SECTION 1. ADMINISTRATIVE INFORMATION

Name and contact information of the award recipient: Skylar Hopkins (srhopkin@ncsu.edu)
Agency or Institution of the recipient: North Carolina State University (with subaward to University of Alabama in Huntsville)
Project title: Assessing patterns of subterranean biodiversity and microclimates to inform cave management and conservation
Agreement number: SE CASC Project Number 061
Date of the report: 11/26/25
Period of time covered by the report: 8/1/22 - 7/31/25
Actual total cost of the project: $320,000

SECTION 2. PUBLIC SUMMARY

The Southeastern United States has vast underground ecosystems that provide valuable services to people, such as recreational opportunities, tourism revenue, and groundwater storage. Caves also provide habitats for unique, important, and endangered species, like bats that eat mosquitoes and crop pests. Many cave-dwelling species have evolved to live in relatively stable conditions, because cave climates stay cool and humid year-round. These animals are especially vulnerable to changes in temperature or precipitation patterns. Yet cave ecosystems remain poorly studied, leaving managers without the necessary information to protect these environments.

This project brought together more than 70 managers and scientists from federal, state, non-profit, and private organizations to improve our understanding of Southeastern cave ecosystems. Working across seven states, we collected novel microclimate data from 43 caves and conducted biodiversity surveys in 47 caves. These efforts revealed previously unknown populations of rare and threatened species and provided managers with important baseline data needed to track changes over time.

Our findings show that cave temperatures do not simply match regional climate patterns. Instead, they are shaped by a combination of factors—including cave entrance size, airflow, elevation, and the amount of forest cover above the cave. Caves with similar surface temperatures often had different internal climates, underscoring how sensitive underground environments are to local conditions and management decisions.

Alongside new field data, we completed a systematic review of 178 scientific publications to identify all known factors that influence cave climates, including management actions. This information is now being used to build a practical "management toolbox" to help managers conserve cave ecosystems and prepare them for future climate change. Together, these efforts provide the most comprehensive evaluation to date of how caves in the Southeastern United States function and how they can be protected for future generations.

SECTION 3. PROJECT SUMMARY

Cave and karst ecosystems in the Southeastern United States support high biodiversity and provide important ecological and societal services. Yet managers lack the climate and biological data needed to predict how these systems will respond to accelerating climate change and take necessary action. To address this gap, we collaborated with partners from 19 federal, state, non-governmental, and private organizations to implement a coordinated, multi-state assessment of cave microclimates, biodiversity, and management strategies. We structured the project around three objectives: (1) identify high-priority caves; (2) quantify how forest cover mediates cave microclimates; and (3) synthesize and evaluate management actions that may enhance cave ecosystem resilience.

Using stratified random sampling across gradients of latitude and forest cover, we selected 56 caves for microclimate monitoring and 28 for systematic biosurveys. Between June 2023 and February 2024, we deployed standardized logger arrays in surface, twilight, and dark zones, recording temperature and humidity at high temporal resolution. Despite substantial logger loss from flooding, vandalism, rodent damage and theft, and access restrictions, we retrieved multi-month datasets from 22 surface loggers, 28 twilight loggers, and 40 dark-zone psychrometers, with additional retrievals planned in early 2026. We also completