Beds National Monument, Tulelake, California.

Cross, S. P. 1997. Estimation of bat community size at Oregon Caves in late summer and early fall, 1996. Unpublished report by Southern Oregon University, Ashland, to Oregon Caves National Monument, Cave Junction, Oregon.

Cross, S. P., and D. L. Waldien. 2002. Estimation of bat community size at Oregon Caves in late-summer and early fall 2002, Oregon Caves National Monument. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Cross, S. P., and D. L. Waldien. 2003. Bat usage patterns at Oregon Caves during June through September 2002, as determined by echolocation detection. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Culver, D. C. 1982. Cave Life: Evolution and Ecology. Harvard University Press, Cambridge, Massachusetts.

Currens, C. R., M. A. Madej, and H. A. Ambrose. 2006. Level 1 baseline water quality report for the Klamath Network: Lava Beds National Monument, Lassen Volcanic National Park, and Oregon Caves National Monument - 2005. USGS Western Ecological Research Center, Arcata, California.

Dasher, G. 1994. On station: A complete handbook for surveying and mapping caves. National Speleological Society, Huntsville, Alabama.

Devereaux, W. 2009. Ice Cave, ice level monitoring, 1999-2009. Unpublished raw data from Oregon Caves National Monument files. Oregon Caves National Monument, Cave Junction, Oregon.

Dinger, E., D. Sarr, and S. Mohren. 2013. Integrated biotic community and water quality monitoring of wadeable streams in the Klamath Network. Natural Resources Technical Report, NPS NPS/KLMN/NRR—2013/669. National Park Service, Fort Collins, Colorado.

Dunne, J. 2002. Report on Bat Cave outflight photo monitoring results for July 16-18 and August 14, 2002. Unpublished report, Lava Beds National Monument Unpublished Report, Tulelake, CA. California.

Eide, S. 1972. Air flow, temperature, relative humidity, and water flow at Oregon Caves National Monument. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Elzinga, C. L., D. W. Salzar, J. W. Willoughby, and J. P. Gibbs. 2001. Monitoring Plant and Animal Populations. Blackwell Science, Inc., Malden, Massachusetts.

Ersek, V. 2008. Past climate variability in southwestern Oregon and relationships with regional and hemispheric climate. Ph.D. dissertation. Oregon State University, Corvallis.

Fuhrmann, K. 1997. 1997 summer bat research summary. Lava Beds National Monument Unpublished Report, Tulelake, California.

Fuller, D. 2006. ORCA bacterial and fungal DNA studies. Completion report typescript. Contracts # 61-1358086. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Hale, E. 2007. ORCA biological survey guidelines. Oregon Caves National Monument Unpublished Protocol, Cave Junction, Oregon. 19 January 2007.

Halliday, W. R. 1963. Basic speleological considerations of Oregon Cave. Western Speleological Survey, Seattle, Washington.

Helf, K. L., R. L. Woodman, and B. J. Moore. 2005. Cave beetle (*Neaphaenops tekklampfi*) monitoring protocol for Mammoth Cave National Park, Kentucky. Version 2.00. National Park Service report prepared for Mammoth Cave. Mammoth Cave National Park, Mammoth Cave, Kentucky.

Hoger, J. L., M. A. Littlejohn, and S. J. Hollenhorst. 2003. Oregon Caves National Monument visitor study. Unpublished report by Boise, Idaho: Social Science Program, National Park Service. Oregon Caves National Monument, Cave Junction, Oregon.

Iskali, G. 2008. Oregon Caves National Monument, biomonitoring 2007 year-end report. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Kerwin, Tony. 2016. Estimation of bat community size at Oregon Caves in late-summer and early-fall 2015. Final Report. Oregon Caves National Monument, Cave Junction, Oregon.

Knutson, S. 1973. Interpretation report 2, Oregon Caves research project, Oregon Caves National Monument. Oregon Grotto of the National Speleological Society, Vancouver, Washington.

Krejca, J. K., and G. R. Myers, III. 2005. Impact of commercial activities on macroinvertebrate distribution and foraging in Carlsbad Cavern. Carlsbad Caverns National Park Unpublished Report, Carlsbad, New Mexico.

Mateljak, J., S. Fryer, and T. Downing. 2006. 2006 Lava Beds National Monument Bat Cave outflight report: Results and monitoring issues of *Tadarida brasiliensis*. Lava Beds National Monument Unpublished Report, Tulelake, California.

Miller, W. R., D. B. Smith, A. L. Meier, P. H. Briggs, P. M. Theodorakos, R. F. Sanzolone, and R. B. Vaughn. 1998. Geochemical baselines for surface waters and stream sediments and processes controlling element mobility, Rough and Ready Creek and Oregon Caves National Monument and vicinity, southwestern Oregon. USGS Open-File Report 98-201.

Mohren, S. R. 2007. Data management plan, Klamath Inventory and Monitoring Network. Natural Resource Report NPS/KLMN/NRR-2007/012. National Park Service, Fort Collins, Colorado.

Oakley, K. L., L. P. Thomas, and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. Wildlife Society Bulletin 31(4):1000-1003.

Odion, D., D. Sarr, and S. Mohren. 2011. A protocol for monitoring vegetation composition, structure, and function in parks of the Klamath Network. Klamath Network. Natural Resource Technical Report NPS/KLMN/NRR—2011/401. National Park Service, Fort Collins, Colorado.

Odion, D., D. Sarr, B. Truitt, A. Duff, S. Smith, W. Bunn, E. Beever, S. Shafer, S. Smith, J. Rocchio, *and others*. 2005. Vital signs monitoring plan for the Klamath Network: Phase II report. U.S. Department of the Interior, National Park Service, Klamath Inventory and Monitoring Network, Ashland, Oregon.

Pleszewski, R. 2005. 2005 Lava Beds National Monument Bat Cave outflight report: Results and monitoring issues of *Tadarida brasiliensis*. Lava Beds National Monument Unpublished Report, Tulelake, California.

Poulson, T. L., and W. B. White. 1969. The cave environment. Science. Vol. 165(3897) :971-981.

Purinton, E. 2004. Report on Bat Cave outflight photo monitoring results for July 7-9, 2004 and August 11, 2004. Lava Beds National Monument Unpublished Report, Tulelake, California.

Rogers, L. 2008. Cave impact inventory. Oregon Caves National Monument Unpublished Data, Cave Junction, Oregon.

Salinas, J. 1999a. Oregon Caves National Monument: A study of water quantity and flow in and around the caves. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Salinas, J. 1999b. Oregon Caves weather stations (inside caves). Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Salinas, J. 2000. Oregon Caves National Monument: A continuing study of water quantity and flow in and around the Oregon Caves. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Salinas, J. 2001. Investigator's annual report: Cave infiltration and water quality. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Salinas, J. 2002a. Investigator's annual report: Cave infiltration and water quality. 2002. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Salinas, J. 2002b. A water quality and quantity survey in the Oregon Caves National Monument 2002. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Salinas, J. 2004. An Oregon Caves water inventory: Oregon Caves National Monument 2003. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Sarr, D. A., D. C. Odion, S. R. Mohren, E. E. Perry, R. L. Hoffman, L. K. Bridy, and A. A. Merton. 2007. Klamath Network vital signs monitoring plan. Natural Resource Report NPS/KLMN/NRR–2007/016. National Park Service, Fort Collins, Colorado.

Schubert, M. 2007. Study of a historical karst geochemical data-set from a Marble Cave, Oregon Caves National Monument. MS thesis. University of Missouri-Columbia, Columbia.

Sims, M. 1980. Environments in Oregon Caves. Pages 16-24 *in* M. Sims and L. Sims, editors, Far West Cave Management Symposium, Redding, California.

Smith, K. 2014. Ice cave monitoring at Lava Beds National Monument. Proceedings of the Sixth International Workshop on Ice Caves, August 17-22, Idaho Falls, Idaho, USA: NCKRI Symposium 4. National Cave and Karst Research Institute, Carlsbad, New Mexico.

Taylor, S. J., and J. K. Krejca. 2006. A biological assessment of caves in Lava Beds National Monument. Illinois Natural History Survey, Center for Biodiversity Technical Report 2006(6) prepared for Lava Beds National Monument. (Dated 20 April 2006)

Taylor, S. J., J. K. Krejca, and M. E. Slay. 2008. Cave biota of Great Basin National Park, White Pine County, Nevada. Illinois Natural History Survey, Technical Report 2008(25):1-398.

Thomas, S. 2010. Monitoring cave entrance communities and cave environments in the Klamath Network: 2010 pilot study results. Lava Beds National Monument Unpublished Report, National Park Service, Klamath Network, Ashland, Oregon.

Thomas, S. 2011. Lava Beds winter hibernacula monitoring. Lava Beds National Monument Unpublished Report, Tulelake, California.

Tobin, A. 2009a. Bat Cave outflight report. Lava Beds National Monument Unpublished Report, Tulelake, California.

Tobin, A. 2009b. *Corynorhinus townsendii* monitoring. Lava Beds National Monument Unpublished Report,, Tulelake, California.

U.S. Environmental Protection Agency (USEPA). 2013. National Rivers and Streams Assessment 2013-2014: Field Operations Manual – Wadeable. EPA-841-B-12-009b.U.S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Geological Survey (USGS). 2003. Monitoring trends in bat populations of the United States and Territories: Problems and prospects. USGS Information and Technology Report 2003-0003. Springfield, Virginia.

White, W. B. 1988. Geomorphology and hydrology of karst terrains. Oxford University Press, New York.

Whiteman, J. D. 1997. A study of potential use of bat detectors at Oregon Caves. MS Thesis. Southern Oregon University, Ashland.

Yates, A. 2007. Photo monitoring protocol, Oregon Caves National Monument. Oregon Caves National Monument Unpublished Report, Cave Junction, Oregon.

Appendix A: Other Bat Monitoring at Lava Beds and Oregon Caves

Bat monitoring at both monuments has occurred for decades in varying capacities according to interest, staff availability, and collaboration with outside researchers. The subset of monitoring included in this protocol (SOP #8: Bats) provides a balance between cost effectiveness and statistical power in estimating population trend detection. Additional monitoring completed by each monument facilitates more directed research and protection of bat resources within respective monuments.

Lava Beds National Monument strives to monitor all known hibernating and maternal populations as well as general species presence and activity levels through hibernacula and roost surveys, exit counts, acoustic monitoring, and limited summer captures. Methods for conducting hibernacula surveys are the same as methods outlined in this protocol (SOP #8). Lava Beds staff are working with a cooperator at the U.S. Forest Service Pacific Southwest Research Station (Dr. Ted Weller) to develop a flexible stratified random sampling design that allows survey effort to vary each year according to available staff and resources while still providing statistically valid data to support population estimation. This stratified random sampling method incorporates surveys of new sites each year, thus enabling discovery of new hibernacula and more complete population trend monitoring. Refinement and publication of this sample design is forthcoming. Monitoring of maternal colonies for *Corynorhinus townsendii*, *Antrozous pallidus*, and *Tadarida brasiliensis* is conducted through the use of visual in-roost and outflight surveys to document presence/absence within known roost sites and calculate abundance when possible. Acoustic monitoring is implemented according to the North American Bat Monitoring Program using primarily stationary points but also driving transects to document species presence and activity levels on the landscape. Additional in-cave acoustic monitoring is utilized at several high-priority summer and winter roosts to estimate seasonal activity levels. Finally, summer species presence is further documented through limited capture and acoustic records from bat survey techniques workshops led by an outside principal investigator (Janet Tyburec, Bat Survey Solutions, LLC.) through a National Park Service Research Permit.

Oregon Caves National Monument monitors bats during all seasons using visual in-roost and acoustic surveys, but focuses most heavily on fall swarming population estimates. Monument staff conduct a survey known as Critter Counts along the tour route inside the main cave to document bats and macroinvertebrates; this count is only completed once during the winter season following the bat-specific survey methods in SOP #8, but occurs many times throughout the rest of the year. Recently, Oregon Caves has begun implementing acoustic monitoring according to the North American Bat Monitoring Program, experimenting with both driving transects and stationary monitoring points. Oregon Caves is well known as a fall swarming site for up to 7 species during the mating period; the monument has supported this research topic through interagency agreements, most recently with Bureau of Land Management bat biologist Anthony Kerwin. These mark-recapture studies date back to the 1950s, making Oregon Caves one of the most important sites for long-term monitoring of fall swarming populations in the Pacific Northwest. They enable a better understanding of species presence and persistence during fall swarming.

As funding becomes available, both monuments will conduct White Nose Syndrome surveillance through fungal swab sampling of bats found in hibernacula or captured on the landscape, and through continued population monitoring. Additionally, both monuments will continue to work with neighboring agencies (i.e., U.S. Forest Service, U.S. Fish and Wildlife Service) to accomplish landscape-scale bat monitoring goals as funding allows.

Appendix B: GRTS Sample Tracking and GRTS Code

The Generalized Random Tessellation Stratified (GRTS) site selection process provides a spatially-balanced sample, complete with overdraw samples (in case selected sites are non-sampleable, or if crews can obtain extra sites). This appendix contains results of the GRTS sample draw and instructions on how to track and maintain records for which caves are sampled.

Table B-1 contains results of the GRTS sample draw and implementation status as of August 2016. The R code and random seed number are provided after Table B-1 to allow reproduction of the sample draw, if needed. Table B-1 in this narrative will not be updated and therefore will become outdated; users should refer to the electronic version of this table in the Cave Vital Sign Database. If changes to the sites monitored are necessary (e.g., if a cave becomes inaccessible or unsafe), follow these important rules to maintain spatial balance:

1. Sites must be sampled in order (no skipping of sites). While logistical constraints might dictate sampling out of order to expedite field crew time, in general a full series needs to be completed. In other words, a crew should not skip down to site-033 if they are not going to be able to do site-032 for timing reasons (if site-032 is skipped for safety, then you use site-033).
2. The entire sample list should be exhausted prior to using the first entries of the "overdraw" list.
3. Sites that are non-sampleable should be recorded and maintained (e.g., not deleted from the record and forgotten). The record of how sites were evaluated, sampled or not sampled (and why) are crucial to transparency and analysis of the sampling frame and overall inference to park resource status.
4. The electronic copy of the included Table B-1 that exists in the Cave Vital Sign Database should be updated. There are 2 tabs within the MS Excel Cave/GRTS tracker spreadsheet: (1) Site Tracking – to record if a cave is being actively sampled, for what SOPs, and other metadata about sampling the cave; and (2) GRTS Output – the raw GRTS output file along with GRTS metadata (e.g., set seed number, and original R code used). The spreadsheet is on file at LABE.
5. The LABE cave technician should update the electronic version of the Table B-1 site tracking table and the GRTS metadata in the cave database throughout the field season as cave sites are visited and evaluated. For the GRTS metadata in the cave database, only the "EvalStatus" and "EvalReason" columns need to be updated. EvalStatus should be either: "Sampled," "NonTarget," "Fragile," or "Hazardous." EvalReason is a text description of the limitation or rejection criteria. Note that LABE staff can add another category to EvalStatus if one is applicable.

This appendix also includes the raw R computing code for transparency and to allow the re-creation of the draw. In the event that the original overdraw is "exhausted" or funds become available to increase the sample size, the GRTS draw can be redone to increase the number of overdraw sites using the original code and the original Random Set Seed. If this is done, the original 60 sites below are retained, but an additional overdraw capacity that retains spatial balance is created.

Table B-1. Site tracking table containing the GRTS draw from the sampling frame of caves ≥300 ft long at Lava Beds National Monument. Caves are ordered by their GRTS number, with 30 sites assigned to the main panel and 30 sites assigned to the oversample. Table may be updated by adding columns to the right.

Cave Code	Cave Name	GRTS Order	GRTS Panel	Status 8/4/2016	Status mm/dd/yyyy	Status mm/dd/yyyy
SKYL	not available	Site-01	Main	Accepted		
PURA	not available	Site-02	Main	Rejected [a]		
FOCA	not available	Site-03	Main	Accepted		
JURI	not available	Site-04	Main	Accepted		
SYMB	not available	Site-05	Main	Accepted		
YELL	not available	Site-06	Main	Accepted		
JUPO	not available	Site-07	Main	Accepted		
MEIC	MERRILL ICE CAVE	Site-08	Main	Accepted		
NOBE	not available	Site-09	Main	Accepted		
IDWL	INDIAN WELL CAVE	Site-10	Main	Accepted		
BLGR	BLUE GROTTO CAVE	Site-11	Main	Accepted		
PEAR	not available	Site-12	Main	Accepted		
VALE	VALENTINE CAVE	Site-13	Main	Accepted		
CGCA	not available	Site-14	Main	Accepted		
SEC8	not available	Site-15	Main	Rejected [b]		
TOWN	not available	Site-16	Main	Rejected [a]		
ANGL	not available	Site-17	Main	Accepted		
POBR	not available	Site-18	Main	Rejected [a]		
JUHE	JUNIPER - HERCULES LEG CAVE	Site-19	Main	Accepted		
INCA	not available	Site-20	Main	Accepted		
SKBR	not available	Site-21	Main	Rejected [a]		
LALA	LABYRINTH - LAVA BROOK CAVE	Site-22	Main	Accepted		
UHBR	not available	Site-23	Main	Rejected [a]		
EMST	not available	Site-24	Main	Accepted		
SPIN	not available	Site-25	Main	Rejected [b]		
CORE	not available	Site-26	Main	Rejected [b]		
COSN	not available	Site-27	Main	Rejected [b]		
RALO	not available	Site-28	Main	Accepted		
DECA	not available	Site-29	Main	Accepted		
CRCA	not available	Site-30	Main	Accepted		
FERM	not available	Site-31	OverSamp	Rejected [b]		
HIMM	not available	Site-32	OverSamp	Accepted		

[a] Cave was rejected because the deep zone did not meet our criteria.

[b] Cave was rejected due to unavoidable fragile cave resources on the path through the cave.

Table B-1 (continued). Site tracking table containing the GRTS draw from the sampling frame of caves >300 ft long at Lava Beds National Monument. Caves are ordered by their GRTS number, with 30 sites assigned to the main panel and 30 sites assigned to the oversample. Table may be updated by adding columns to the right.

Cave Code	Cave Name	GRTS Order	GRTS Panel	Status 8/4/2016	Status mm/dd/yyyy	Status mm/dd/yyyy
LOPI	not available	Site-33	OverSamp	Accepted		
SEAN	not available	Site-34	OverSamp	Accepted		
CRIC	CRYSTAL ICE CAVE	Site-35	OverSamp	Accepted		
ROCO	not available	Site-36	OverSamp	Accepted		
ICEB	not available	Site-37	OverSamp	Accepted		
THDB	THUNDERBOLT CAVE	Site-38	OverSamp	Accepted		
SOLA	SOUTH LABYRINTH CAVE	Site-39	OverSamp	Accepted		
ELLO	not available	Site-40	OverSamp	Rejected [a]		
SPID	not available	Site-41	OverSamp	Accepted		
PSYC	not available	Site-42	OverSamp	Unused		
SHMO	not available	Site-43	OverSamp	Unused		
SNSC	not available	Site-44	OverSamp	Unused		
BR02	not available	Site-45	OverSamp	Unused		
LOTH	not available	Site-46	OverSamp	Unused		
FERN	FERN CAVE	Site-47	OverSamp	Unused		
REUN	not available	Site-48	OverSamp	Unused		
SHIP	not available	Site-49	OverSamp	Unused		
BACH	BALCONY CHAMBER	Site-50	OverSamp	Unused		
DWTO	not available	Site-51	OverSamp	Unused		
OHIO	not available	Site-52	OverSamp	Unused		
LYRO	not available	Site-53	OverSamp	Unused		
MAHO	not available	Site-54	OverSamp	Unused		
MAZE	not available	Site-55	OverSamp	Unused		
CHRI	not available	Site-56	OverSamp	Unused		
SCHO	not available	Site-57	OverSamp	Unused		
ADRA	not available	Site-58	OverSamp	Unused		
BOUL	BOULEVARD CAVE	Site-59	OverSamp	Unused		
ARSE	not available	Site-60	OverSamp	Unused		

[a] Cave was rejected because the deep zone did not meet our criteria.

[b] Cave was rejected due to unavoidable fragile cave resources on the path through the cave.

R Code

```
# Utilization of this code without first installing R packages rgdal and
spsurvey will result
#in error.
# This output results from the grts.equi.r function of the SDrawGUI package,
WEST Inc.,
#2015, Version 1.04.

      library(rgdal)
      library(spsurvey)

# Read in the shapefile of interest from which sampling occurs.

      shp <- readOGR( "S:/Monitoring/Caves/Cave_GIS/Cave
Selection/Selection20160404/LABE I&M GRTS Cave List 2016-04-04.shp", "LABE
I&M GRTS Cave List 2016-04-04" )

#Set the random number seed

      set.seed(62403580) #Use this specific number to reproduce the GRTS
sample in Table B-1.

# Prepare the design of the sampling for use in the grts function.

        Equaldsgn <- list(None=list(panel=c(Main=(30)),
        seltype='Equal',over=30))

# Draw the sample via the grts function in package spsurvey.

       Equalsites <- grts(design=Equaldsgn,
                     DesignID='Site',
                     type.frame="finite",
                     src.frame='sp.object',
                     sp.object=shp,
                     shapefile=FALSE)
```

Appendix C. Examples of Cave Site Dossier Materials

Each monitored cave at Lava Beds National Monument and Oregon Caves National Monument and Preserve has a site dossier that provides cave-specific information to technicians when performing SOPs. These documents contain descriptions, directions, and/or photos that assist staff in preparing for sampling, relocating sampling points or equipment, and performing the survey in that specific cave. These documents exist in .pdf form on the park server, and hard copies are printed as needed. Here we list the contents of each site dossier, identify the locations of site dossier files on each park's server, and provide examples of each type of site dossier document.

Site Dossier Information for Each Cave

Digital folders for each cave will contain the SOP-specific guidance in .pdf form, folders (for images), and other supplemental information where needed. For example, other documents may describe whether a cave contains particularly difficult passages or requires vertical caving. Below is a list of information each digital folder may contain; contents will vary depending on the type of cave (random, judgment ice, judgement bat) and associated SOPs performed.

1. Cave Zone Map—Demarcations for entrance, middle, and deep zones—multiple SOPs
2. Vegetation Photo Monitoring Stations—for SOP #9: Cave Entrance Vegetation
3. Vegetation Transect Locations and Datasheet—for SOP #9: Cave Entrance Vegetation
4. Climate Data Logger Locations—for SOP #5: Climate
5. Ice Monitoring Locations—for SOP #6: Ice (Ice Caves Only)
6. Bat Hibernacula Survey Guidance—for SOP #8: Bats (Bat Caves Only)
7. *Original_Documents* folder for reference and updating when necessary—for SOPs #5, #6, #8, and #9
8. *Original_Images* folder containing images to support relocation of monitoring stations—for SOPs #5, #6, #8, and #9

Site Dossier Locations

Site dossiers at Lava Beds National Monument reside on the park server at:

> S:\TEAMS\Resource Management\Branches\Caves_Bats\Cave Program\I & M\Protocol_Implementation\Site_Dossiers

Site dossiers at Oregon Caves National Monument and Preserve reside on the park server at:

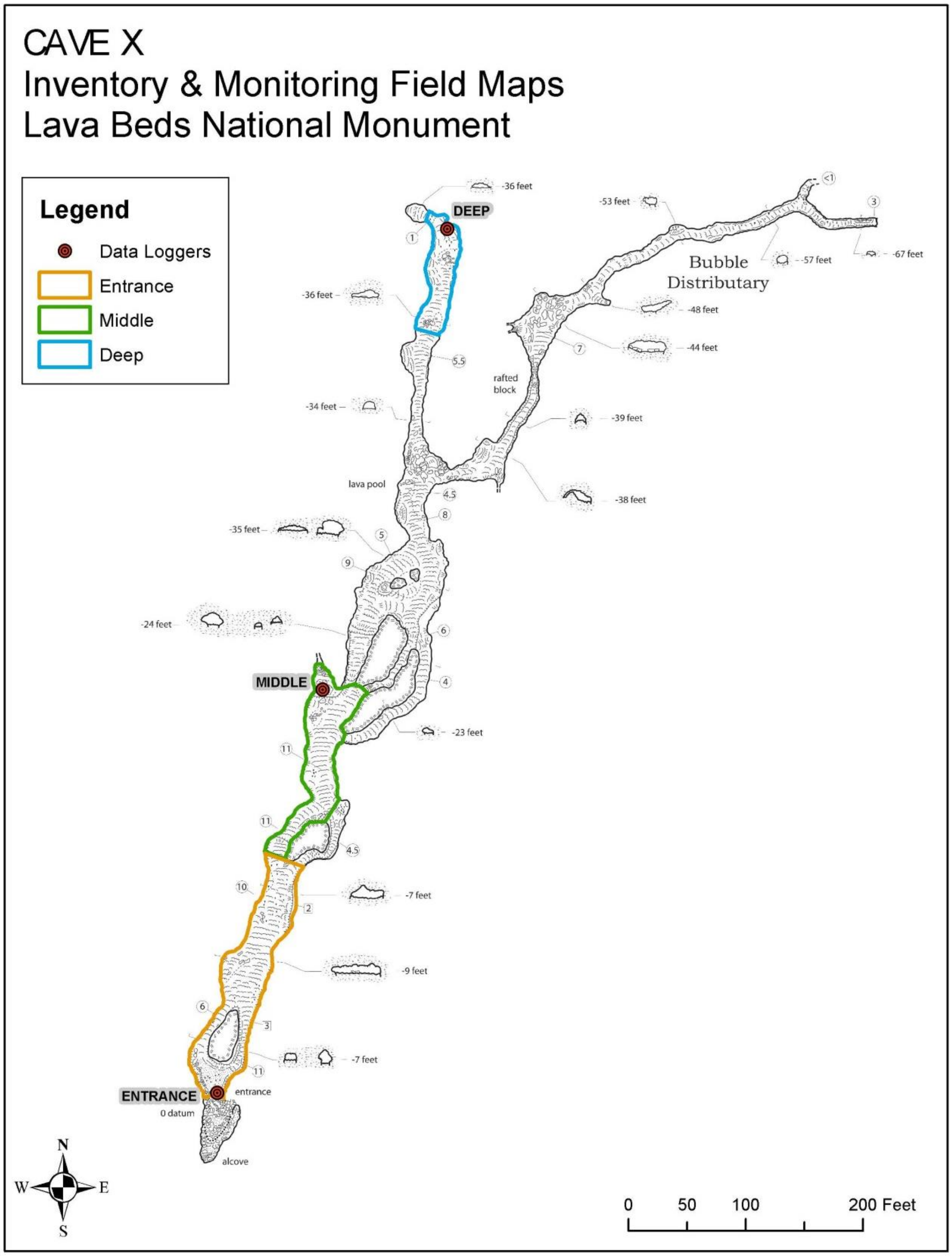
> O:\shdata\Public\RMDocuments\Natural_Resources\Monitoring\KLMN\Cave_Monitoring\

Copies of site dossiers for both parks are located on the Klamath Network server at:

> S:\Monitoring\Caves\Cave_Documents\Implementation\Site_Dossiers\

Site Dossier Example Material

Example 1. Cave Zone Map



Valentine (VALE) - 3 photos

Taken 6/14/2016
At 7:12 AM

Photograph standing near the outer left transect hook looking towards the outer right transect hook. (Exposure: **0,** with a flash)

Taken 6/14/2016
At 7:14 AM

Photograph from inside the cave looking out. Walk about 10 feet from the last step into the cave, stand near or over the breakdown blocks and look out the cave, keeping the wooden pole centered in the photo. (Exposure: **0**)

Always take exposures at +1, 0, and -1 for each photo. Additional exposures may be taken if necessary to capture all vegetation within the cave entrance.

Photograph from outside the cave, on the lip opposite the entrance. Keep the wooden pole in the upper center of the photograph and the asphalt path in the upper right corner in order to get most of the vegetation inside the collapse area. (Exposure: **0**)

Always take exposures at +1, 0, and -1 for each photo. Additional exposures may be taken if necessary to capture all vegetation within the cave entrance.

Example 3. Vegetation Transect Locations and Datasheet

Cave X

Outer and Inner Transect

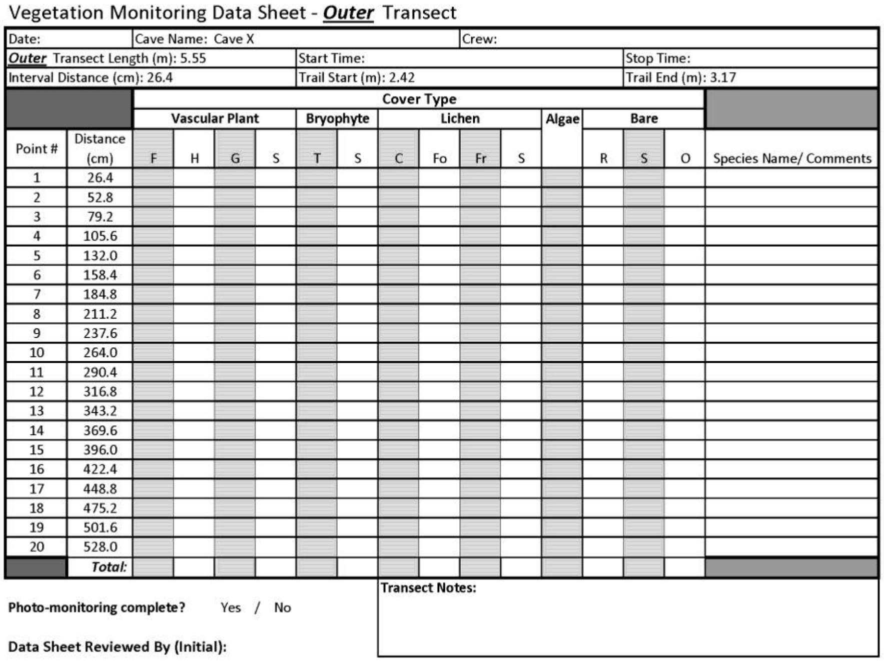
Outer Left— Point is under the dripline, in line with top stairs, and 5' from floor.

Outer Right—Point is under the dripline on ceiling rock, 10'' below horizontal crack, and 5' from floor. Close to the mossy breakdown pile.

Inner Left— Point is 4' from floor and above junction of sediment floor and breakdown pile.

Inner Right—Point is mid chest height from lava bench, next to square white mineral patch.

Datasheet—pages 1 and 2



Vegetation Monitoring Data Sheet - ***Outer*** Transect

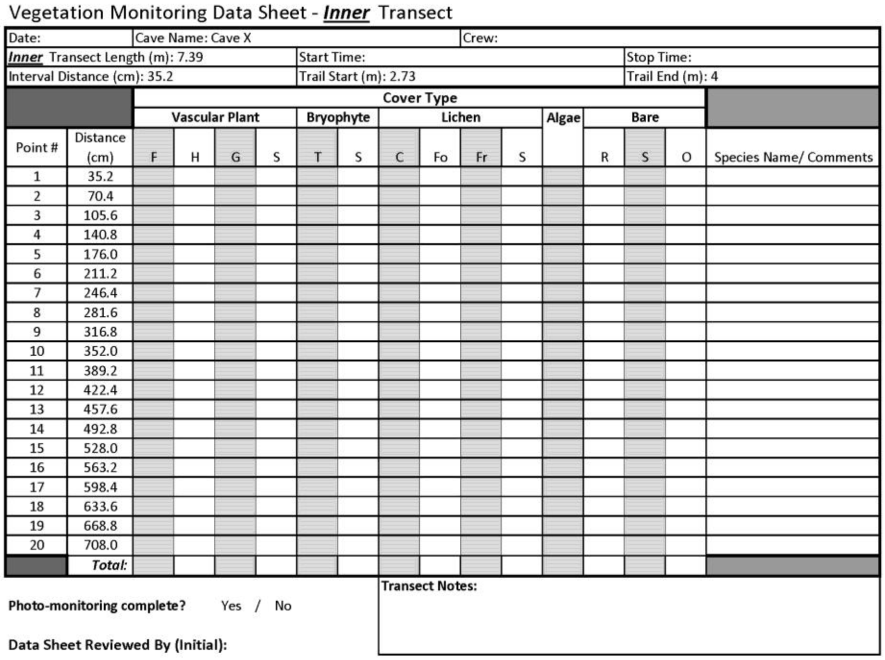
Date:
Cave Name: Cave X
Crew:
Outer Transect Length (m): 5.55
Start Time:
Stop Time:
Interval Distance (cm): 26.4
Trail Start (m): 2.42
Trail End (m): 3.17

		Cover Type														
		Vascular Plant				Bryophyte		Lichen				Algae	Bare			
Point #	Distance (cm)	F	H	G	S	T	S	C	Fo	Fr	S		R	S	O	Species Name/ Comments
1	26.4															
2	52.8															
3	79.2															
4	105.6															
5	132.0															
6	158.4															
7	184.8															
8	211.2															
9	237.6															
10	264.0															
11	290.4															
12	316.8															
13	343.2															
14	369.6															
15	396.0															
16	422.4															
17	448.8															
18	475.2															
19	501.6															
20	528.0															
	Total:															

Photo-monitoring complete? Yes / No

Data Sheet Reviewed By (Initial):

Transect Notes:



Vegetation Monitoring Data Sheet - ***Inner*** Transect

Date:
Cave Name: Cave X
Crew:
Inner Transect Length (m): 7.39
Start Time:
Stop Time:
Interval Distance (cm): 35.2
Trail Start (m): 2.73
Trail End (m): 4

		Cover Type														
		Vascular Plant				Bryophyte		Lichen				Algae	Bare			
Point #	Distance (cm)	F	H	G	S	T	S	C	Fo	Fr	S		R	S	O	Species Name/ Comments
1	35.2															
2	70.4															
3	105.6															
4	140.8															
5	176.0															
6	211.2															
7	246.4															
8	281.6															
9	316.8															
10	352.0															
11	389.2															
12	422.4															
13	457.6															
14	492.8															
15	528.0															
16	563.2															
17	598.4															
18	633.6															
19	668.8															
20	708.0															
	Total:															

Photo-monitoring complete? Yes / No

Data Sheet Reviewed By (Initial):

Transect Notes:

Cave X Entrance

XXXX-ent

As you step off the very last step going into the cave, the logger is located directly to your right in a pile of breakdown that makes a natural wall. If you are looking directly at this wall, the logger is located in a crevice underneath the largest, moss-covered boulder closest to the steps. It is also beside the TrafX counter for this cave.

General view of where the data logger is located.

Cave X Entrance

Close-up views of where the data logger is hidden. Top picture shows without the cap rock; bottom picture shows with the cap rock.

Cave X Middle

XXXX-mid

Where the cave branches for the third pillar, an alcove on the left leads to a blocked passage with conspicuous boulders. The data logger is located behind and underneath the first large boulder in this alcove, blocked by a few smaller cap rocks.

General view of where the data logger is located. You can see part of the branching for the third pillar on the right side of the picture.

Cave X Middle

Top of photo shows the underside of the large boulder above logger. Bottom photo shows logger hidden under cap rock.

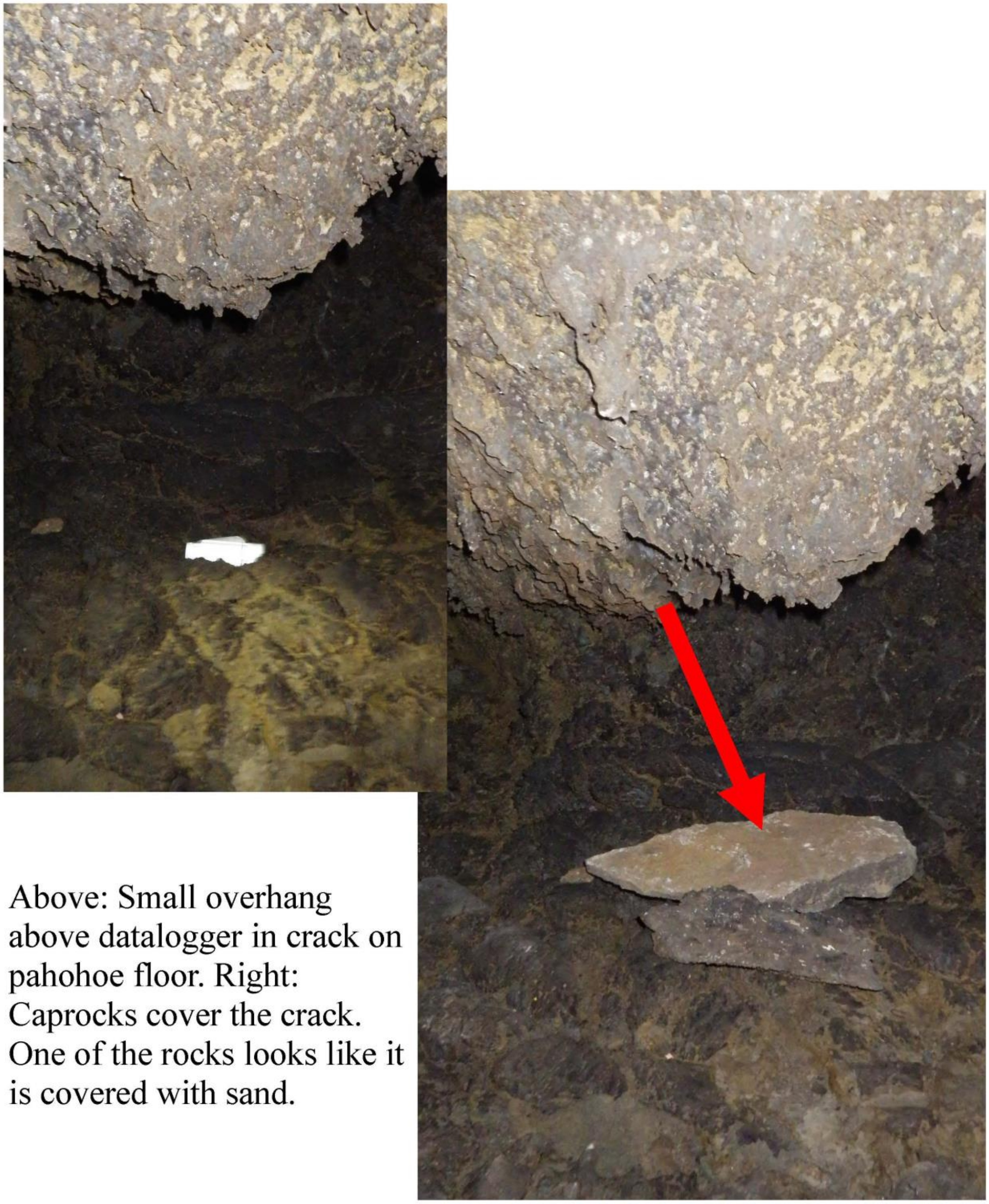
Cave X Deep

<u>XXXX-deep</u>

Continue to the "Millipede Distributary" passage, climbing left through the large breakdown pile to get there. Near the end, the passage starts to narrow and curves left. The logger is located on the right side of the passage, just before the curve at the end of a five foot long alcove, hidden in a crack in the pahoehoe floor and covered by two cap rocks.

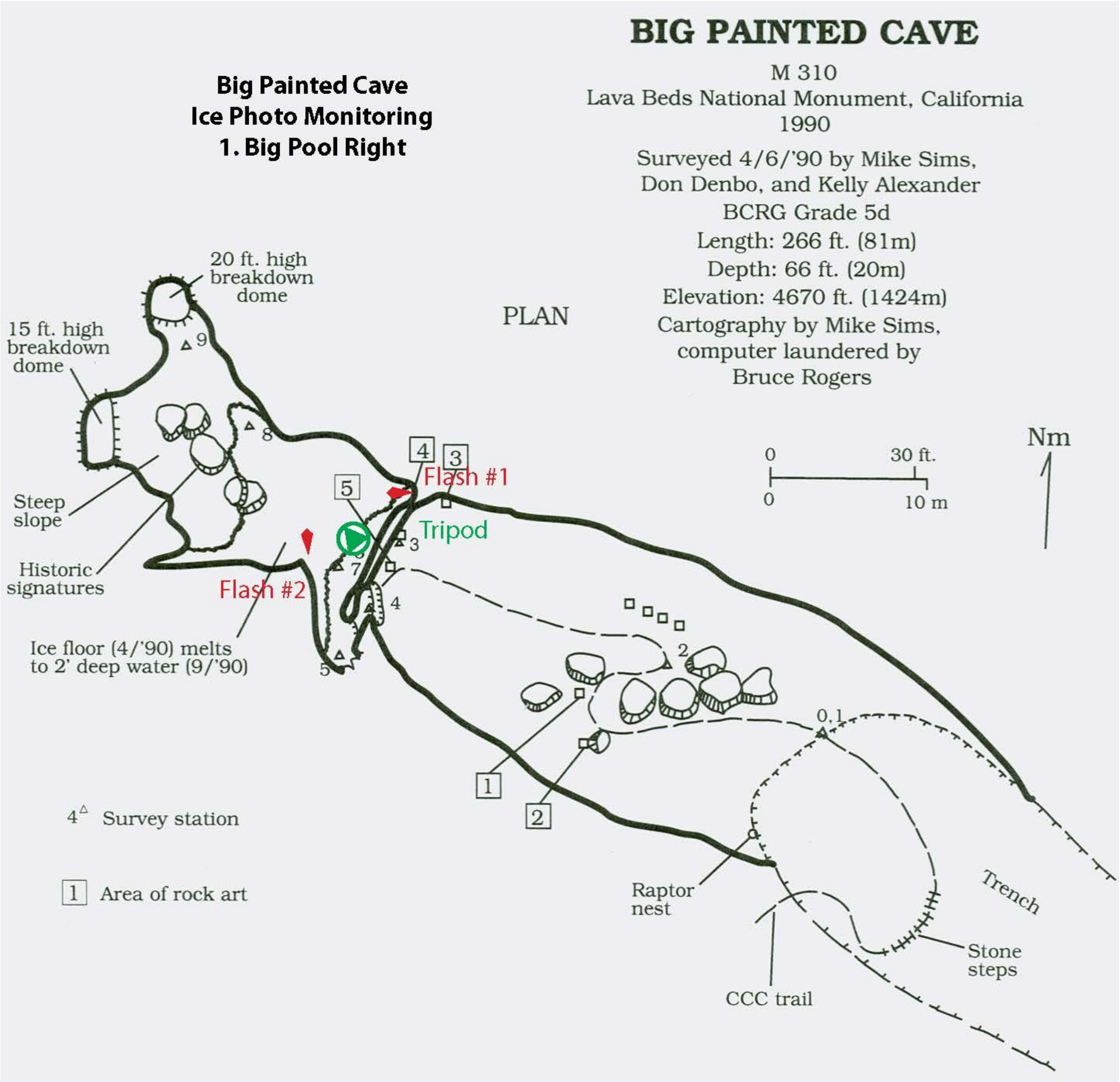
Looking towards the end of the passage as it curves, alcove is visible on the right.

Cave X Deep



Above: Small overhang above datalogger in crack on pahohoe floor. Right: Caprocks cover the crack. One of the rocks looks like it is covered with sand.

Example 5. Ice Monitoring Locations



Cave X Ice Photo Monitoring

KLMN Cave I&M Protocol

1. Big Pool Right

External Flashes: yes - 2

Flash 1 location: approx. 2m to the right of the camera

Flash 2 location: approx. 2.5m to the left of the camera on breakdown bridge between Big Pool and Small Pool

From Tripod to <cave code> 002

Distance: 0.63 m from top of on-camera flash to <cave code> 002

Azimuth: N/A (tripod directly below <cave code> 002)

Inclination: +90°

Camera Settings

ISO: 400

F-stop: f/5.6

Exposure Time: 1/125 sec

Lens focal distance: 14mm

Exposure bias: 0 step

Aspect ratio: 16:9

Tripod Location for all Photos in Cave X

Cave X Ice Photo Monitoring

KLMN Cave I&M Protocol

2. Big Pool Left

Flash 1 location: approx. 2m to the right of the camera

Flash 2 location: approx. 2.5m to the left of the camera on breakdown bridge between Big Pool and Small Pool

From Tripod to <cave code> 002

Distance: 0.63 m from top of on-camera flash to <cave code> 002

Azimuth: N/A (tripod directly below <cave code> 002)

Inclination: +90°

Camera Settings

ISO: 400

F-stop: f/5.6

Exposure Time: 1/125 sec

Lens focal distance: 14mm

Exposure bias: 0 step

Aspect ratio: 16:9

3. Small Pool

Flash 1 location: approx. 1.5m to the right of the camera, pointing center

Flash 2 location: approx. 1.5m to the left of the camera, pointing center

From Tripod to <cave code> 002

Distance: **0.31 m** from top of on-camera flash to <cave code> 002

Azimuth: N/A (tripod directly below <cave code> 002)

Inclination: +90°

Camera Settings

ISO: 400

F-stop: f/5.6

Exposure Time: 1/125 sec

Lens focal distance: 14mm

Exposure bias: 0 step

Aspect ratio: 16:9

Reference Photo - Big Pool Right

Camera Settings

ISO: 400

F-stop: f/5.6

Exposure Time: 1/125 sec

Lens focal distance: 14mm

Exposure bias: 0 step

Aspect ratio: 16:9

From Tripod to <cave code> 002

Distance: 0.63 m from top of on-camera flash to <cave code> 002

Azimuth: N/A (tripod directly below <cave code> 002)

Inclination: +90°

Reference Photo - Big Pool Left

From Tripod to <cave code> 002

Distance: 0.63 m from top of on-camera flash to <cave code> 002

Azimuth: N/A (tripod directly below <cave code> 002)

Inclination: +90°

Camera Settings

ISO: 400	Lens focal distance: 14mm
F-stop: f/5.6	Exposure bias: 0 step
Exposure Time: 1/125 sec	Aspect ratio: 16:9

Reference Photo - Small Pool

From Tripod to <cave code> 002

Distance: **0.31 m** from top of on-camera flash to <cave code> 002

Azimuth: N/A (tripod directly below <cave code> 002)

Inclination: +90°

Camera Settings

ISO: 400

F-stop: f/5.6

Exposure Time: 1/125 sec

Lens focal distance: 14mm

Exposure bias: 0 step

Aspect ratio: 16:9

Cave X Ice Photo Monitoring

KLMN Cave I&M Protocol

Survey Data Tying Tripod Location to <cave code> 001 through <cave code> 003

<cave code> 001: screw in wall (historic ice monitoring pin)

<cave code> 002: aluminum nail and tag in ceiling above breakdown slope before ice pools; tripod stationed directly below <cave code> 002

<cave code> 003: prominent ceiling point above large boulder before breakdown bridge between Big and Small Pools (see photo)

<cave code> 002 to Tripod:

Distance: m

Azimuth: N/A

Inclination: -90°

Tripod to <cave code> 003: (check this)

Distance: 2.13 m

Azimuth: 277.5°

Inclination: -8.0°

<cave code> 003 to <cave code> 001:

Distance: m

Azimuth: °

Inclination: °

Photo Compilation - Big Pool Right

November 2015

March 2016

Photo Compilation - Big Pool Left

November 2015

March 2016

Photo Compilation - Small Pool

November 2015

March 2016

Example 6. Bat Hibernacula Survey Guidance

Cave X: Bat Hibernacula Survey Site Dossier

Lava Beds National Monument
August 2016

Number of surveyors: 2
Parking location: YYYY parking area
Time required (round-trip from vehicle): 1.5 – 2 hours
Special equipment:

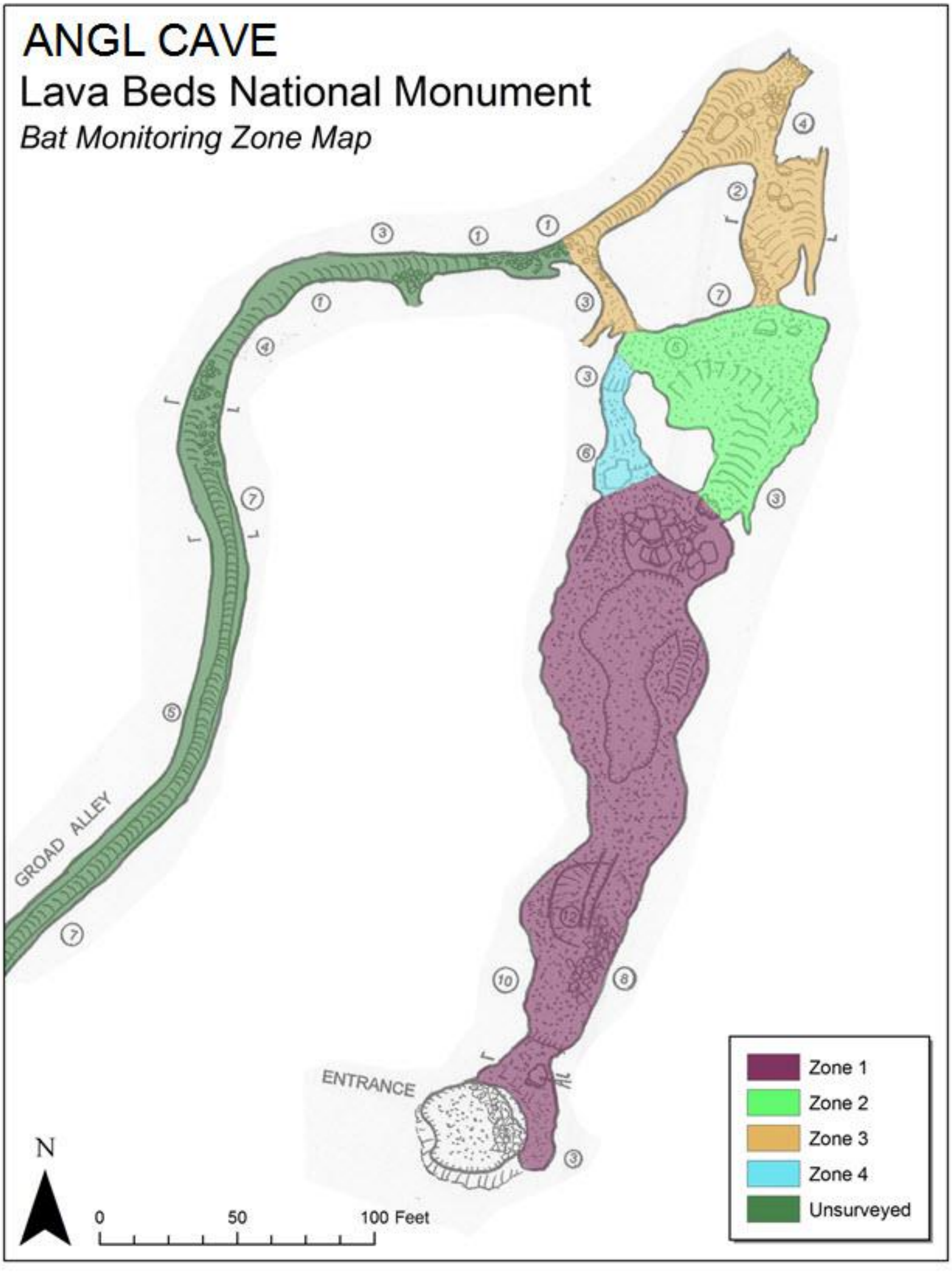
- GPS for locating cave entrance
- extra data sheet if surveyors split cave

Overview / survey instructions:
Cave X contains a variety of passage sizes including a significant amount of crawling passage. Much of the areas occupied by bats are characterized by floors lined with small rocks that rotate and create significant noise when walked upon. For these reasons, **counts are best conducted by experienced, agile cavers**. Due to the complexity of navigating through Zone 3 and the loud disturbance created by crawling over unavoidable plated rocks, it is **recommended that Zone 3 be counted by a single surveyor**; Zone 4 can be counted concurrently by the other surveyor. There are no high ceilings in the cave, so all bats can be readily counted and identified without the use of binoculars.

Begin at the entrance of the cave in walking passage, which extends for a fair distance until encountering a **north wall, which marks the end of Zone 1**. At the base of this wall are 2 constrictions (west and east) that lead further into the cave. Proceed through the eastern constriction to enter **Zone 2**; move carefully through this section, as the **floor is covered in loose, uneven rocks adjacent to the highest concentration of bats in the cave**. At the north end of Zone 2, a short crawl marks the start of Zone 3, quickly opening into another room. On the northwest side of this room is a breakdown pile; there is a **passable route through the center of the pile that requires some contortions**. Be cautious when emerging from the pile, as bats may be encountered on the undersides of the breakdown blocks. The passage beyond the breakdown pile heads southwest, eventually turning into a crawl that leads into Cave Y. Proceed to the start of this crawl, which marks the end of Zone 3; the crawl and area beyond is not surveyed. Adjacent to the start of the crawl is a passage that heads south and connects back to Zone 2 near the junction with Zone 4. This connection is extremely small and awkward, so it is best to **retrace the route through Zone 3 and reenter Zone 2 from the original crawl**. To find Zone 4, proceed to the western edge of Zone 2 to locate a crawl (initially small) which soon opens into Zone 4, consisting of hands-and-knees crawling and stoop walking. Proceed through this short zone until reaching the top of a slope that leads up into Zone 1. After returning to Zone 1, the survey is complete.

Location of bats:
The majority of bats are located in Zone 2, just beyond the eastern connection with Zone 1. Several clusters and solitary bats are located in this area. Zone 3 contains several solitary bats and clusters of 2 bats. Bats are rare in Zones 1 and 4.

ANGL Cave: Bat Monitoring Zone Map



Appendix D: Restrictions for Cave Information at Lava Beds National Monument

This table identifies sensitive caves monitored for the Klamath network cave protocol at Lava Beds National Monument (LABE). The full names and/or location of caves identified as sensitive here should not be publicly available. Throughout this protocol and the SOPs, caves are represented either by their full name or a cave code, depending on their classification in the LABE Cave Management Plan. Class I caves are those made accessible to the public (i.e., caves are identified in the park brochures and have signage and trails leading to them). We identify Class I caves in this protocol by name because they are public knowledge. Codes must be used for LABE Class II to IV caves because the full names should not be released to the public.

While KLMN will retain information on cave names and corresponding codes, requests for full cave names should be made to the Chief of Natural Resource Management at LABE.

For resource protection purposes, documents containing full cave names or locations of sensitive caves will not be released to any person not associated with implementation of this protocol. FOIA requests for protected information such as cave locations will be denied as this information is exempt from FOIA under the Federal Cave Resources Protection Act.

CAVE CODE	CAVE NAME	Do Not Use Full Cave Name in Public Documents
Nonrandom		
BEAC		X
DRHE		X
SENT	SENTINEL	
BIPA	BIG PAINTED	
CAIC		X
COIC		X
SKIC	SKULL ICE CAVE	
Random		
ANGL		X
BLGR	BLUE GROTTO CAVE	
CGCA		X
CRCA		X
CRIC	CRYSTAL ICE CAVE	
DECA		X
EMST		X
FOCA		X
HIMM		X
ICEB		X
IDWL	INDIAN WELL CAVE	
INCA		X
JUHE	JUNIPER - HERCULES LEG CAVE	
JUPO		X
JURI		X
LALA	LABYRINTH - LAVA BROOK CAVE	
LOPI		X
MEIC	MERRILL ICE CAVE	
NOBE		X
PEAR		X
RALO		X
ROCO		X
SEAN		X
SKYL		X
SOLA	SOUTH LABYRINTH CAVE	
SPID		X
SYMB		X
THDB	THUNDERBOLT CAVE	
VALE	VALENTINE CAVE	
YELL		X

Appendix E: Administrative Record

The purpose of the Administrative Record is to provide a history of protocol development and refinement. The Project Lead should update the record as major changes are made or milestones are achieved.

After cave environments and cave entrance communities were selected as 2 of 10 vital signs to be monitored by the Klamath Inventory and Monitoring Network (KLMN), the components of this protocol were developed during scoping meetings held in Ashland, Oregon, between KLMN monitoring specialists, Lava Beds National Monument and Oregon Caves National Monument and Preserve staff, and cave scientists at Zara Environmental LLC (Contract Number P8480080027). The first meeting (October 2008 in Ashland, Oregon) covered the history of monitoring at the parks, and used many factors, including data collection continuity, as a means for prioritizing the parameters to be measured. One of the authors attended a nationwide cave resource monitoring meeting in Denver, Colorado, (November 2008, see acknowledgments for details) in order to compare this protocol and specific parameters against standards used in other cave parks. The national meeting also served to introduce KLMN's intent to monitor cave resources and tap into other cave resource managers' expertise for cave protocol development. After that meeting, an implementation plan was created (November 2008).

The first draft of the narrative, SOPs, and Appendices was created in February 2009, reviewed shortly thereafter, and a second draft was created in August 2009. At the second meeting of all parties (December 2009 in Ashland, Oregon), we solidified the methods and conceived of a pilot study, which was executed by Shawn Thomas (Thomas 2010). A third draft was created in April 2010 and incorporated results of the pilot study. After internal review, a fourth draft was created in June 2010. During this entire process, many conference calls and emails were exchanged between all parties to ensure the envisioned direction was being followed.

The June 2010 draft was submitted for peer review, which was coordinated by Dr. Jim Agee (Peer Review Coordinator (PRC); University of Washington) and Dr. Penelope Latham (Pacific West Region Inventory and Monitoring Program Manager). Three anonymous reviewers, Dr. Agee, and Dr. Latham provided an abundance of comments. Significant comments focused on integrating different protocols for White Nose Syndrome in bats, specifying the ability of field technicians to identify bats and invertebrates, clarifying the roles and responsibilities of different parties, demonstrating adequacy of the budget, adding a glossary, and various formatting issues. All comments were addressed in the version created in April 2011. Authors included Jean Krejca (Zara Environmental), Robert Myers (Zara Environmental), Sean Mohren (KLMN), and Daniel Sarr (KLMN). After submitting the revision of April 2011, the protocol was re-reviewed by Drs. Agee and Latham, and received a preliminary approval of, "Needs Minor Revision" (Letter of Dr. Agee, dated March 22nd, 2012). At this point, the PRC only needed to see the author's reviewer response document and a Job Hazard Analysis for caving safety. Follow up conversations between the network Program Manager, Daniel Sarr, and Dr. Latham in the spring of 2012 revealed that while provisionally approved, the methodology detail and implementation plan for the protocol was not as developed as other KLMN protocols. Sarr and Latham made a joint decision to delay final approval and not rush the protocol, and to further refine the methodology details through additional pilot testing.

In spring 2012, further pilot testing was initiated at Lava Beds National Monument (hereafter, Lava Beds) and Oregon Caves National Monument and Preserve (hereafter, Oregon Caves), including sampling in randomly selected and nonrandomly selected (judgment) caves. In March 2013, co-author Sean Mohren left KLMN to become terrestrial ecologist at Crater Lake National Park, and in May 2014, co-author and network program manager Daniel Sarr left KLMN to join the USGS Southwest Biological Science Center. In 2014, Jean Krejca was contracted to perform final edits and address reviewer comments, and she delivered the revised version to KLMN in August 2014.

The new KLMN Data Manager (Allison Snyder) and Program Manager (Dr. Alice Chung-MacCoubrey) started in June and October 2014, respectively. With all of the original authors having departed, Chung-MacCoubrey, Snyder, and Dr. Eric Dinger (KLMN Aquatic Ecologist) reviewed and revised the protocol in consultation with park staff (Nancy Nordensten, Katrina Smith, David Riggs, John Roth) and authors of the 2011 draft. While the sampling design at Oregon Caves remained unchanged, the sampling design at Lava Beds was updated. The scope of inference for the original randomized sampling frame at Lava Beds was limited to single-level caves >500 ft in length and ≤1 km from roads. Lava Beds staff felt this sampling frame was too restricted because it provided inference to only 55 of the park's 700+ caves. KLMN staff also had identified problems with the original sample frame development that compromised randomness of the resulting sample. Thus the park and network collectively decided to 1) broaden the scope to all caves ≥300 ft in length, with no constraints on distance to roads or whether caves were multilevel or contained fragile resources; and 2) perform a new random GRTS draw. This expanded the scope of inference to 114 known caves in the park. Lava Beds staff also felt capable of monitoring 30 random caves (instead of the original 20 random caves), and thus a GRTS draw was performed to select 30 caves for monitoring plus 30 caves in the oversample. Upon implementation, Lava Beds staff rejected 8 caves in the main sample and 2 caves in the oversample because they lacked appropriate deep zones or they had fragile cave resources in the middle of the trail/path through the cave. The next caves in the GRTS order were selected as replacements. Eleven of the final 30 caves had been established as monitoring sites from the original sampling design and thus have data dating back to 2012. The remaining 19 new caves were installed and monitored for the first time in 2016.

Lava Beds staff are also interested in long-term monitoring at 6 caves that provide roost habitat for ~70% of the Townsend's Big-eared Bat (*Corynorhinus townsendii*) population in the park and 5 caves with significant ice resources. Three of the 6 bat caves and 1 of the 5 ice caves were selected via the random GRTS draw and thus will be monitored as part of the random sample. The remaining 3 bat caves and 4 ice caves will be monitored as judgment sites. Only bats, climate, and visitation will be monitored at the 3 judgment bat caves, and all but scat will be monitored at the 4 judgment ice caves. With 30 random caves, 3 judgment bat caves, and 4 judgment ice caves, Lava Beds plans to monitor 37 caves total.

A review of pilot testing and data from 2012 to 2015 led to revision of the scat and visible organics SOP. At Lava Beds, we changed procedures from scat counts to scat presence/absence because 1) scat was difficult to quantify, especially when it occurred in large piles, 2) it was difficult to distinguish between current and past years' deposits, and 3) power analyses suggested very low power to detect change. Oregon Caves will continue to count scat with hyphomycetes (fungal growth), which are indicative of recent deposition.

The revised protocol was resubmitted in December 2016 to the new PRC, Dr. Jon Bakker (University of Washington), and new PWR I&M Program Manager, Lisa Garrett, for final approval.

Appendix F: Power Analyses for Cave Monitoring Parameters

This appendix includes the results and text of 3 separate power analyses used in the development of this cave monitoring protocol. Multiple analyses were contracted for and performed by 2 statisticians, as the development spanned several years and different sampling frames and schemes over the course of the pilot period. A preface is provided to synthesize the results of the 3 analyses into a single summary document.

Power Analysis Summary

Power analyses are a valuable step to assess whether the proposed sampling effort (i.e., number of caves sampled per park unit) is sufficient for detecting long-term trends in environmental and ecological indicators. Power is a function of the sample size (number of caves in Lava Beds National Monument (LABE), number of sites in Oregon Caves National Monument and Preserve (ORCA)), number of years of sampling, variance of the indicator, magnitude of trend, and Type 1 error (probability of detecting a trend when in fact there is not one). Power analyses are a useful tool for determining whether a monitoring project will provide relevant and timely information for management of natural resources. The variance of a parameter is typically unknown and is therefore estimated from available pilot data. For the parameters in this protocol, very few long-term datasets are available.

However, not all measured parameters require a power analysis to justify their inclusion in the protocol. These parameters may have inherent value or may be useful as a co-variable for exploring change in primary parameters. For example, in this cave protocol, we have not done a power analysis on Visitor Traffic, which is a potential co-variable to explain observed trends in other measured parameters.

Section 1: Original Climate Variable Power Analysis

Pilot data are available from LABE and ORCA, but were collected under an initial sampling scheme that mixed judgment and probabilistic sites from an earlier sampling frame (Section 1 in this appendix). This power analysis addressed relative humidity and temperature, using only the annual mean temperature and annual mean relative humidity (a single average over the entire year, incorporating seasonal variation). Although it is a simplistic way to condense the continuous climatic variables, it is an appropriate way to summarize annual trends and does not preclude later seasonal analyses. However, subsequent changes to the sampling frame and sampling design at LABE renders these initial power analyses moot; no conclusions should be drawn from these preliminary LABE power analyses (Section 1, below, in this appendix). They have been included below as background information. Power analyses were redone for LABE climatic variables with an enhanced time series.

At ORCA, the sampling design has not changed, and the power analyses in Section 1 provide a robust method for determining sampling adequacy. ORCA pilot data for climatic variables (relative humidity and temperature) were available for a 3 year time span at 12 locations for determining variation. Because the samples (for pilot data and the proposed design) are all from a single cave, the scope of inference is in terms of the annual trend in the 1 cave. Using 23 loggers and a 10% Type 1 error rate, 80% power is obtained for relative humidity within 7 years for a 0.50% annual trend (or

5% net change over 10 years), assuming pilot data from 12 sites reflects the cave variation and that the 3 year time span represents annual variation. For temperature (with same caveats), 80% power is obtained after 8 years for a 2% annual change (a cumulative change of 2.78 degrees Celsius over 20 years).

*Section 2: Townsend's Big-eared Bat (*Corynorhinus townsendii*) Hibernacula Count Power Analysis*

Early in protocol development, a time series of 12 years was available for determining the adequacy of bat hibernacula counts in LABE (Section 2, below, in this appendix). This time series spanned from 1998 to 2010 and used the same methodology as this cave protocol. Although bats are counted by species, the power analysis focuses on the Townsend's Big-eared Bat (*Corynorhinus townsendii*). Multiple power analyses were performed under different sampling scenarios (6, 10, and 12 caves). Our cave monitoring protocol focuses on 6 bat caves because they are believed to contain ~85% of the known population of *C. townsendii*. Three of the 6 caves are part of the randomly selected caves at LABE, and the other 3 were added as judgment sites. Bat-related inferences from data collected at these 6 caves are limited to these 6 caves.

Because the final implemented design proposed in this protocol uses only the 6 cave sampling scheme, we report here the results from the 6 cave scenario. Eighty percent power to detect *C. townsendii* declines of 5% annual trend in the median log counts is reached in approximately 12 years. For subtler declines of 2% annual decline, more than 20 years is needed to reach 80% power (both using 10% Type 1 error). Of note, power to detect population declines was higher in the 6 cave sampling scenario than sampling 10 or 12 caves. This counterintuitive result is due to the fact that expanding the sample size from the 6 main "bat caves" to include more sparsely/infrequently populated caves increases the site variation, so that power is actually reduced at a larger sample size.

Section 3: Final Power Analysis for Cave Parameters

Lastly, a final set of power analyses were done to determine the adequacy of the final sampling scheme at LABE (Section 3, below, in this appendix). These power analyses revisited relative humidity and temperature for LABE, and added analyses aimed at conservatively estimating power to detect trends in both vegetation and invertebrate communities. All pilot data used to estimate variance components were collected between 2012 and 2016 using the proposed methodology and sampling frame. For climate (relative humidity and temperature), 4 years of data were available and power was explored for the entrance and deep cave zones. For vegetation, 2 years of data (2012 and 2014) were available; for invertebrates only 1 year (2014) was available.

Power to detect change for multiple sampling sizes was calculated (20, 30, and 40 caves) using a 10% Type 1 error rate.

These climate power analyses were more appropriate than the earlier power analyses presented in section 1 because they were performed on mean monthly values and included a seasonal component. For temperature, a one-sided test for an increase in mean temperature was performed. For the proposed sample size of 30, power over a 10 year sampling period (2.5% annual change) was 100% for both monthly mean temperature and mean monthly temperature range (max-min) at both the entrance and deep zones. For mean monthly relative humidity, a one-sided test for a decrease in humidity was done. Power to detect a 2.5% decline was 100% for the deep zone and 98% in the entrance zone in a 10 year span.

Given that vegetation and invertebrates are sampled every other year, power analyses for these parameters were examined over a longer (20 year) time span. Vegetation was analyzed using a metric of vegetation complexity—essentially taxa group richness along with bare ground. For a two-sided test (allowing increasing or decreasing trends) on a 2% annual trend, power was 60% in the inner vegetation zone and 77% in the outer zone for 30 sampling sites (see SOP #9: Cave Entrance Vegetation for description of inner versus outer zone). For invertebrate taxa richness per cave, a two-sided test on 1% annual trend found that a power of 73% was achieved after 20 years for 30 caves monitored. Both vegetation and invertebrate communities will be analyzed for community composition change using non-parametric multivariate based trend tests, which are not suitable to power analysis. These tests have been generally more sensitive than univariate techniques used here (Somerfield et al. 2002; see reference list in Section 1). Hence, these power results should be seen as conservative estimates of the more robust multivariate methods.

Two parameters, ice and water levels, were not examined for power to detect trends because little or no data were available, and because of their inherent importance to park resources. For these key resources, even if the parameters have limited power, they are still important to monitor.

Section 1: Power Analysis for Annual Trend Detection in Climate Variables for ORCA and LABE Caves Protocol

K. Irvine, PhD
Assistant Professor of Statistics
Montana State University, Bozeman

*Steve Hayes assisted with organizing the data from LABE for use in this report.

Introduction

The following questions are addressed in this report to inform the sampling design choices for monitoring Oregon Caves National Monument and Preserve (ORCA) and Lava Beds National Monument (LABE) climate variables—specifically, annual relative humidity (%) and annual temperature (Celsius):

1. How many data loggers are needed in ORCA 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 in LABE to monitor parkwide 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?

These questions are addressed by a power analysis based on the current available pilot data from both parks. The annual magnitude of trend investigated for relative humidity and temperature is based on input from Jean Krejca with Zara Environmental, Inc., and Daniel Sarr and Sean Mohren of the Klamath Inventory and Monitoring Network (KLMN). In terms of a power analysis, I specify the Type 1 error to 10% and investigate a range of sample sizes and years to detect varying magnitudes of annual trend. I assume the mixed linear model for trend proposed in Urquhart et al. (1993) is appropriate for analyzing future KLMN caves climate data. This model is quite flexible and can accommodate the different types of sampling units and sampled populations in ORCA and LABE. The main difference is the scope of statistical (model-based) inference is different for the 2 parks. At ORCA, we are interested in annual trends within 1 cave, whereas at LABE, we are interested in parkwide annual trends encompassing multiple caves.

Proposed Sampling Designs

At LABE 31 caves were randomly selected with unequal probability from a population of 59 caves using GRTS (Generalized Random Tessellation Stratified). For each selected cave, 1 HOBO logger will be located within 1 of 4 strata (deep zone, middle zone, entrance zone, outside zone). Four loggers will be used in 31 caves for a total of 124 loggers in LABE. The caves were selected with unequal probability because 6 caves with known bats and 5 caves with ice were selected with probability 1; the remaining 20 caves were selected with probability equal to 0.53. The sampling unit is a cave and the sampled and target population is the 59 preselected caves located in LABE. Therefore, within this park we are interested in the annual parkwide trends in temperature and relative humidity of these 59 caves.

At ORCA there is 1 cave of interest - the main cave. Currently, 23 HOBO loggers will be randomly located throughout the cave. For ORCA the sampling unit is a location within the cave where the HOBO is placed; thus, the scope of inference is in terms of the annual trend in the 1 cave. Also, data loggers will be placed in the deep, middle, entrance, and outside zones (1 logger each zone) in Blind Leads Cave within ORCA.

For both parks, the loggers will be gathering hourly data on temperature and relative humidity. The data will be downloaded 3 times a year. In terms of a trend analysis, we compute an annual estimate for each HOBO based on averaging over hours, days, and months. This is reasonable for an annual trend power analysis; however, this does not preclude the parks from investigating seasonal patterns in the climate data once they are available. Or using a control chart approach to track trends for each cave separately once a reasonable baseline is established (Morrison 2009).

Power Analysis for Trend Detection

In order to perform a power analysis for univariate trend, a model must be assumed for the future data. I adopt the linear model presented in Urquhart and Kincaid (1999), Larsen et al. (2001), Kincaid et al. (2004), and Urquhart et al. (1993). The model is as follows $Y_{ij} = \mu + S_i + T_j + E_{ij}$ where Y_{ij} is the observed characteristic of interest (e.g., temperature) for site *i* in year j, $S_i \sim N(0, \sigma^2{}_{SITE})$, $T_j \sim N(0, \sigma^2{}_{YEAR})$, $E_{ij} \sim N(0, \sigma^2{}_{RESIDUAL})$,and the components are assumed independent. There have been many modifications to this general model idea that allow for varying trends for each site (Piepho and Ogutu 2002; VanLeeuwen et al. 1996). However, given the scarcity of pilot data, particularly for LABE, I used a model assuming that trends over time do not vary by site. I used the functions written by Tom Kincaid to estimate power based on the model above; for specific details refer to the paper by Urquhart et al. 1993. These are *estimates* of the power because we are estimating the variance components. These estimates can be improved once more sampling is conducted within LABE.

For LABE the model is used separately for the different zones, so the site = a cave, whereas for ORCA the site is simply a logger location.

<u>Pilot data</u>

The data used to estimate the necessary variance components were provided by Sean Mohren (KLMN) via Elizabeth Hale and John Roth (ORCA) and Shawn Thomas (LABE).

The available climate data for LABE are summarized in Table F-1, and more detail is provided in Supplement 1 of this appendix. HOBO data are available from CAIC from January 25 through February 25, 2010; WISH Cave from January 25 through February 25, 2010; and Catacombs Cave from February 16 through March 3, 2010, for the 4 different zones of interest. The complication based on these data is that we have no estimate of temporal variation in yearly averages and the site-to-site variance is based on only 3 caves.

A longer time series of temperature and relative humidity is available for both CGCA and ANGL for the “middle zone” for the months of January and February in the years 2000–2002. Also, data from a weather station are available for 2006 to 2010 in the months of January, February, and March. These datasets can be used to estimate the temporal variance component for the middle and outside zones. One thing to bear in mind is that across the different caves, the definition of a zone may vary due to the variety of cave architecture. For example, a middle zone in one cave may be much further from the entrance than a middle zone in another cave; statistically, this results in greater variation among caves within a zone. The data used for estimating the variance components are presented in Figures F-1 and F-2. One major issue is that we are assuming that the average of the Jan–Feb (sometimes March for outside zone) data is representative of the annual average in Temperature and Relative Humidity.

Table F-1. Summary of pilot data available for the different cave zones within Lava Beds National Monument. The number corresponds to the number of caves sampled for a given year and zone.

	Year							
Zone	**2000**	**2001**	**2002**	**2006**	**2007**	**2008**	**2009**	**2010**
Deep	0	0	0	0	0	0	0	3
Entrance	0	0	0	0	0	0	0	3
Middle	2	2	2	0	0	0	0	3
Outside	0	0	0	1	1	1	1	4

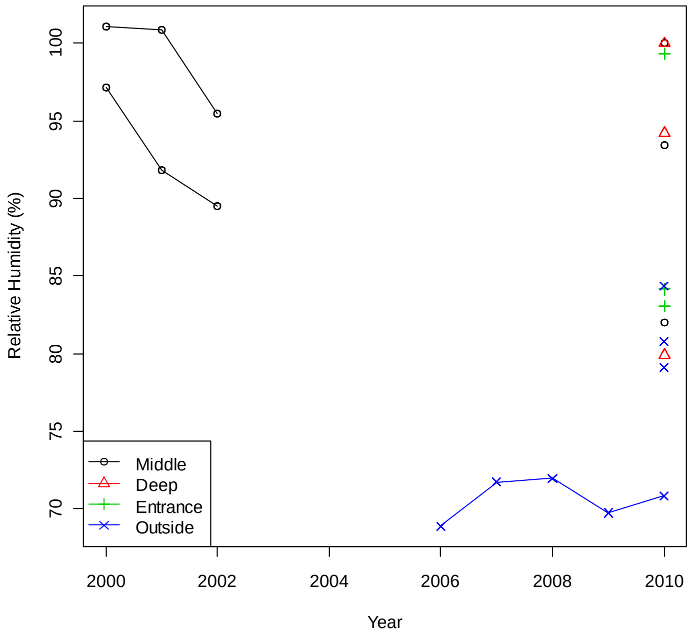


Figure F-1. Relative humidity annual averages from pilot cave data at Lava Beds National Monument. The legend describes the 4 cave zones. The sample sizes for the year and zone combinations are in Table F-1.

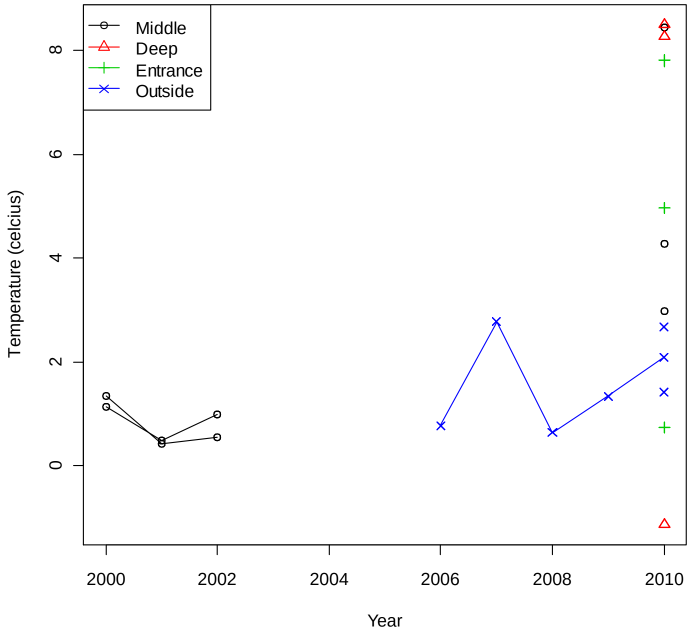


Figure F-2. Annual average temperatures (Celsius) for each zone-year combination from pilot cave data at Lava Beds National Monument. The legend describes the 4 cave zones.

ORCA has more pilot data available. There were 12 locations with relatively continuous measurements of relative humidity and temperature for the years 2007 to 2010. The monthly data are presented in Supplement 2 of this appendix. Based on the data in Figures F-3 and F-4, we can estimate the site, year, and site*year variance components for the power analysis for ORCA.

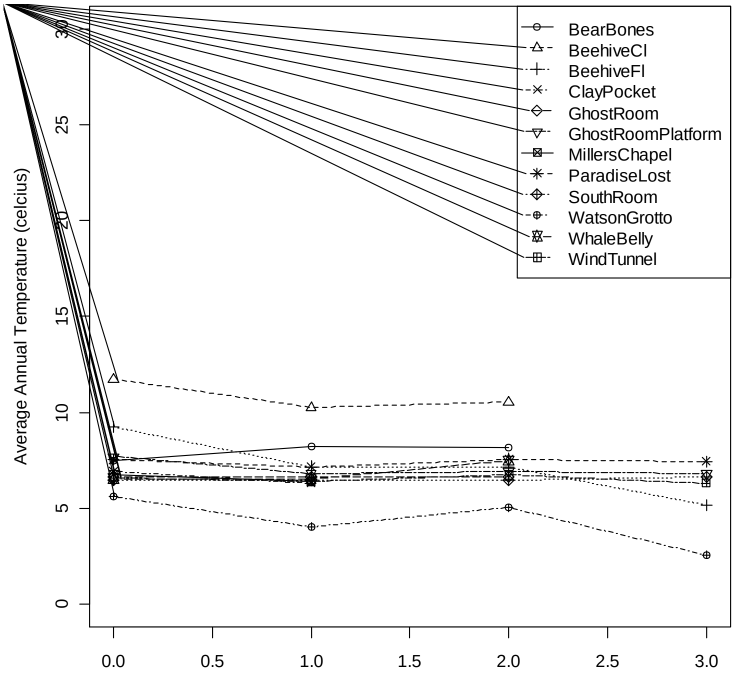


Figure F-3. Average annual temperature (Celsius) for 12 different locations within The Cave for 2007–2010 at Oregon Caves National Monument and Preserve.

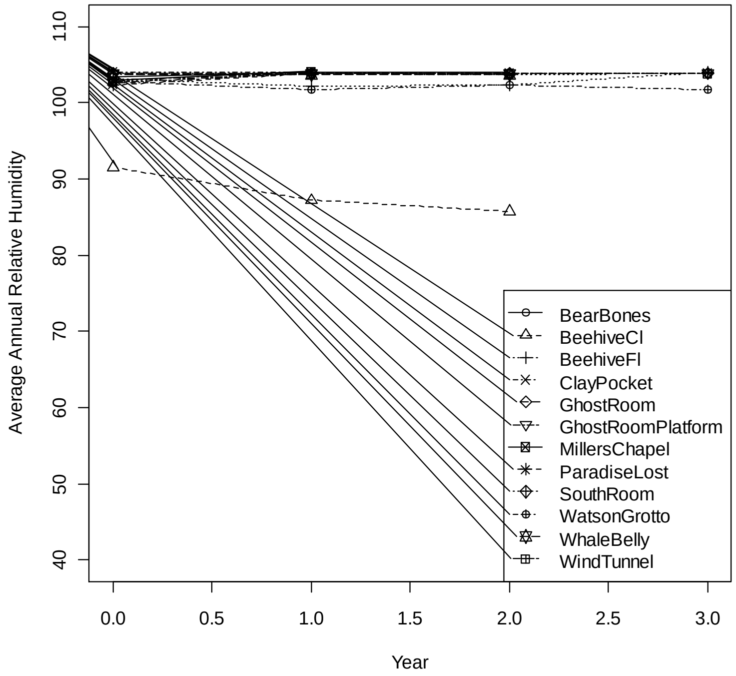


Figure F-4. Average annual relative humidity (percent) for 12 different locations within The Cave for 2007–2010 at Oregon Caves National Monument and Preserve.

Variance components estimates

I used the lmer function in the lme4 package (Bates et al. 2014) in the *R* freeware statistical platform to estimate the random and fixed components of the mixed model using restricted maximum likelihood (REML). The estimated variance components are displayed in Table F-2 for Temperature and Relative Humidity for Oregon Caves National Monument and Preserve and Table F-3 for Lava Beds National Monument.

Table F-2. Estimated variance components and fixed effects using REML for Oregon Caves National Monument and Preserve. The untransformed response variable was used.

Response	Parameter	Estimate
Temperature (Celsius)	σ^2_{SITE}	1.95
	σ^2_{YEAR}	0.19
	$\sigma^2_{RESIDUAL}$	0.45
	μ	6.94
Relative Humidity (%)	σ^2_{SITE}	19.52
	σ^2_{YEAR}	0
	$\sigma^2_{RESIDUAL}$	0.92
	μ	102.21

Table F-3. Estimated variance components and fixed effects using REML for Lava Beds National Monument. The untransformed response variable was used. Only 2 zones were used because of the severe scarcity of data.

		Zone	
Response	**Parameter**	**Middle**	**Outside**
Relative Humidity (%)	σ^2_{CAVE}	48.57	32.67
	σ^2_{YEAR}	8.56	1.7
	$\sigma^2_{RESIDUAL}$	3.46	0.00029
	μ	93.83	78.56
Temperature (Celsius)	σ^2_{CAVE}	9.67	~0
	σ^2_{YEAR}	0.13	0.34
	$\sigma^2_{RESIDUAL}$	0.05	0.41
	μ	3.43	1.54

Results

The values in Tables F-2 and F-3 were used as inputs into the function written by Tom Kincaid, EPA Statistician, for estimating power for detecting trends. The assumed revisit design is an always revisit design, assuming that once caves or locations are selected the HOBO placement does not change over time.

ORCA

The usual desired 80% power to detect a net change of 1% in relative humidity after 10 years will be reached around 7 years for a sample size of 30 HOBO loggers with Type 1 error of 10% (Figure F-5). This is a relatively conservative change based on the pilot data in Figure F-4; there is little fluctuation in relative humidity for the 3 years of sampling. A larger net change of 5% would be detected after only 3 or so years of sampling, with 80% power and a 10% Type 1 error. Based on the estimated variance components, it appears that using 23 data loggers is sufficient to detect annual trends in relative humidity in the cave (Figure F-6). However, the biggest assumption is that the pilot data adequately represent both the spatial and temporal variation of relative humidity within the cave.

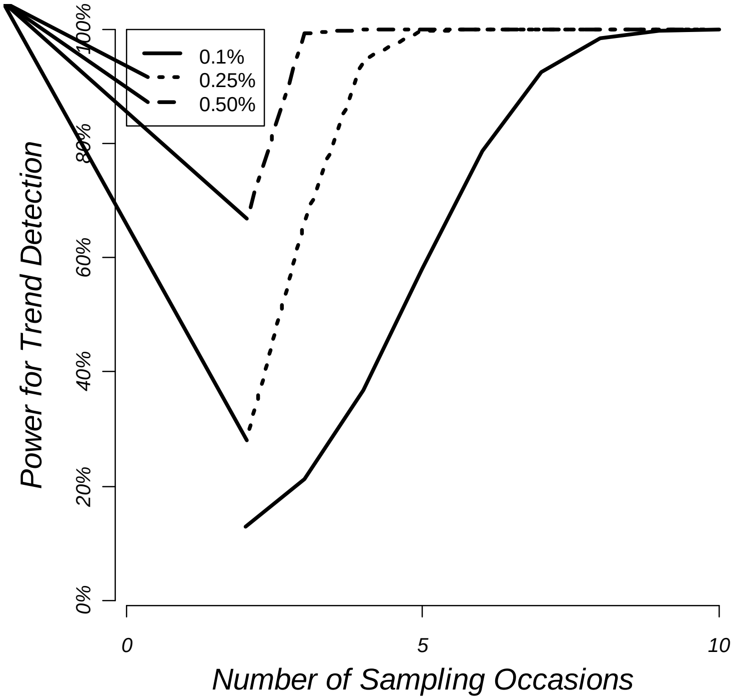


Figure F-5. Estimated power for detecting annual change in relative humidity over 10 years for 30 fixed locations in Oregon Caves National Monument and Preserve. The annual changes of 0.1%, 0.25%, and 0.50% correspond to cumulative 1, 2.5, and 5% net changes in relative humidity after 10 years.

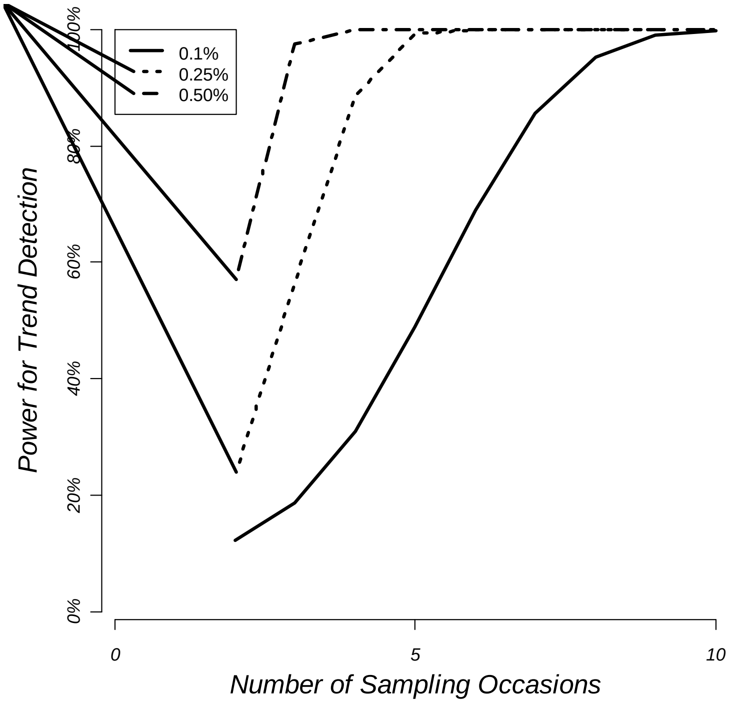


Figure F-6. Estimated power for detecting annual change in relative humidity over 10 years for 23 fixed locations in Oregon Caves National Monument and Preserve. The annual changes of 0.1%, 0.25%, and 0.50% correspond to cumulative 1, 2.5, and 5% net changes in relative humidity after 10 years.

In terms of detecting trends in annual temperature measurements, Figure F-7 suggests that 80% power will be achieved after ~8 years of sampling for a 2.78 degree net change in temperature after 20 years. However, for a smaller 0.5% annual change in temperature, power is only 60% after 20 years of sampling; increasing to 30 or 40 HOBO data loggers does not improve the power (not shown). Presumably, power will increase as the number of years sampled increases.

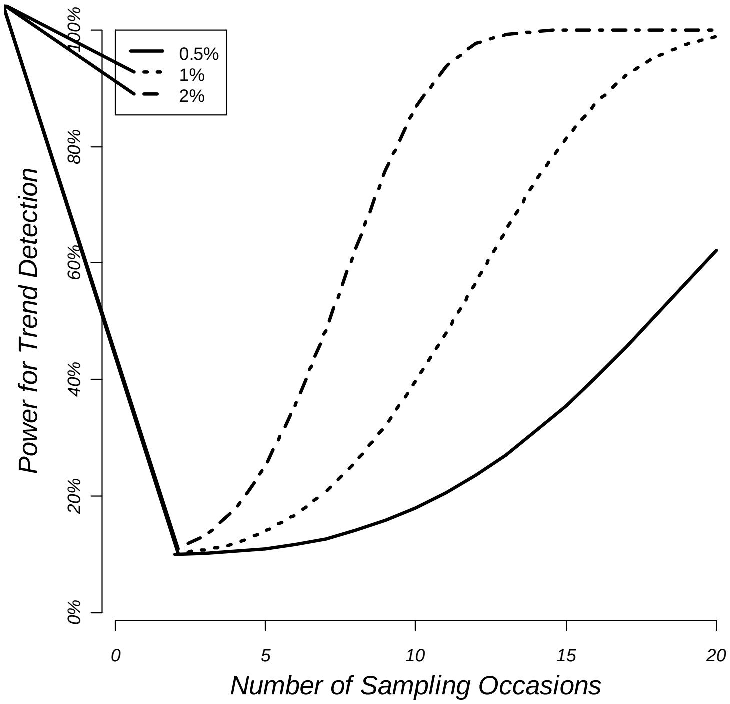


Figure F-7. Estimated power for detecting annual change in temperature (Celsius) over 20 years for 23 fixed locations in Oregon Caves National Monument and Preserve. The annual changes of 0.5%, 1%, and 2% correspond to cumulative 0.69, 1.39, and 2.78 degree Celsius net changes in temperature after 20 years.

LABE

For LABE, 80% power to detect annual trends in temperature in the middle zone will be achieved after ~12 years for a 2% annual change, and after 20 years for a smaller 1% change (Figure F-8). For a 0.5% annual change, ~35 years of sampling are needed to achieve 80% power for 30 caves, and increasing the number of caves to 60 does not change the power to detect trends. To increase the power to detect trends in annual temperature in the middle zone, increasing the number of years is more important than increasing the number of caves surveyed.

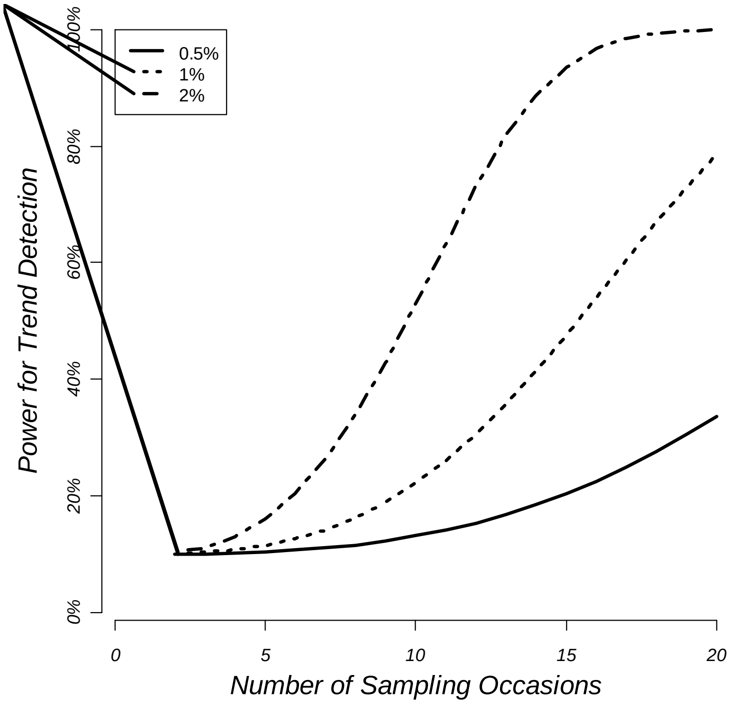


Figure F-8. Estimated power for detecting annual change in temperature (Celsius) over 20 years for 30 fixed caves in Lava Beds National Monument for the middle zone. The annual changes of 0.5%, 1%, and 2% correspond to 0.343, 0.69, 1.37 degree Celsius net changes in temperature after 20 years.

For the annual trends in relative humidity within the middle zone, a similar pattern emerges in that for a small annual change of 0.1%, >40 years are needed to achieve 80% power, and increasing the number of caves does not substantially increase power for the smaller annual change (Figure F-9). However, for the larger annual change of .5%, corresponding to a net change of 9.38 in average annual relative humidity, 80% power is reached after 15 years for 30 caves.

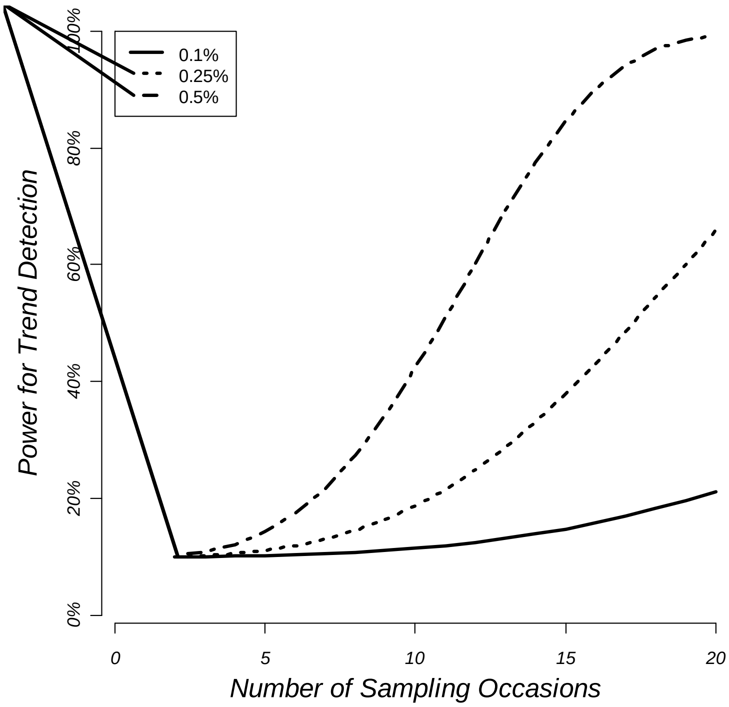


Figure F-9. Estimated power for detecting annual change in relative humidity over 20 years for 30 fixed caves in Lava Beds National Monument for the middle zone. The annual changes of 0.1%, 0.25%, and 0.5% correspond to 1.88, 4.69, and 9.38 net changes in relative humidity after 20 years.

The power is substantially lower for the outside zone for detecting annual trends in temperature (Figure F-10). Reasonable power is achieved for detecting a 1.23 net change in annual temperature after 40 years with only 30 caves (Figure F-11).

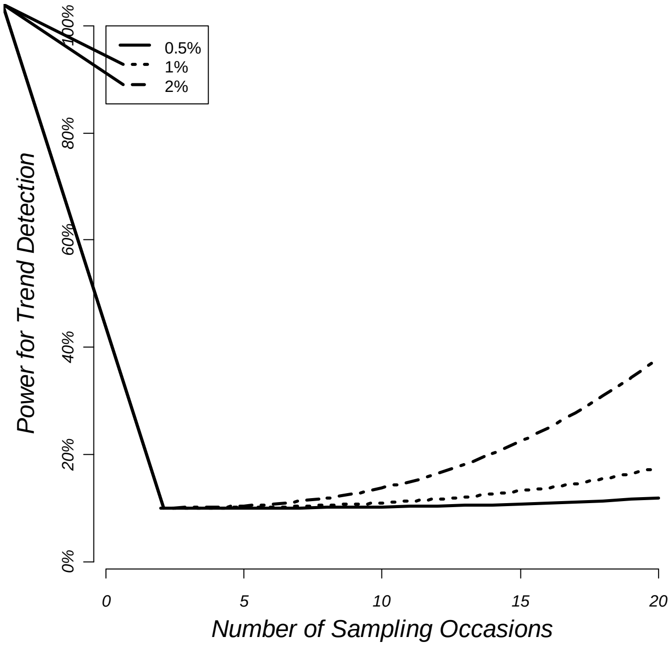


Figure F-10. Estimated power for detecting annual change in temperature (Celsius) over 20 years for 30 fixed caves in Lava Beds National Monument for the outside zone. The annul change of 0.5%, 1%, and 2% correspond to 0.154, 0.308, 0.616 Celsius net change in temperature after 20 years.

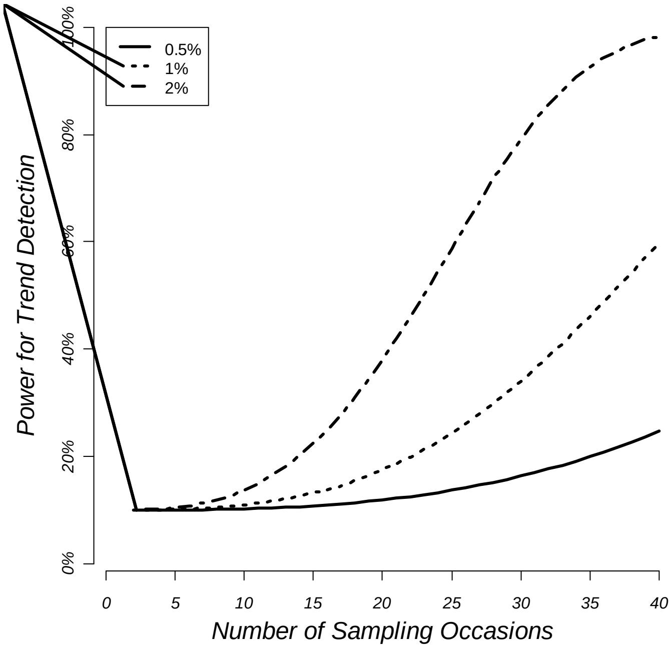


Figure F-11. Estimated power for detecting annual change in temperature (Celsius) over 40 years for 30 fixed caves in Lava Beds National Monument for the outside zone. The annul change of 0.5%, 1%, and 2% correspond to 0.308, 0.616, 1.232 Celsius net change in temperature after 40 years.

In terms of trends in relative humidity in the outside zone, 30 caves sampled for 20 years results in >80% power for a 7.86 net change in relative humidity after ~8 years of sampling (Figure F-12). For a smaller net change of 3.93 after 20 years, >80% power is reached after around 15 years of sampling with 30 caves.

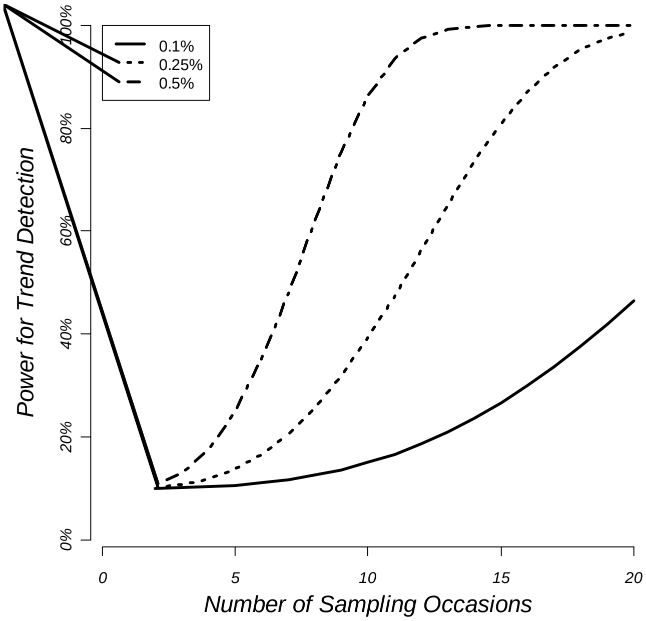


Figure F-12. Estimated power for detecting annual change in relative humidity over 20 years for 30 fixed caves in Lava Beds National Monument for the outside zone. Annual changes of 0.1%, 0.25%, and 0.5% correspond to net changes in relative humidity after 20 years of 1.57, 3.93, and 7.86.

Conclusions

Assuming that the pilot data adequately represent the spatial and temporal variation within the ORCA cave, using 23 data loggers is sufficient to monitor annual trends in relative humidity and temperature. For LABE, assuming the pilot data adequately represent the cave-to-cave variability and the temporal variation in relative humidity and temperature, the proposed sampling of 30 caves for the outside and middle zones should be adequate with enough years of monitoring.

References

Kincaid, T. K., D. P. Larsen, and N. S. Urquhart. 2004. The structure of variations and its influence on the estimation of status: indicators of condition of lakes in Northeast, U.S.A. Environmental Monitoring and Assessment 98(12):1-21.

Larsen, D. P., T. K. Kincaid, S. E. Jacobs, and N. S. Urquhart. 2001. Designs for evaluating local and regional scale trends. Bioscience 51(12):1069-1078.

Morrison, L. W. 2009. The use of control charts to interpret monitoring data. Natural Areas Journal 28(1):66-73.

Piepho, H.-P., and J. O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. Journal of Agricultural, Biological, and Environmental Statistics 7(7):350-360.

Somerfield, P. J., K. R. Clarke, and F. Olsgard. 2002. A comparison of the power of categorical and correlational tests applied to community ecology data from gradient studies. Journal of Animal Ecology 71:581-593.

Urquhart, N. S., and T. K. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological, and Environmental Statistics 4(4):404-414.

Urquhart, N. S., W. S. Overton, and D. S. Birkes. 1993. Comparing sampling designs for monitoring ecological status and trends: Impact of temporal patterns. Pp. 71-86 in V. Barnett and K. F. Turkman, eds., Statistics for the Environment. John Wiley and Sons Ltd., London.

VanLeeuwen, D. M., L. W. Murray, and N. S. Urquhart. 1996. A mixed model with both fixed and random trend components across time. Journal of Agricultural, Biological, and Environmental Statistics 1(4):435-453.

Supplement 1. LABE Climate Data Plots

<u>Wishbone Cave</u>

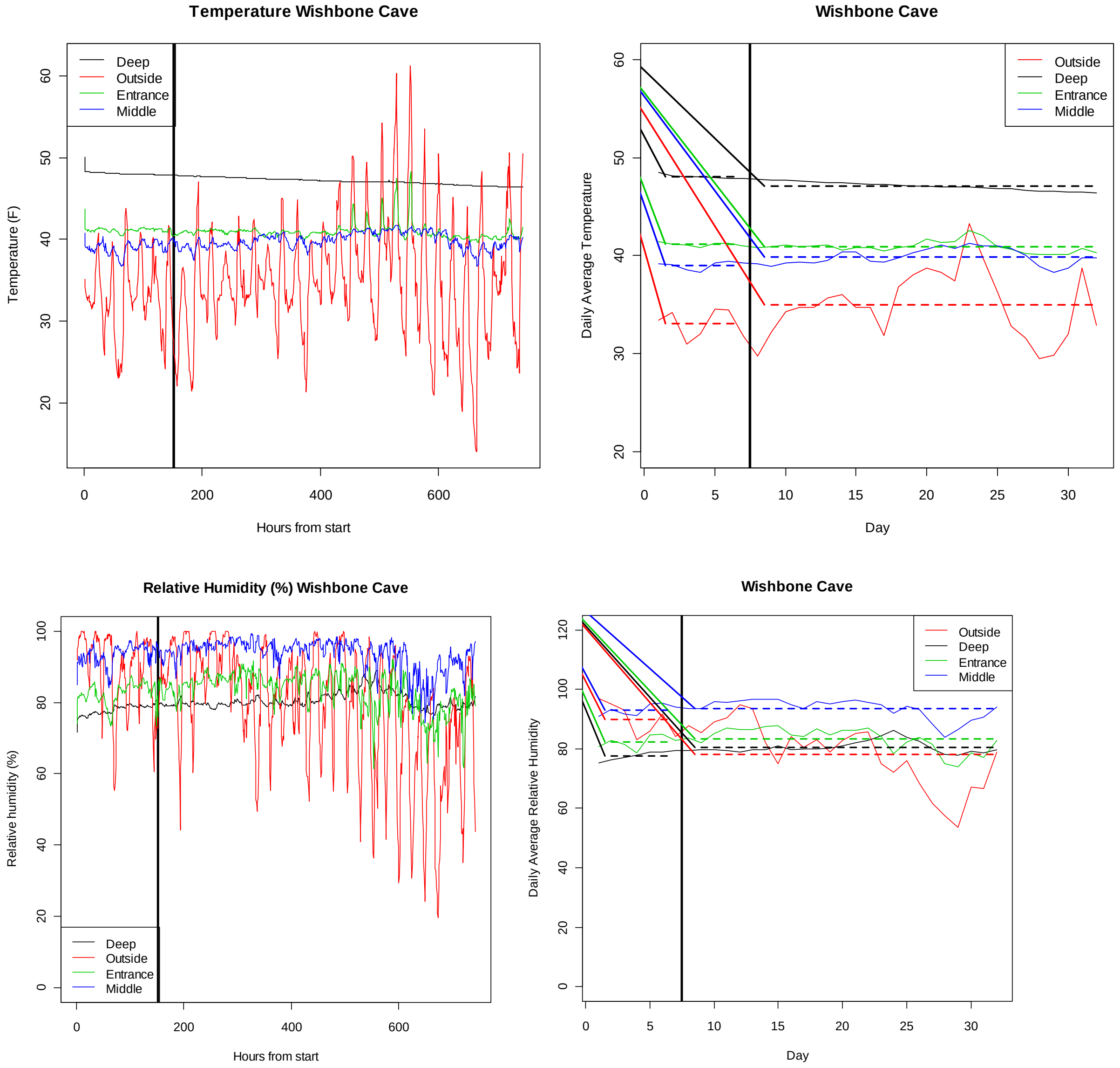


Figure F-13. Wishbone Cave climate data from 2010 at Lava Beds National Monument.

CAIC

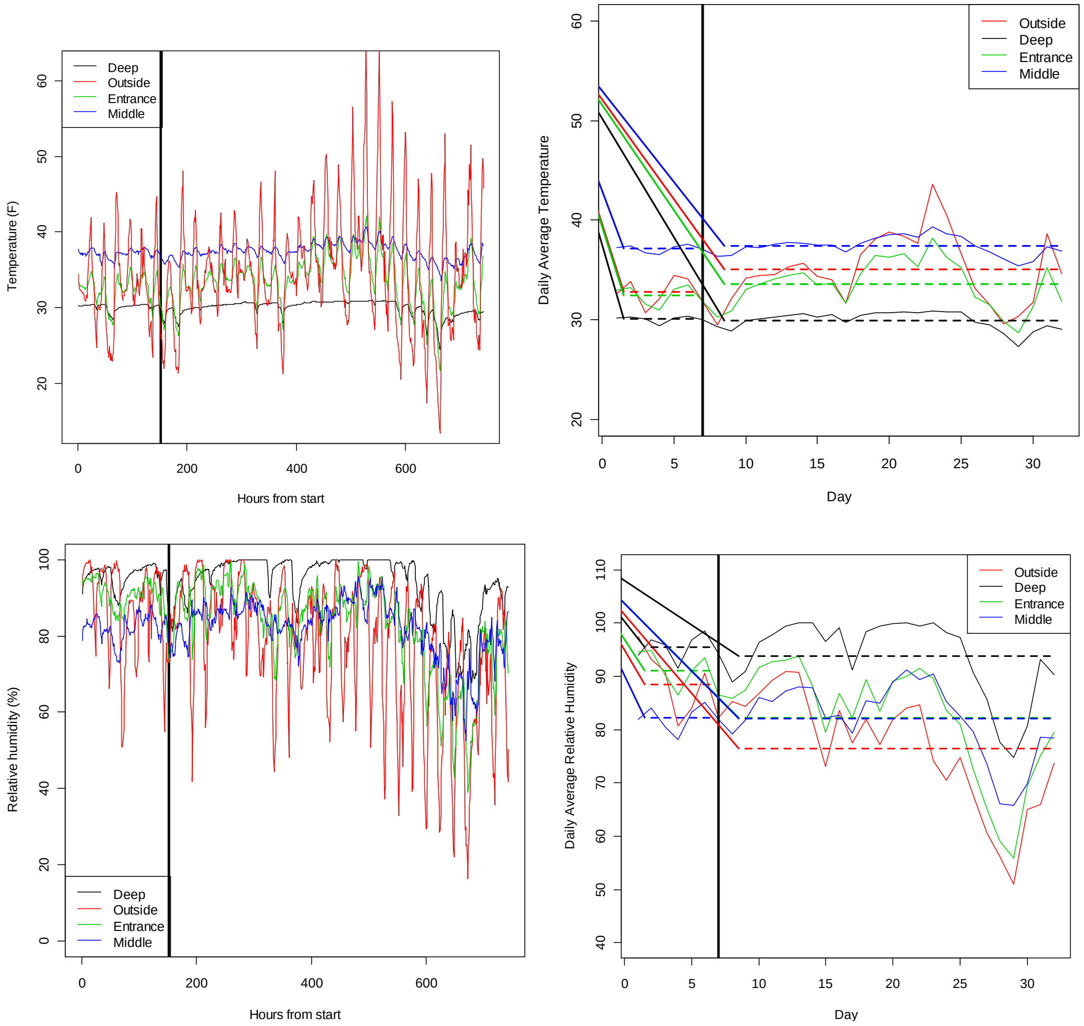


Figure F-14. CAIC Cave climate data from 2010 at Lava Beds National Monument. Feb and March-vertical line is division.

Catacombs Cave

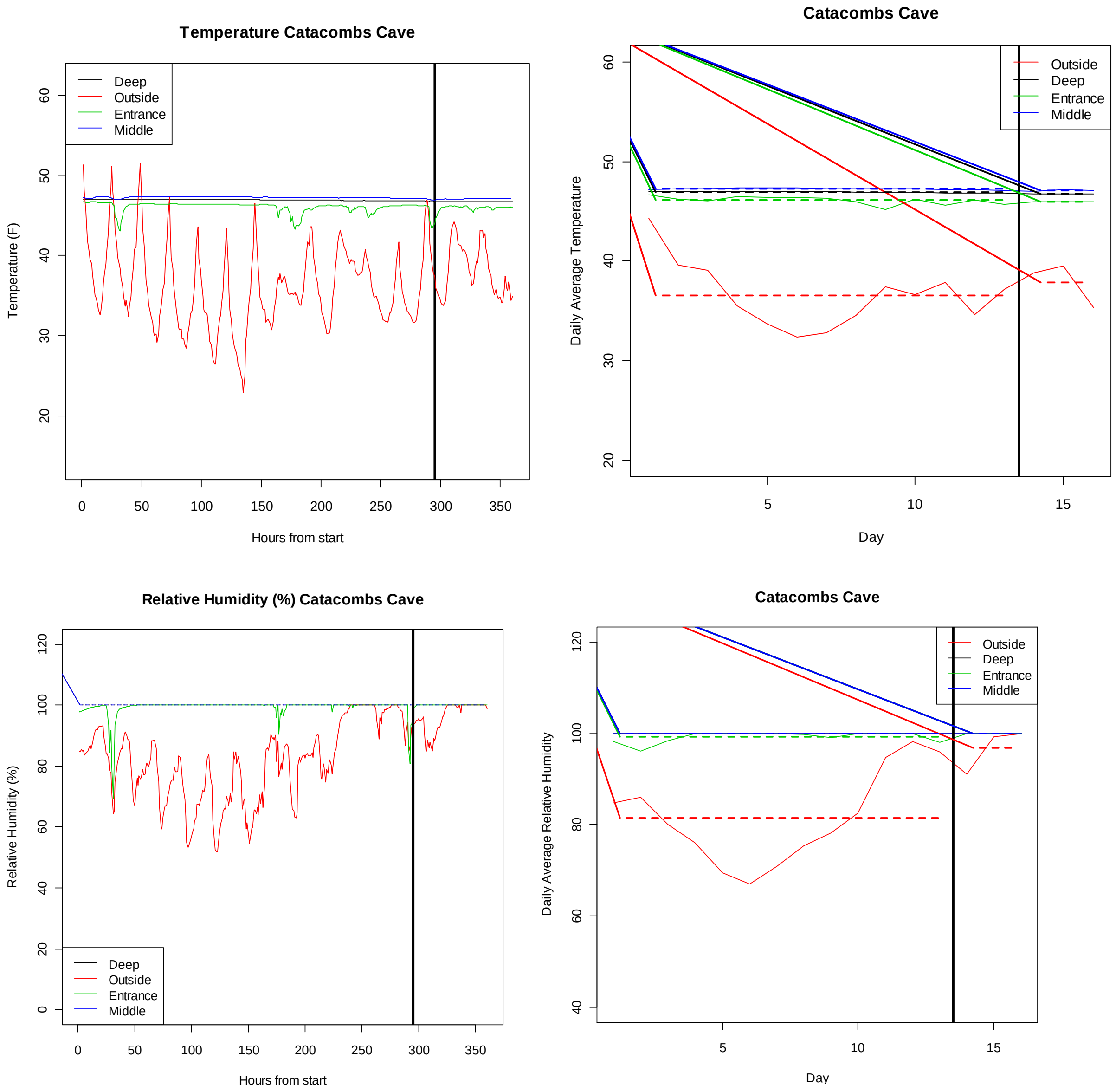


Figure F-15. Catacombs Cave climate data from 2010 at Lava Beds National Monument.

CGCA

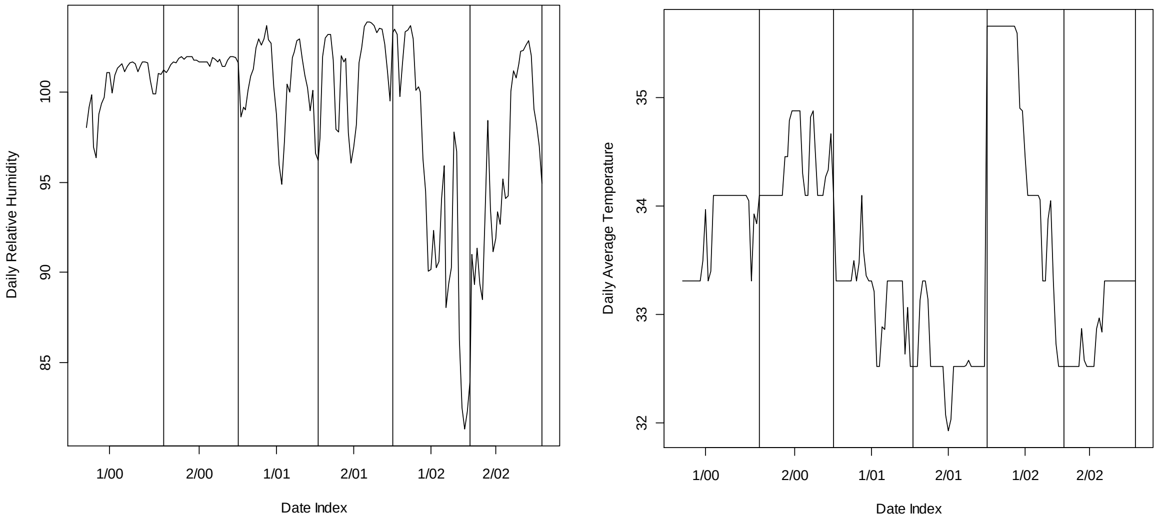


Figure F-16. CGCA Cave climate data from 2010 at Lava Beds National Monument.

ANGL

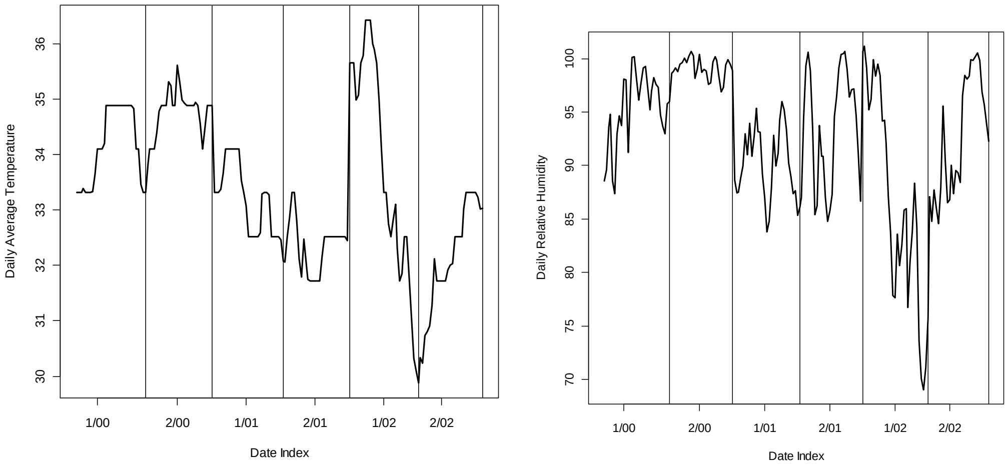


Figure F-17. ANGL Cave climate data from 2010 at Lava Beds National Monument.

Weather Station

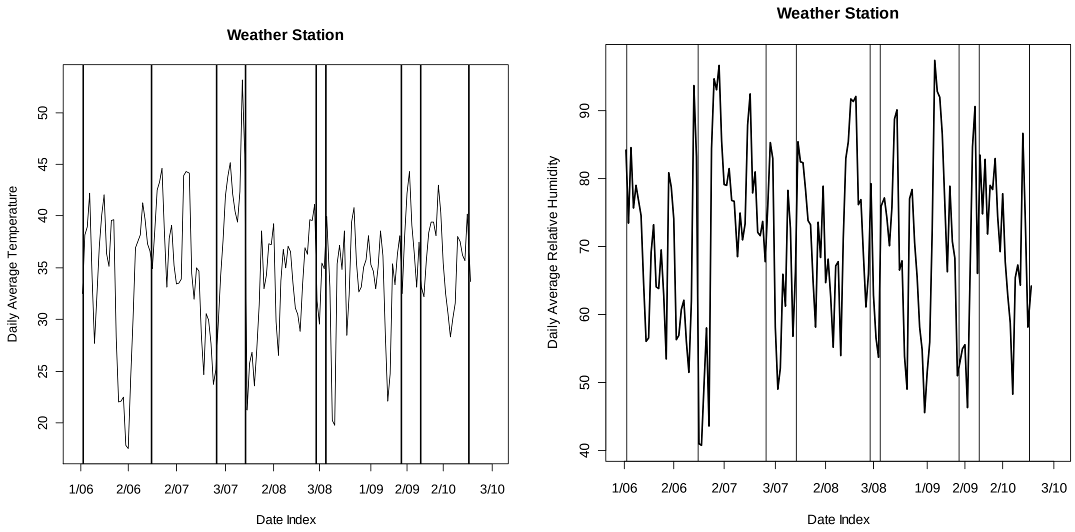


Figure F-18. Climate data from weather station near Lave Beds National Monument headquarters. Temperature is degrees Fahrenheit. Relative humidity is percent.

Supplement 2: ORCA Monthly Climate Data

Temperature

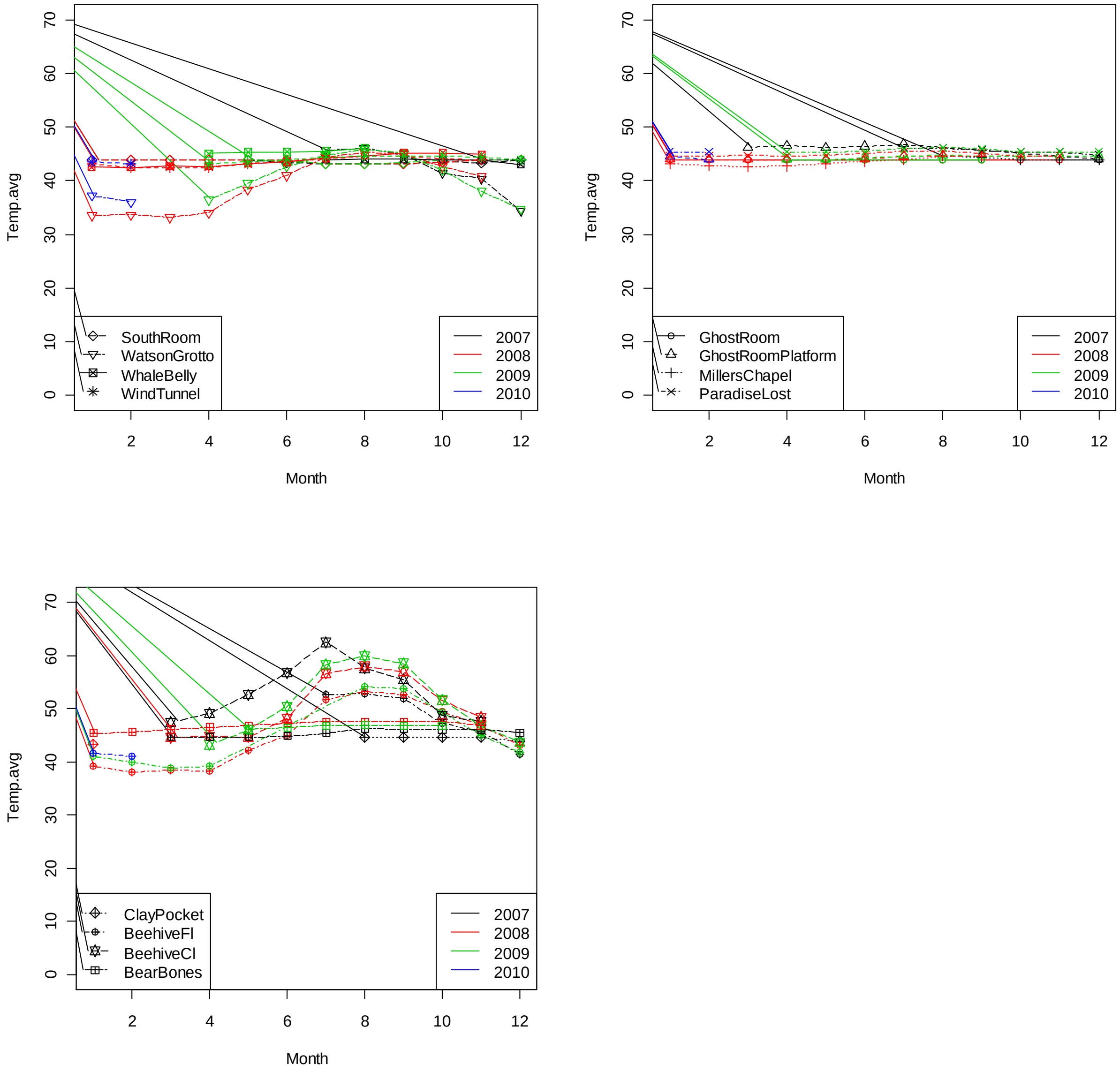


Figure F-19. The monthly temperature averages (°F) for each location plotted for each year separately at Oregon Caves National Monument and Preserve. Temperatures are averaged over hours and days. There does not appear to be much month-to-month variability, except for Watson Grotto, Beehive ceiling, and Beehive floor locations. The patterns are basically the same across the 4 years of data.

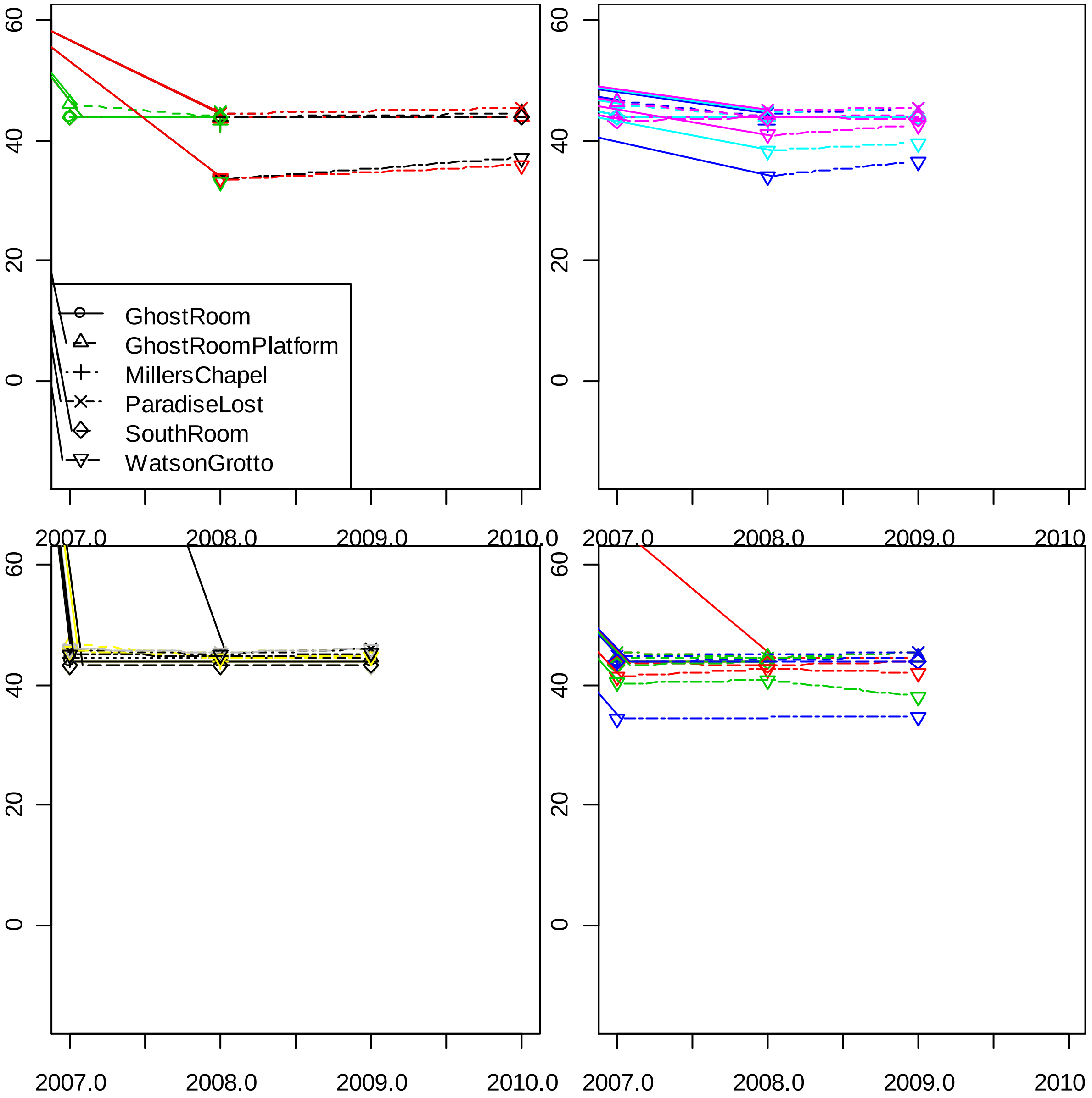


Figure F-20. Monthly temperature (°F) time trends for Ghost Room, Ghost Room Platform, Millers Chapel, Paradise Lost, South Room, and Watson Grotto at Oregon Caves National Monument and Preserve. Each month is plotted with a different color. Top left Jan-Mar; top right April-June; bottom left July Sept; bottom right Oct-Dec. A strong month effect would manifest as the colors separating out---they do not.

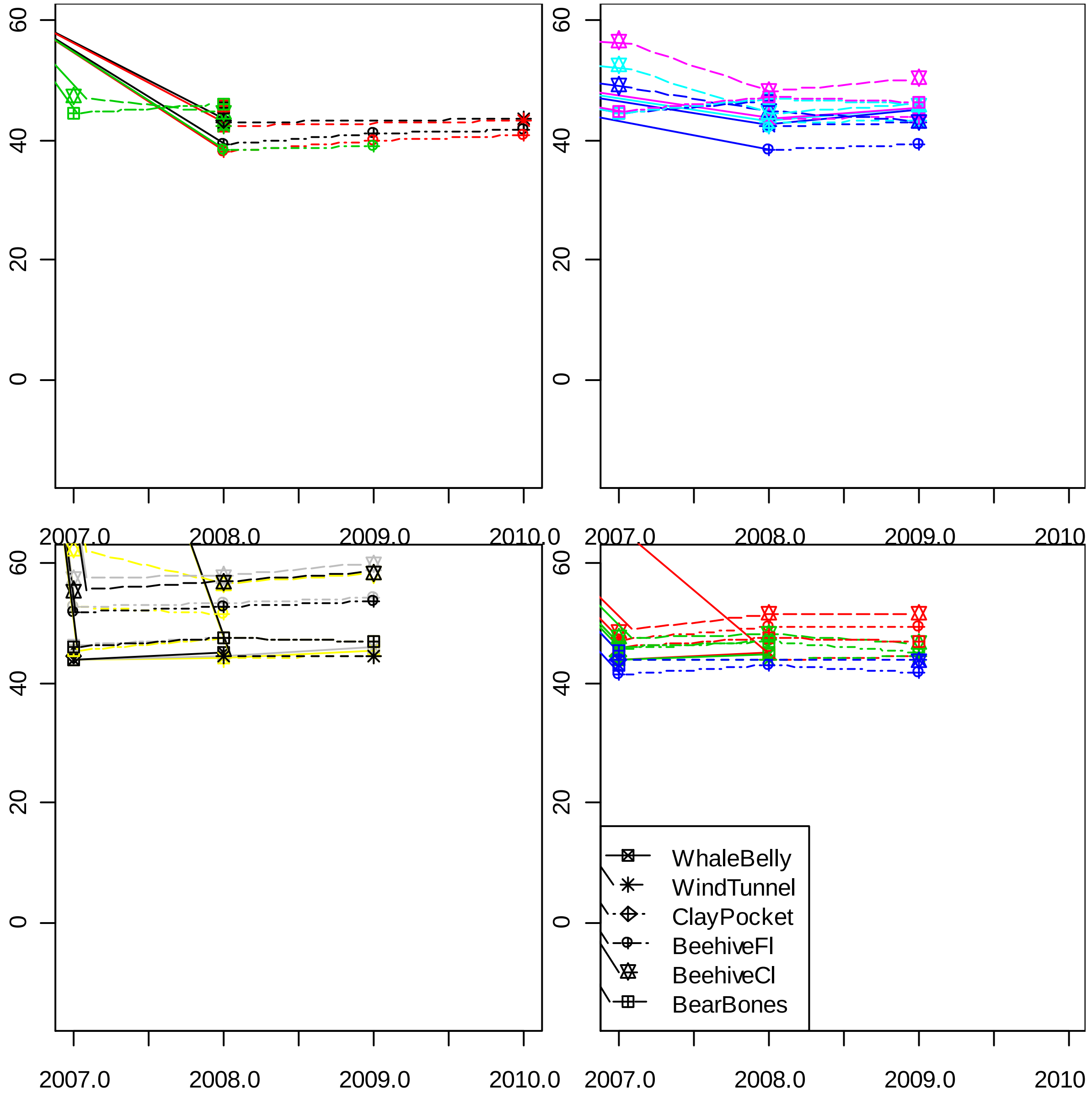


Figure F-21. Monthly temperature (°F) time trends for Whale Belly, Wind Tunnel, Clay Pocket, Beehive FL, Beehive Cl, and Bear Bones at Oregon Caves National Monument and Preserve. Each month is plotted with a different color. Top left Jan-Mar; top right April-June; bottom left July Sept; bottom right Oct-Dec. A strong month effect would manifest as the colors separating out---they do not.

Relative humidity

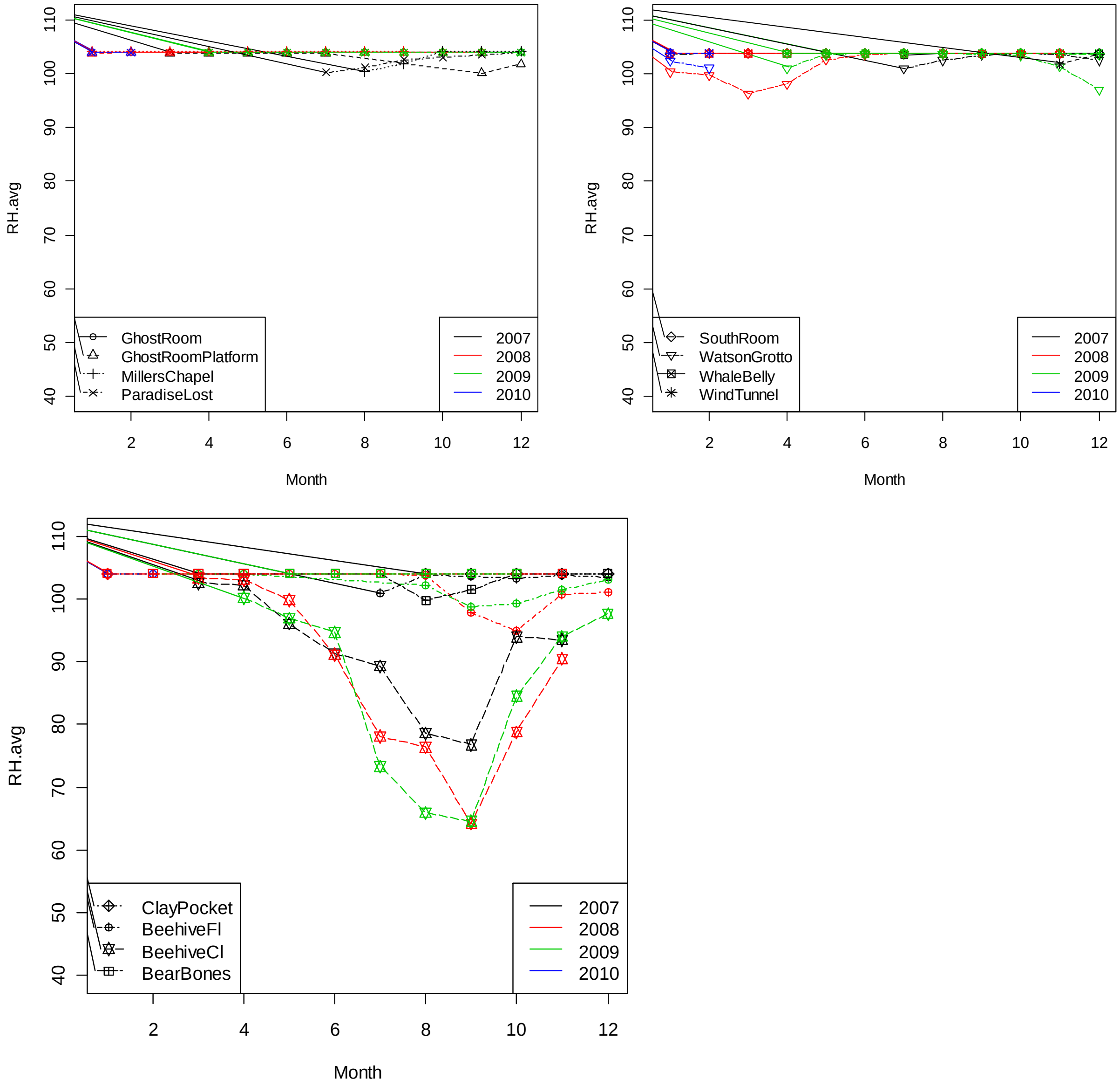


Figure F-22. Monthly relative humidity (%) averages for each location plotted for each year separately at Oregon Caves National Monument and Preserve. Humidity is averaged over hours and days. There does not appear to be much month-to-month variability, except for Beehive ceiling. The patterns are basically the same across the 4 years of data for all locations.

Section 2: Power Analysis for Annual Trends in Townsend's Big-eared Bat *(Corynorhinus townsendii)* Hibernacula Counts

Prepared by K. Irvine, PhD
Consulting Statistician for the KLMN
Montana State University

May 3, 2010

Introduction

This document investigates the power for detecting annual trends in hibernacula counts of the Townsend's Big-eared Bat. The proposed sampling design as described by Shawn Thomas of Lava Beds National Monument (LABE) is described next. Six caves were selected because they are known to contain ~85% of the known population of Townsend's Big-eared Bats (caves #1, #4, #12, #17, #25, #44). Also, 3 additional randomly selected caves (#27, #31, #40) will be monitored every year for bats. The bats will be counted each year at these caves and this analysis assumes that there is perfect detectability of bats during the counting process. Based on the targeted selection of these caves, inferring to the entire bat population across all caves in LABE is not statistically justified. Annual trends in bat counts represent only these 10–12 sampled caves; we cannot assume the same patterns hold in the unsampled caves. Given that the majority of the bats are thought to be present in these caves, this is a reasonable choice for sampling bats in LABE within budget and time constraints.

Initially the plan was to survey bats at 6 caves. In this report, therefore, we also investigate these sample sizes to determine if they represent a sufficient number for detecting annual trends in bat counts over time with the proposed sampling effort of the network.

Power Analysis for Annual Trends in Hibernacula Counts

Power is a function of the variability in bat counts (among caves and years), Type 1 error, specified magnitude of annual trend, number of years of sampling, and number of caves sampled. In this analysis we use estimated variance components from pilot data (Figures F-23 and F-24), set the Type 1 error and magnitude of annual trend, and then investigate power as a function of years and caves. The power analysis is evaluating the probability of rejecting the hypothesis of no trend when in fact there is a specified annual trend (2%, 3%, or 5%). I use a Type 1 error—the probability of detecting a trend when in fact there is no trend—of 10%, which is common for long-term monitoring objectives.

Pilot Data Used For Estimating Variance Components

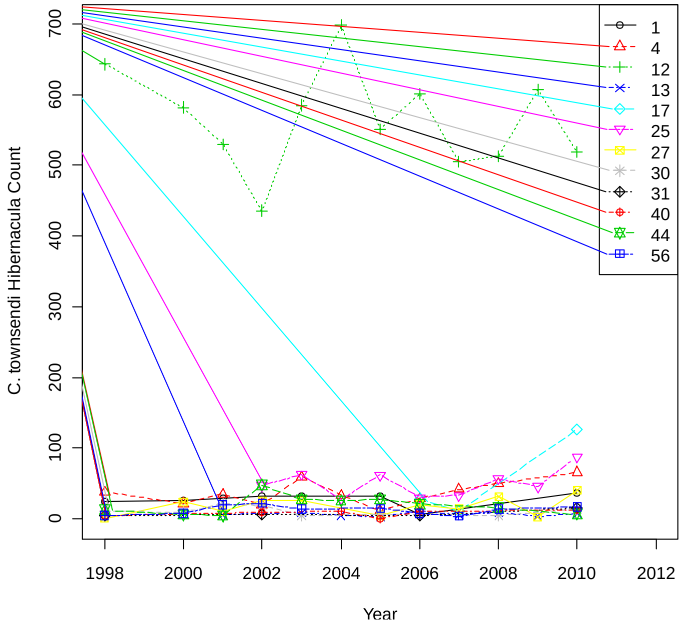


Figure F-23. Hibernacula counts for *Corynorhinus townsendii* at Lava Beds National Monument. Numbers in the legend correspond to numbered caves.

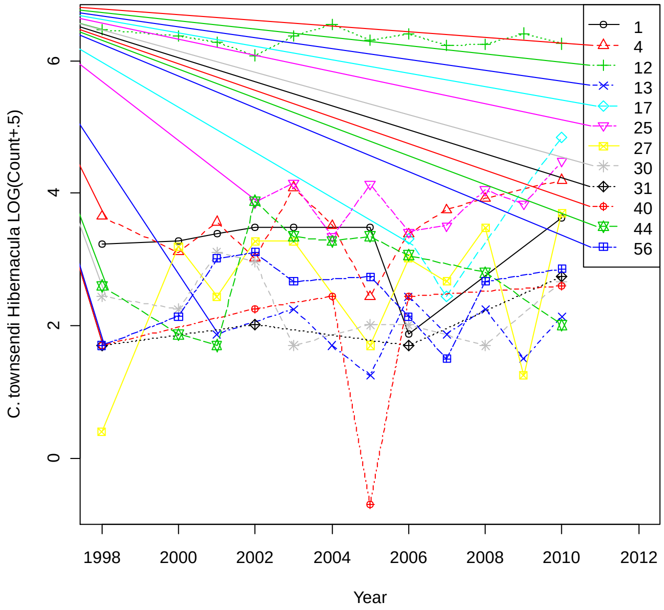


Figure F-24. Log transformed hibernacula counts for *Corynorhinus townsendii* at Lava Beds National Monument. Numbers in the legend correspond to numbered caves.

Model for Trend Analysis

In order to perform a power analysis for univariate trend, a similar model as that for the climate data in Section 1 of this appendix is assumed for the future data analysis. I adopt the linear model presented in Urquhart and Kincaid (1999), Larsen et al. (2001), Kincaid et al. (2004), and Urquhart et al. (1993). The model is as follows:

$$\log(Y_{ij} + .5) = \mu + S_i + T_j + E_{ij}$$

where Y_{ij} is the observed hibernacula count for cave i in year j, $S_i \sim N(0, \sigma^2_{CAVE})$, $T_j \sim N(0, \sigma^2_{YEAR})$, $E_{ij} \sim N(0, \sigma^2_{RESIDUAL})$,and the components are assumed independent. The counts are log-transformed because of the large counts in cave 12. A small value is added to the counts to adjust for the one zero count in 2005 at cave 40.

There have been many modifications to this general model idea that allow for varying trends for each site (Piepho and Ogutu 2002; VanLeeuwen et al. 1996). However, for computational simplicity, I used a model assuming trends over time do not vary by site. I used the functions written by Tom Kincaid to estimate power based on the model above; for specific details refer to the paper by Urquhart et al. 1993. These are *estimates* of the power because we are estimating the variance components. Fortunately, the available pilot data, although unbalanced (not every cave was sampled every year), is from those caves that are going to be sampled by either the park or the network as part of the caves long-term monitoring protocol. Therefore, the estimated variance components should be representative of both the cave-to-cave variability in counts and the temporal variation across years for the 10 or 12 caves to be sampled for Townsend's Big-eared Bats.

Results

I used the lmer function in the lme4 package in the *R* freeware statistical platform to estimate the random components of the mixed model using restricted maximum likelihood (REML). The estimated variance components are displayed in Table F-4 for log-transformed hibernacula counts. I looked at all of the caves that may be sampled if time allows and also the subset of 10 caves that will definitely be sampled each year.

Table F-4. Estimated variance components using REML for various groups of proposed caves to be sampled at Lava Beds National Monument.

Data Used	Parameter	Estimate
All Caves	σ^2_{CAVE}	1.523
	σ^2_{YEAR}	0.052
	$\sigma^2_{RESIDUAL}$	0.383
Only 10 sampled by park + network	σ^2_{CAVE}	1.748
	σ^2_{YEAR}	0.059
	$\sigma^2_{RESIDUAL}$	0.411
Six caves sampled by network	σ^2_{CAVE}	1.559
	σ^2_{YEAR}	0.007
	$\sigma^2_{RESIDUAL}$	0.289

Conclusions

Figures F-25 and F-26 suggest that to detect an annual trend of 3% in the median bat counts (with Type 1 error of 10%), 80% power is achieved after 20 years. This annual trend corresponds to a net change in the median bat count of 60% (quite large). However, Figures F-27, F-28, and F-29 suggest that reducing to only 10 or 9 caves does not significantly affect the power to detect annual trends, so much as the number of years of data collection. The power is quite sensitive to the magnitude of the year variance component; a way to increase power for detecting trends in bat counts would be to incorporate covariates that may account for this yearly variation in bat populations. The estimated power for the 6 caves that were selected to be monitored by the network is slightly higher than the power based on sampling 12 caves, even though the sample size is smaller (Figure F-30 and Figure F-26). This is not surprising because the variance component estimates based on only those 6 caves are slightly smaller (Table F-4).

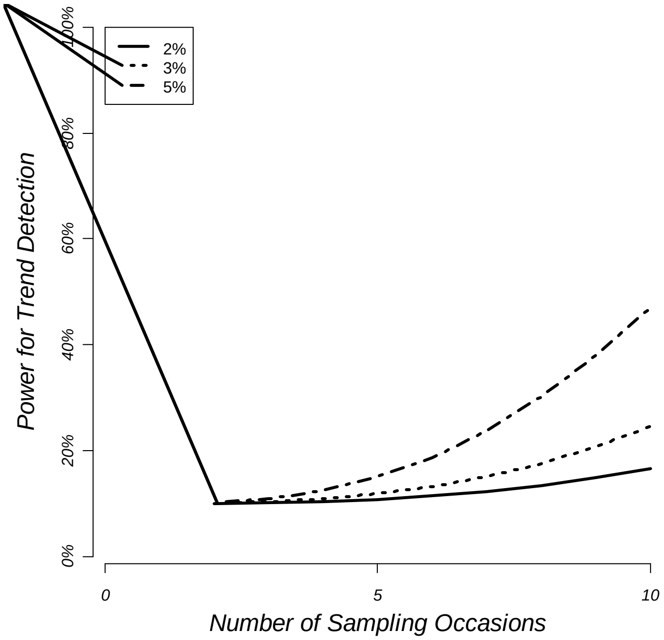


Figure F-25. Estimated power for detecting annual trends in the median log-counts of 2%, 3% and 5% for 10 years with 12 caves sampled each year using the variance components of all caves at Lava Beds National Monument.

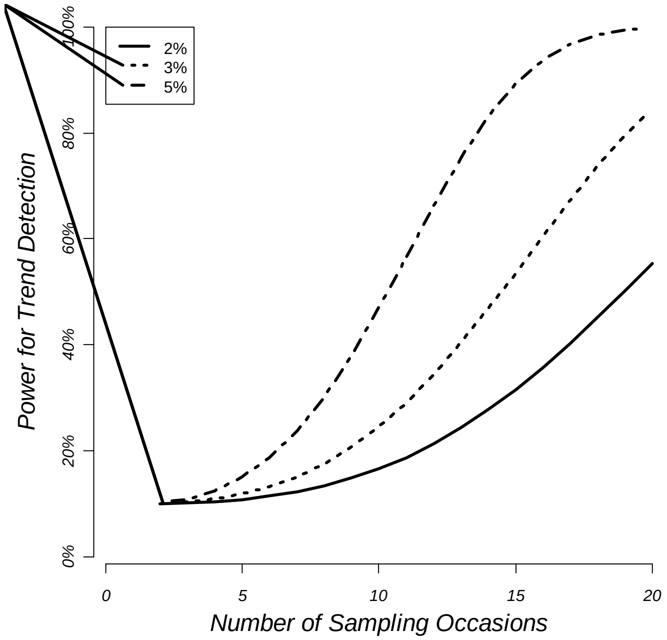


Figure F-26. Estimated power for detecting annual trends in the median log-counts of 2%, 3% and 5% for 20 years with 12 caves sampled each year using the variance components of all caves at Lava Beds National Monument.

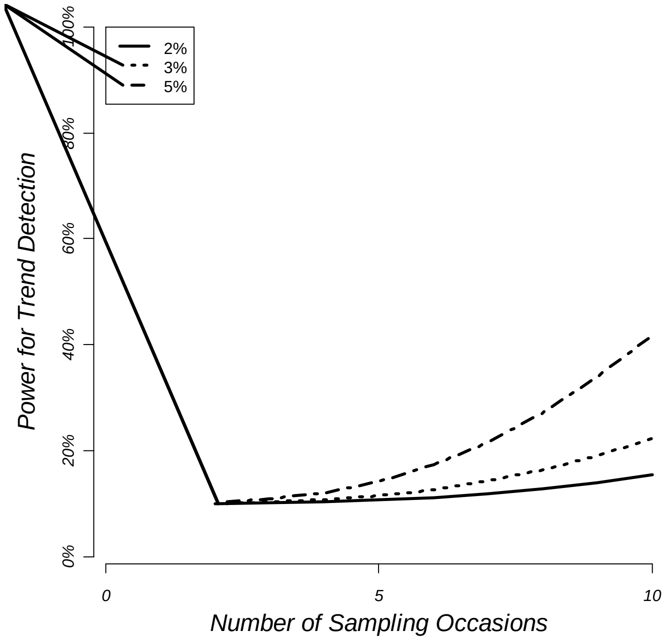


Figure F-27. Estimated power for detecting annual trends in the median log-counts of 2%, 3% and 5% for 10 years with 10 caves sampled each year using the variance components of only 10 caves at Lava Beds National Monument.

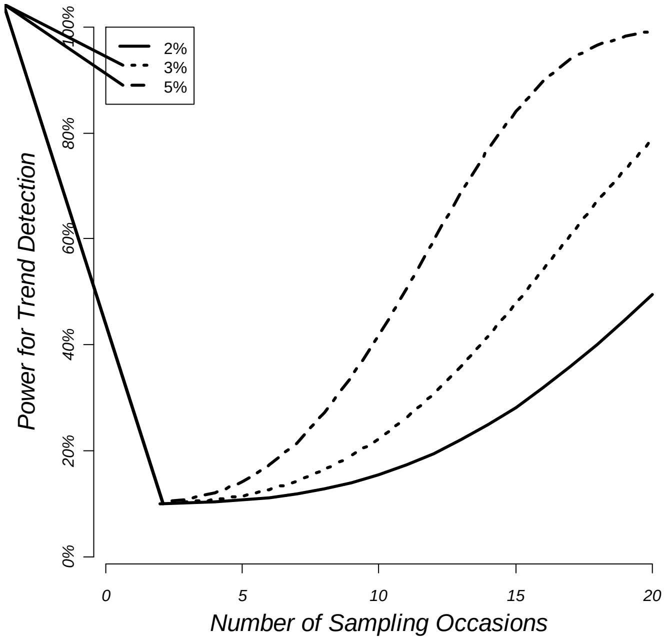


Figure F-28. Estimated power for detecting annual trends in the median log-counts of 2%, 3% and 5% for 20 years with 10 caves sampled each year using the variance components of only 10 caves at Lava Beds National Monument.

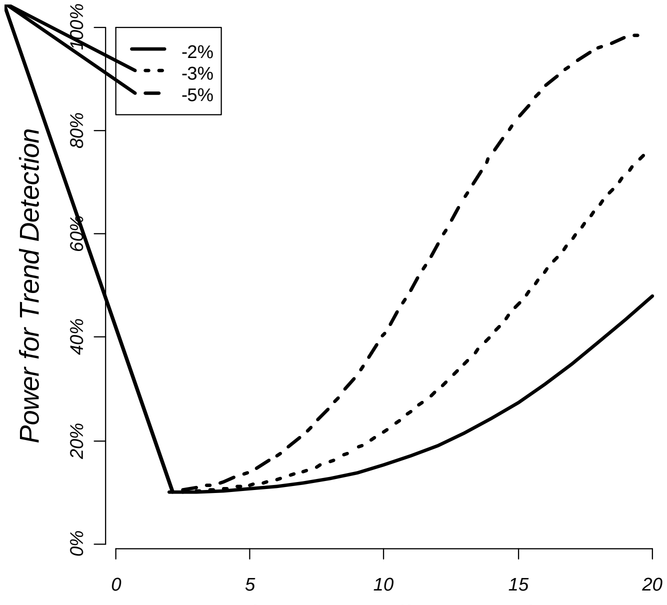


Figure F-29. Estimated power for detecting annual trends in the median log-counts of -2%,- 3% and -5% for 20 years with 9 caves sampled each year using the variance components of only 10 caves at Lava Beds National Monument.

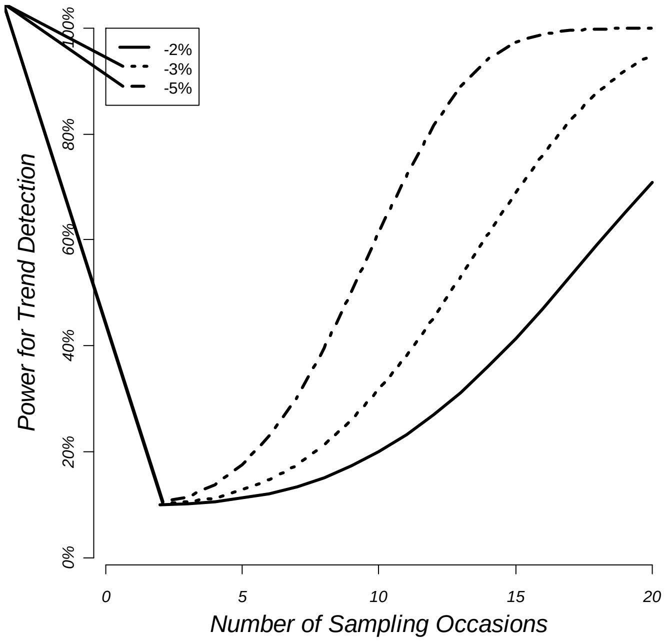


Figure F-30. Estimated power for detecting annual trends in the median log-counts of -2%,- 3% and -5% for 20 years with 6 caves sampled each year using the variance components of only those 6 caves at Lava Beds National Monument.

References

Kincaid, T. K., D. P. Larsen, and N. S. Urquhart. 2004. The structure of variations and its influence on the estimation of status: indicators of condition of lakes in Northeast, U.S.A. Environmental Monitoring and Assessment 98(12):1-21.

Larsen, D. P., T. K. Kincaid, S. E. Jacobs, and N. S. Urquhart. 2001. Designs for evaluating local and regional scale trends. Bioscience 51(12):1069-1078.

Piepho, H.-P., and J. O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. Journal of Agricultural, Biological, and Environmental Statistics 7(7):350-360.

Urquhart, N. S., and T. K. Kincaid. 1999. Designs for detecting trend from repeated surveys of ecological resources. Journal of Agricultural, Biological, and Environmental Statistics 4(4):404-414.

Urquhart, N. S., W. S. Overton, and D. S. Birkes. 1993. Comparing sampling designs for monitoring ecological status and trends: Impact of temporal patterns. Pp. 71-86 *in* V. Barnett and K. F. Turkman, eds., Statistics for the Environment. John Wiley and Sons Ltd., London.

VanLeeuwen, D. M., L. W. Murray, and N. S. Urquhart. 1996. A mixed model for both fixed and random trend components across time. Journal of Agricultural, Biological, and Environmental Statistics 1(4):435-453.

Section 3: Power Analysis for Trend Detection in Cave Parameters at Lava Beds National Monument in the Klamath Network

Prepared for:
Klamath Network

U.S. Department of the Interior
National Park Service
Southern Oregon University
1250 Siskiyou Blvd
Ashland, OR 97520

Prepared by:
Western EcoSystems Technology, Inc.*
456 SW Monroe Ave, Suite 106
Corvallis, OR 97333

June 22, 2016

*Eric Dinger, KLMN Network Aquatic Ecologist assisted in editing and minor revisions to the Vegetation and Invertebrate power analyses.

Table of Contents for Appendix F Section 3

Page

Introduction

The Klamath Network (KLMN) of the National Park Service (NPS) identified cave communities and cave environments as “Vital Signs” at Oregon Caves National Monument and Preserve (ORCA) and Lava Beds National Monument (LABE) for long-term monitoring. Several indicators for KLMN caves, such as temperature, relative humidity, invertebrate taxa richness, and vegetative complexity, will be monitored over time to determine if changes are occurring relative to stressors such as climate change, visitor impacts, and other stressors. In this report, trends in metrics collected between 2012 and 2016 are analyzed, and modeling results are used to inform a power analysis to determine if the proposed sampling design is adequate for detecting management-relevant trend detection.

The target population consists of about 120 caves within LABE (see the monitoring protocol for details on the sampling frame). Pilot data were collected from a spatially-balanced generalized random tessellation stratified (GRTS) sample of caves from an overlapping pilot sampling frame. Since cave monitoring requires substantial setup time for instrumentation, the same caves were visited every year as part of an always revisit design. Caves were divided into 4 zones for climatic measurements and invertebrate collections: deep, middle, entrance, and outer. For this analysis, the trend outcomes collected at the deep and entrance zones were of particular interest for climatic data, across the entrance, middle, and deep zones for invertebrate taxa richness, and an inner and outer zone for vegetation complexity. Zones and how they are defined are presented in greater detail in section 2.3 of the protocol narrative.

The presented power analyses for climatic data (temperature and relative humidity) mirror the proposed analyses for future trend detection. However, for both invertebrate and vegetative data, the implemented techniques for trend detection will also include non-parametric multivariate techniques (e.g., Clarke and Warwick 2001) that have been generally more sensitive than univariate techniques used here (Somerfield et al. 2002). Hence, the power estimates for invertebrates and vegetation should be seen as conservative (i.e., implemented analyses in the future are likely to be more powerful for detecting community composition change). This does not preclude future trend analysis of community univariate metrics (e.g., taxa richness, Shannon Index, etc.) as presented here as a complement to multivariate techniques.

Methods

Four main outcomes were examined: temperature, relative humidity, invertebrate taxa richness, and vegetative complexity. Temperature and relative humidity were provided as hourly measurements, so data summaries were needed to model larger-scale trends in time. Vegetative complexity was measured in 2012 and 2014 at the entrance zone at transects categorized as Inner and Outer. Invertebrate taxa richness was provided for 2014 only. A trend analysis was conducted that then informed a power analysis on tests to detect trends in each outcome.

Trend Analysis

Trend analysis for the real-valued temperature outcomes was conducted using a linear mixed model (Piepho and Ogutu 2002) with random effects for years, sites, and site-level slopes. Because relative humidity is bounded in the interval of 0% to 100%, the outcome was converted to a proportion and transformations such as the logit and arc-sine square-root functions were considered. Seasonal and cyclical effects were modeled with fixed effects for season and trigonometric functions of month, respectively. Trends over time by season were also examined. Vegetative complexity and invertebrate taxa richness were measured at the year level and did not require within-year modeling terms.

Model selection initially began by comparing the AIC values of models. Models with close AIC values were compared with likelihood-ratio tests when appropriate. Final model selection incorporated a qualitative examination of residual plots, including partial autocorrelation plots of model residuals, to assess assumptions of linear mixed models (Pinhiero and Bates 2004). For metrics collected at the monthly scale, partial autocorrelation plots often indicated some remaining temporal correlation at a few sites for the final model. Therefore, model selection focused on obtaining a broadly applicable model that accounted for the majority of serial autocorrelation.

Power Simulation

The power of a statistical hypothesis test is the probability that the null hypothesis is rejected when the alternative hypothesis is true (Cohen 1988). The power to detect trend depends on the Type I error rate (here $\alpha = 0.10$), the magnitude of the trend, and the variance of the trend estimate, which depends on the sample size of sites and the length of the monitoring period. Power analysis is used to assess the performance of a proposed test. The results of the power analysis can inform designs on the monitoring design before implementation (Sims et al. 2006).

This power analysis examined pilot data for 4 cave indicators and assessed the ability of annual samples of 20, 30, and 40 caves to detect a range of trends in cave indicators within or across cave zones over monitoring periods of either 10 or 20 years (Table F-5). For each outcome of interest, Monte Carlo simulation was used to generate random samples of data reflecting the mean and variance structure of the pilot data and exhibiting a known annual trend. The annual trend is defined as the proportional increase or decrease in the mean for each year. For example, an annual 2% decrease is represented by $p = -0.02$. The resulting net trends for each scenario are given in Table F-6.

Table F-5. Simulation scenarios to assess the power of the proposed Klamath Network cave vital signs sampling plan.

Outcome	Annual trends	Test direction	Sample size	Monitoring period
Temperature	1%, 2.5%, and 5%	One-sided test of an increase	20, 30, and 40 caves	10 years
Relative humidity	1%, 2.5%, and 5%	One-sided test of a decrease	20, 30, and 40 caves	10 years
Invertebrate taxa richness	0.5%, 1%, and 2%	Two-sided test of change in either direction	20, 30, and 40 caves	20 years
Vegetative complexity	0.5%, 1%, and 2%	Two-sided test of change in either direction	20, 30, and 40 caves	20 years

Table F-6. Annual and net trends for 2 monitoring periods (10 and 20 years). Net trend is the total change over the time period (as %) and includes the effect of increasing or decreasing per year net changes (similar to compounding interest).

Annual trend	Years	Net trend
1.0%	10	10%
2.5%	10	28%
5.0%	10	63%
-1.0%	10	-10%
-2.5%	10	-22%
-5.0%	10	-40%
0.5%	20	10%
1.0%	20	22%
2.0%	20	49%

The baseline status of each indicator was estimated as the mean of the outcome of interest in the final year of the pilot data. For each simulation, using 500 iterations each, a population was generated for a given baseline status, estimated variance composition, monitoring period length (10 or 20 years), and annual trend. For two-sided hypothesis testing, trend was randomly assigned in each iteration of the power simulation to be increasing or decreasing. For each simulated population, samples of specified sizes were randomly selected and the appropriate trend test, as identified in the trend analysis, was conducted.

Trend tests were conducted at the $\alpha = 0.10$ level. Trend test size and test power were assessed in the power simulation. Test size was obtained as the proportion of iterations for which the null hypothesis of no trend was rejected at the 0.10 level when no trend was simulated. Similarly, test power was estimated by the proportion of iterations for which the null hypothesis was rejected when a non-zero trend was simulated.

Results

Trend Analysis

Temperature was summarized in 2 different ways. For months in which at least 112 measurements were collected (for an average of 4 daily measurements over 28 days), the mean of each daily temperature range (maximum temperature minus the minimum temperature) was calculated for the month. Additionally, the monthly mean temperature and monthly mean relative humidity were computed as outcomes of interest. Trends in monthly mean temperature (Figure F-31), monthly mean temperature range (Figure F-32), and monthly mean relative humidity (Figure F-33), are examined for deep and entrance zones from data collected from 2012 through early 2016. The mean structure of taxa richness of invertebrates (Figure F-34) observed in caves during the 2014 survey is examined. Change from 2012 to 2014 in the vegetative complexity (Figure F-35) as measured by counts of vegetation taxa and a classification for bare ground is also estimated.

Mean and variance structures were modeled for KLMN caves temperature, relative humidity, invertebrates, and vegetation metrics. When more than 1 year of data were available, trend was estimated as part of the mean structure. The variety of data types and correlation structures in this monitoring dataset required a range of modeling approaches. Table F-7 provides the modeling results for all outcomes of interest.

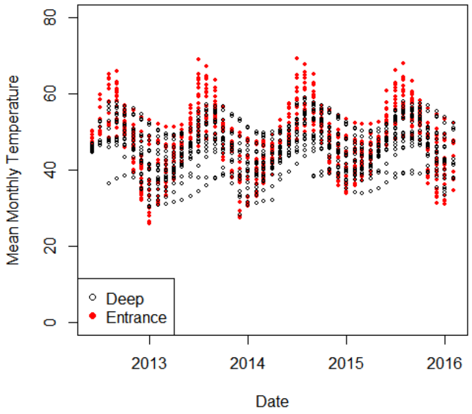


Figure F-31. Mean monthly temperature by zone, 2012–2016.

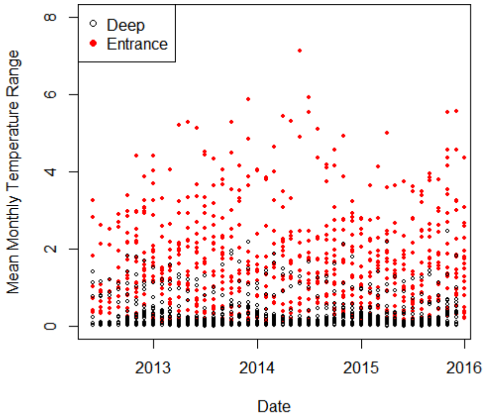


Figure F-32. Mean monthly temperature range by zone, 2012–2016.

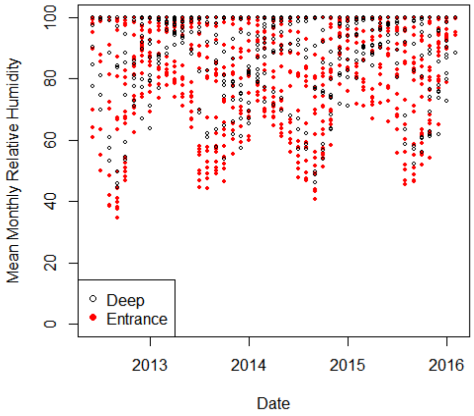


Figure F-33. Mean monthly relative humidity by zone, 2012–2016.

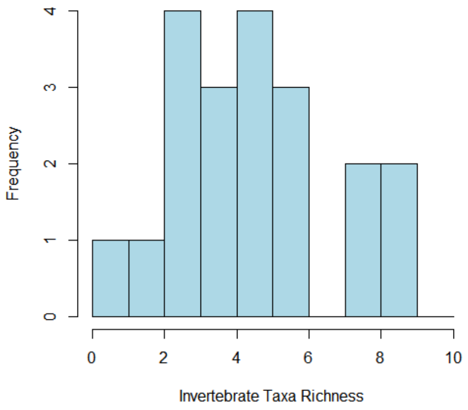


Figure F-34. Histogram of 2014 invertebrate richness at the cave level across zones.

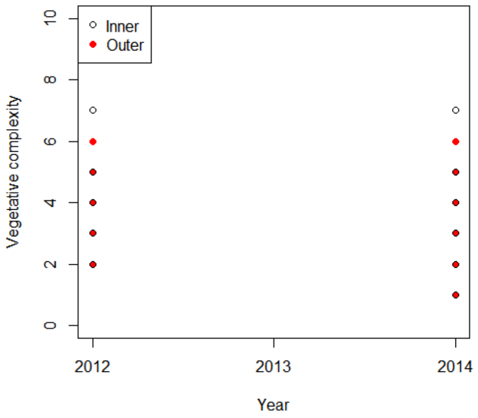


Figure F-35. Vegetative complexity, 2012 and 2014.

Table F-7. Modeling approaches and results of trend analyses for Klamath Network cave vital signs.

Metric	Zone	Model	Intercept (SE)	Trend (SE)	Other Effects	Cave-to-Cave Variation	Variation among Cave-level slopes	Covariance of Cave intercept and slope	Year-to-Year Variation	Residual Variance
Mean monthly temperature range	Deep	LMM of logged outcome	-1.9059 (0.2613)	-0.0045 (0.0395)	cos(Month*π/6): 0.3088 (0.0266)	1.2521	0.0009	-0.0341	0.0055	0.2644
	Entrance	LMM of logged outcome	0.1733 (0.2076)	0.0233 (0.0225)	Spring: -0.1216 (0.0658) Summer: -0.1105 (0.0468) Winter: -0.1643 (0.0797) sin(Month*π/6): -0.0940 (0.0532)	0.8104	0.0028	-0.0080	0.0009	0.1819
Mean monthly temperature	Deep	LMM of logged outcome	3.7803 (0.0274)	0.0043 (0.0062)	Spring: 0.0365 (0. 0103) Summer: 0.0355 (0.0073) Winter: 0.0105 (0.0126) sin(Month*π/6): -0.0978 (0.0083)	0.0106	0.000001	-0.0001	0.0003	0.0048
	Entrance	LMM of logged outcome	3.7610 (0.0457)	-0.0187 (0.0183)	Spring: 0.1774 (0. 0214) Summer: 0.1735 (0.01583) Winter: 0.0002 (0.0268) sin(Month*π/6): -0.1652 (0.0110) Spring*WYear: 0.0024 (0. 0095) Summer*WYear: -0.0069 (0.0079) Winter*WYear: 0.0371 (0.0107)	0.0050	0.000014	0.0003	0.0028	0.0079
Mean monthly relative humidity	Deep	LMM of arcsine-square-root of outcome	1.3986 (0.0519)	0.0078 (0.0095)	Spring: 0.0246 (0. 0266) Summer: -0.0085 (0.0216) Winter: 0.0369 (0.0136) cos(Month*π/6): -0.0532 (0.0148)	0.0441	0.0004	-0.0031	0.0004	0.0147
	Entrance	LMM of arcsine-square-root of outcome	1.2274 (0.0683)	0.0245 (0.0182)	Spring: -0.0804 (0.0181) Summer: -0.0475 (0.0127) Winter: -0.0746 (0.0222) sin(Month*π/6): 0.1792 (0.0146)	0.0592	0.0008	-0.0059	0.0026	0.0140
Invertebrate Taxa Richness	Across Zones	Poisson GLM	1.5994 (0.1005)	NA		NA	NA	NA	NA	NA
Vegetative Complexity	Inner and Outer	Zero-truncated Poisson GLM	1.0621 (0.1459)	-0.0417 (0.0773)	Outer: 0.4246 (0.1595)	NA	NA	NA	NA	NA

Temperature

Temperature was summarized in 2 different ways: 1) a mean monthly temperature was calculated as the mean of all hourly temperature measurements collected within a month, and 2) a mean monthly temperature range was calculated as the monthly mean of the maximum daily temperature minus the minimum daily temperature. Monthly measurements obtained from fewer than 112 observations (requiring an average of at least 4 daily measurements for at least 28 days) or more than 744 readings (24 per day for 31 days) were omitted from the analysis. Linear mixed models with random effects for year-to-year variation, cave-to-cave variation, and variation among cave-level trend slopes (Piepho and Ogutu 2002) were used to model trend and partition variation.

For the deep zone, the logarithmically-transformed mean of the monthly temperature range was modeled as a function of the year and a cosine function of the month to account for cyclical within-year effects. No significant trend in the logged mean monthly temperature range was detected for the monitoring period (slope = -0.0045, SE = 0.0395, df = 2.2, p = 0.9190). The logged monthly temperature range in the entrance zone was also modeled as a function of the year, a sine function of the month, and season-level effects. No significant trend in the logged mean monthly temperature range was detected for the monitoring period (slope = 0.0233, SE = 0.0225, df = 6.1, p = 0.3394).

The logged mean monthly temperature metric was also analyzed with a linear mixed model. For the deep zone, the final model included fixed effects for year, a sine function of the month, and season. No significant trend in the logged mean monthly temperature in the deep zone was detected for the monitoring period (slope = 0.0043, SE = 0.0062, df = 3.9, p = 0.5288). The same terms were included in the final model for logged mean monthly temperature in the entrance zone. No significant trend was detected for this outcome (slope = -0.0187, SE = 0.0183, df = 3.5, p = 0.3727).

Relative Humidity

Mean monthly relative humidity was calculated as the mean of all hourly relative humidity measurements collected within a month. Monthly measurements obtained from fewer than 112 observations (requiring an average of at least 4 daily measurements for at least 28 days) or more than 744 readings (24 per day for 31 days) were omitted from the analysis.

In theory, the mean monthly relative humidity ranges from 0 to 100%. Neither a logit transformation nor a beta regression model could be used because values of 100% were common in this dataset. The data are not binomial trials, so a binomial GLMM was also inappropriate. The relative humidity means were divided by 100 to obtain a proportion-like response and were then transformed with the arc-sine square-root function to obtain a real-valued outcome suitable for analysis with a linear mixed model. Fixed effects for year and season were incorporated as well as trigonometric functions of monthly measurements to account for seasonal variation.

The final model of the log-transformed mean of the monthly relative humidity range in the deep zone included fixed effects for year, season, and a cosine function of the month for cyclical effects. No significant trend in the logged mean monthly relative humidity range was detected for the period of data collection (slope = 0.0078, SE = 0.0095, df = 6.7, p = 0.4388). The logged monthly relative humidity range in the entrance zone was also modeled as a function of the year, a sine function of the month, and season-level effects. No significant trend in the logged mean monthly relative humidity range was detected for the period of data collection (slope = 0.0245, SE = 0.0182, df = 4.3, p = 0.2460).

Invertebrate Taxa Richness

Invertebrate taxa richness was measured at the zone level within each cave during 2014. Since only 1 year of data was available for this metric, trend cannot be estimated. However, the mean structure and within year variation can be examined. Invertebrate taxa richness, a count variable, was first examined with a Poisson GLMM. A fixed zone effect and a random cave effect were included in the original model but a chi-square test indicated that the zone effect could be dropped from the model (χ^2 = 1.811, df = 2, p-value = 0.4043). The overall mean of zone-level taxa richness reflects the mean number of taxa observed within a zone rather than the total number of taxa observed at each cave, so cave-level taxa richness across zones was calculated and modeled. Random effects were inestimable for this data set, so a Poison GLM was used to model invertebrate taxa richness. Since only 1 year of data was available and cave-level taxa richness was calculated across zones, the model contains only a single intercept representing the mean number of taxa across caves.

Vegetative Complexity

The vegetation metric examined in this trend analysis is a measure of vegetative complexity. Similar to taxa richness, this metric also includes several different substrate classifications used for sites with no vegetation. The different types of substrate classes defining areas with no vegetation were not collected during all years and were therefore combined into a single bare ground class for this analysis. Note that this vegetative complexity metric cannot take the value of 0, since any vegetation or lack of vegetation will be classified into a grouping that contributes to the calculation of the metric.

Because only 2 years of data were available, only the caves visited in both years were used for the trend analysis. Standard Poisson and negative binomial trend models were considered, but the residual diagnostics indicated poor fits. A zero-truncated Poisson model (Coleman and James 1961) better accounted for the absence of zero counts in the vegetative complexity method as indicated by residual diagnostics and information criteria comparisons. Modeling both zones in the same model resulted in similar but more precise estimates of the zone-level outcomes. Zone-level trends were not significantly different (z = 0.380, p-value = 0.7038) and trend was not significant for either the inner zone (z = -0.630, p-value = 0.5290), the outer zone (z = -0.0190, p-value = 0.8450), or across zones in the final model (z = -0.0417, p-value = 0.5892).

Power Simulation

The power simulation was used to examine both test size and test power. The trend test size was estimated as the proportion of times the null hypothesis of no trend was erroneously rejected (Table F-8). Near-nominal trend test size of 0.10 was attained for almost all of the outcomes of interest. The exceptions are the trend tests for the vegetative complexity outcome, which are derived from the results of the truncated Poisson model. The lower-than-nominal trend test sizes values indicate that the trend test identified that no trend was present more frequently than specified, so power may be lower for these tests than if nominal test size was achieved.

Table F-**8.** Trend test size for 4 outcomes of interest (for tests conducted at α = 0.10).

		Sample size of caves		
Outcome	**Zone**	**20**	**30**	**40**
Mean Monthly Temperature	Deep	0.11	0.12	0.12
	Entrance	0.10	0.10	0.10
Mean Monthly Temperature Range	Deep	0.12	0.09	0.12
	Entrance	0.07	0.11	0.09
Mean Monthly Relative Humidity	Deep	0.07	0.10	0.08
	Entrance	0.09	0.11	0.09
Vegetative Complexity	Inner	0.07	0.07	0.08
	Outer	0.06	0.06	0.05
Invertebrate Taxa Richness	All	0.09	0.09	0.11

The results of the power analysis are provided in Table F-9 and Figures F-36 through F-44. Power for detecting increasing trends in monthly mean temperature in the deep zone with a one-sided test for an increase was perfect for all sample sizes and trends examined (Figure F-36). For the entrance zone, power was consistently measured as 1 for all scenarios, except for a trend of 1% per year (Figure F-37). Note that increasing the number of caves visited each year did not impact the power to detect trends in mean monthly temperature as much as the magnitude of the trend.

Power to detect increasing trends in the monthly mean temperature range in the deep zone of KLMN caves achieved at least 0.8 for trends of 2.5% and 5% (Figure F-38). Similar results were obtained for the entrance zone but power was slightly lower than 0.8 for sample sizes of 20 caves and increasing annual trend of 2.5% over 10 years (Figure F-39). Decreasing trends in monthly mean relative humidity were uniformly 1 for one-sided trend tests for the deep zone (Figure F-40) and greater than 0.8 for the entrance zone for annual trends of 2.5% and 5% (Figure F-41).

The power to detect trends in either direction over a 20-year monitoring period was examined for the vegetative complexity variable and for invertebrate taxa richness. Power of close to 0.8 (0.60 for inner, 0.77 for outer) was obtained for annual samples of at least 30 caves when vegetative complexity in the inner zone changed by 2% annually over a 20-year period (Figure F-42). Adequate power was achieved for a sample of size of 20 caves per year for 2% annual trends in vegetative complexity in the outer zone (Figure F-43). The power to detect trends in either direction for invertebrate taxa richness exceeded 0.9 for annual trends of 2% for all sample sizes of caves (Figure F-44).

Table F-9. Power to detect trends at the 0.10 level for Klamath Network cave indicators for a range of sample sizes, monitoring periods, and annual trends**,** where p is the simulated rate of annual change (e.g., p of 0.010 equivalent to 1% annual change).

			Sample size of caves		
Outcome	**Zone**	**p**	**20**	**30**	**40**
Mean Monthly Temperature	Deep	0.010	1.00	1.00	1.00
	Deep	0.025	1.00	1.00	1.00
	Deep	0.050	1.00	1.00	1.00
	Entrance	0.010	0.68	0.67	0.69
	Entrance	0.025	1.00	1.00	1.00
	Entrance	0.050	1.00	1.00	1.00
Mean Monthly Temperature Range	Deep	0.010	0.37	0.33	0.37
	Deep	0.025	0.82	0.86	0.87
	Deep	0.050	1.00	1.00	1.00
	Entrance	0.010	0.33	0.36	0.40
	Entrance	0.025	0.72	0.82	0.90
	Entrance	0.050	1.00	1.00	1.00
Mean Monthly Relative Humidity	Deep	0.010	1.00	0.99	1.00
	Deep	0.025	1.00	1.00	1.00
	Deep	0.050	1.00	1.00	1.00
	Entrance	0.010	0.59	0.65	0.70
	Entrance	0.025	0.96	0.98	0.99
	Entrance	0.050	1.00	1.00	1.00
Vegetative Complexity	Inner	0.005	0.10	0.11	0.14
	Inner	0.010	0.16	0.21	0.25
	Inner	0.020	0.51	0.60	0.73
	Outer	0.005	0.11	0.12	0.16
	Outer	0.010	0.24	0.30	0.38
	Outer	0.020	0.60	0.77	0.88
Invertebrate Taxa Richness	All	0.005	0.22	0.32	0.36
	All	0.010	0.56	0.73	0.81
	All	0.020	0.98	1.00	1.00

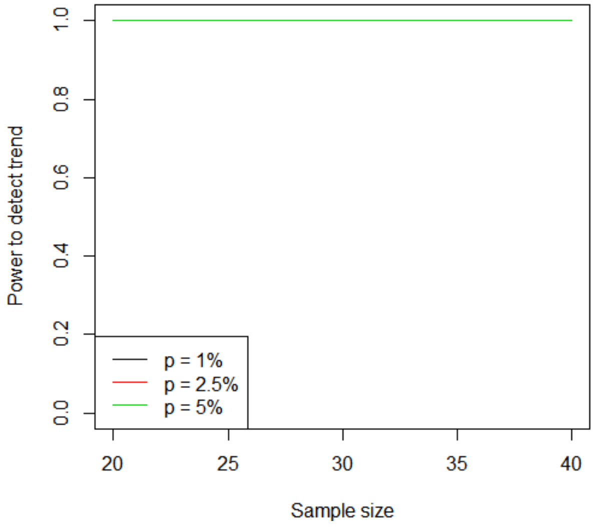


Figure F-**36.** Power to detect 1%, 2.5%, and 5% annual increasing trends in mean monthly temperatures in the deep zone of Klamath Network caves over a 10-year monitoring period with a one-sided test at the 0.10 level.

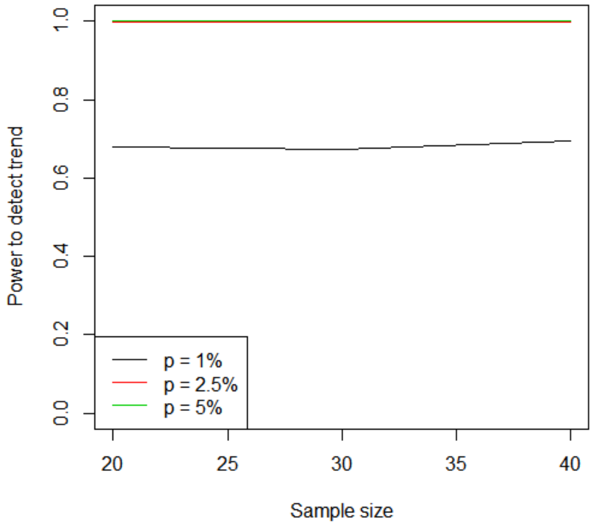


Figure F-**37.** Power to detect 1%, 2.5%, and 5% annual increasing trends in mean monthly temperatures in the entrance zone of Klamath Network caves over a 10-year monitoring period with a one-sided test at the 0.10 level.

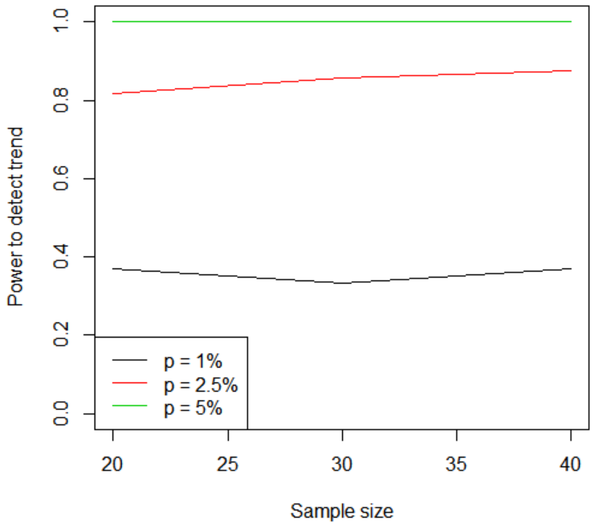


Figure F-**38.** Power to detect 1%, 2.5%, and 5% annual increasing trends in mean monthly temperature ranges in the deep zone of Klamath Network caves over a 10-year monitoring period with a one-sided test at the 0.10 level.

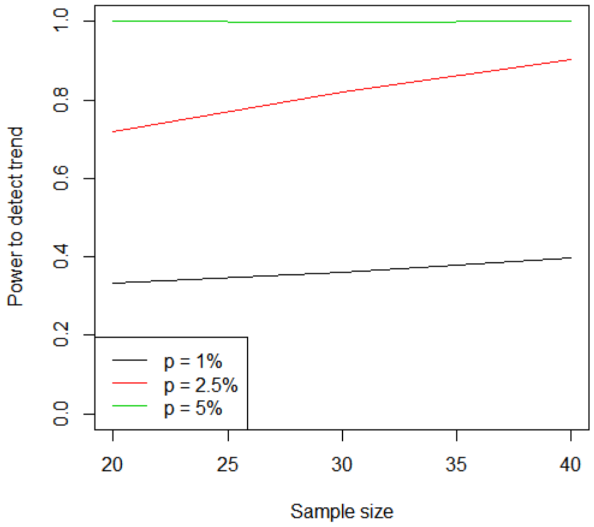


Figure F-39. Power to detect 1%, 2.5%, and 5% annual increasing trends in mean monthly temperature ranges in the entrance zone of Klamath Network caves over a 10-year monitoring period with a one-sided test at the 0.10 level.

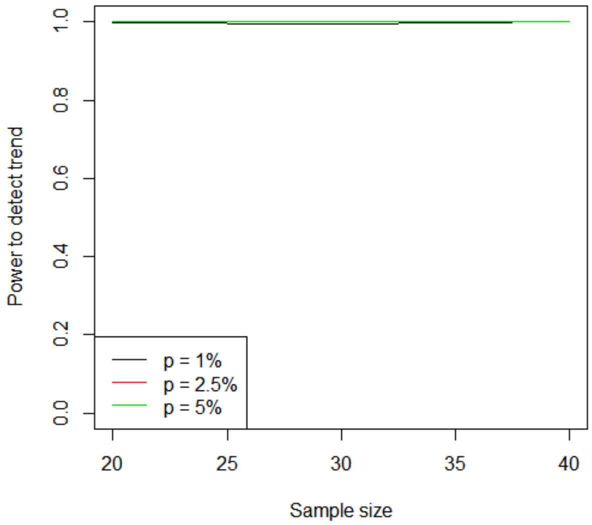


Figure F-**40.** Power to detect 1%, 2.5%, and 5% annual decreasing trends in mean monthly relative humidity in the deep zone of Klamath Network caves over a 10-year monitoring period with a one-sided test at the 0.10 level.

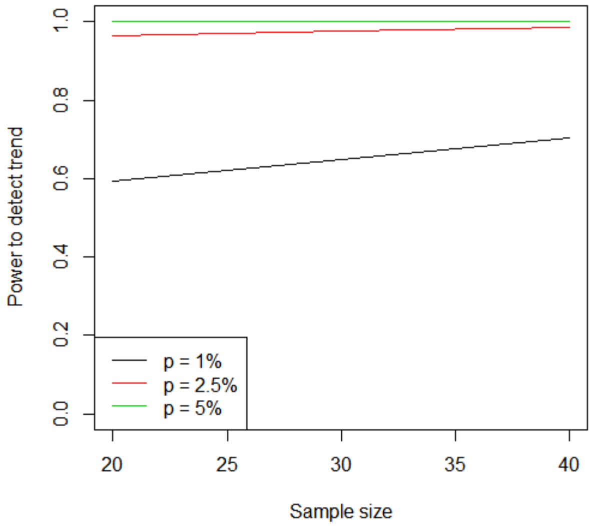


Figure F-41. Power to detect 1%, 2.5%, and 5% annual decreasing trends in mean monthly relative humidity in the entrance zone of Klamath Network caves over a 10-year monitoring period with a one-sided test at the 0.10 level.

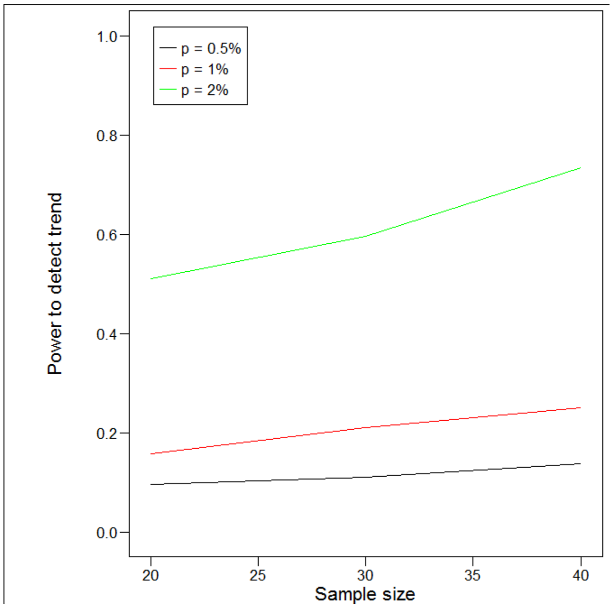


Figure F-**42.** Power to detect 0.5%, 1%, and 2% annual increasing trends in vegetative complexity in the inner zone of Klamath Network caves over a 20-year monitoring period with a two-sided test at the 0.10 level.

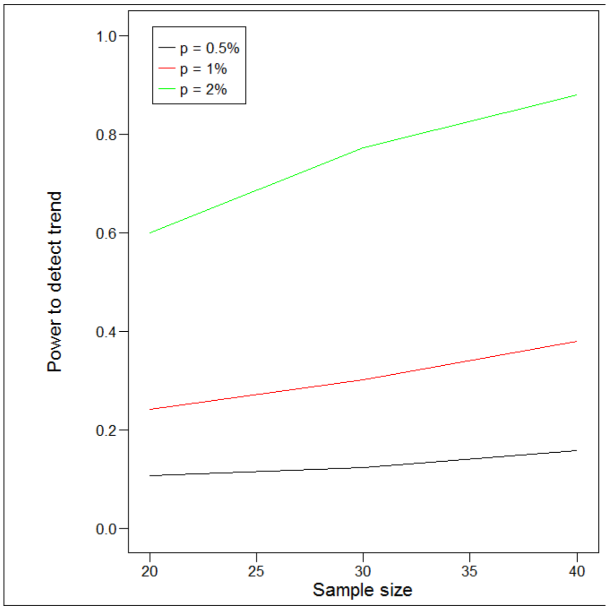


Figure F-43. Power to detect 0.5%, 1%, and 2% annual increasing trends in vegetative complexity in the outer zone of Klamath Network caves over a 20-year monitoring period with a two-sided test at the 0.10 level.

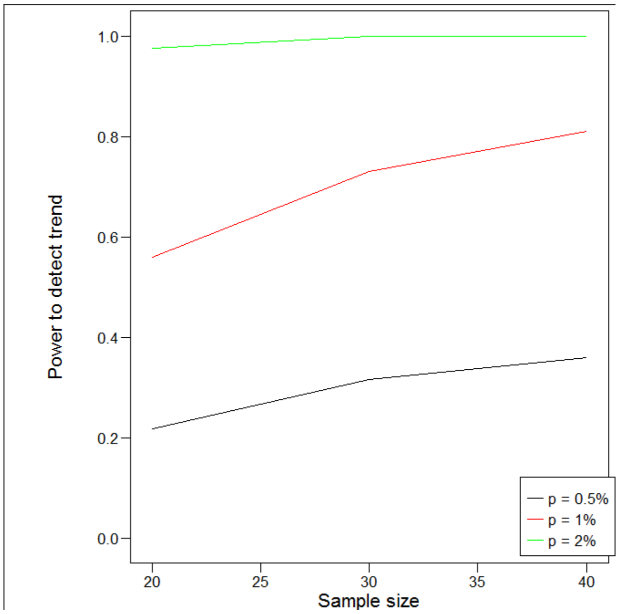


Figure F-**44**. Power to detect 0.5%, 1%, and 2% annual increasing trends in cave-level invertebrate taxa richness of Klamath Network caves over a 20-year monitoring period with a two-sided test at the 0.10 level.

Discussion

A power analysis based on results from trend analyses of KLMN cave indicators from Lava Beds National Monument was used to assess the annual sample size of caves. The results of the power analysis indicated that annual trends in temperature and relative humidity outcomes of at least 2.5% may be detected for all indicators with at least 0.8 power for annual samples of 20 caves with one-sided trend tests, except for mean monthly temperature range in the entrance zone. For mean monthly temperature range in the entrance zone, adequate power to detect a 2.5% annual trend was achieved with an annual sample of 30 caves.

Two-sided trend test power of 0.6 (inner) and 0.77 (outer) or more was obtained for the vegetative complexity indicators in inner and outer zones only when a 2% annual trend was exhibited by the population over a 20-year monitoring period at a 30 cave sample size. Two-sided trend tests of cave-level invertebrate taxa richness achieved 0.8 power for annual samples of at least 20 caves when the population changed at least 2% annually.

Note that the power analysis results for invertebrate taxa richness and vegetative complexity are based on 1 and 2 years of data, respectively. The power analysis should be revised when more years of monitoring data are available and the variance composition of each outcome can be accurately estimated to determine its impact on the power to detect trend. Given the results of this power analysis for this suite of KLMN cave indicators, annual sample sizes of at least 30 caves are recommended. Consistent annual surveys of 30 caves per sampling period (currently planned for every 2 years) for the invertebrate taxa richness and vegetative complexity indicators will provide a more robust basis for a revised power analysis to determine if sample sizes are adequate for these outcomes.

References

Bates D., M. Maechler, B. Bolker, and S. Walker. 2014. lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-7, URL: http://CRAN.R-project.org/package=lme4.

Clarke, K. R., and R. M. Warwick. 2001. Changes in marine communities: An approach to statistical analysis and interpretation, 2nd edition. Primer-e, Plymouth, UK.

Cohen, J. 1988. Statistical Power Analysis for the Behavioral Sciences, 2nd edition. Lawrence Erlbaum Associates, New Jersey.

Coleman, J. S., and J. James. 1961. The equilibrium size distribution of freely-forming groups. Sociometry 24:36-45.

Piepho, H. P., and J. O. Ogutu. 2002. A simple mixed model for trend analysis in wildlife populations. Journal of Agricultural, Biological, and Environmental Statistics 7(3):350-360.

Pinheiro, J. C., and D.M. Bates. 2004. Mixed-Effects Models in S and S-PLUS. Springer, New York.

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Sims, M., S. Wanless, M. P. Harris, P. I. Mitchell, and D. A. Elston. 2006. Evaluating the power of monitoring plot designs for detecting long-term trends in the numbers of common guillemots. Journal of Applied Ecology 43:537-546.

Somerfield, P. J., K. R. Clarke, and F. Olsgard. 2002. A comparison of the power of categorical and correlational tests applied to community ecology data from gradient studies. Journal of Animal Ecology 71:581-593.

NPS 963/136789, March 2017

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov

EXPERIENCE YOUR AMERICA ™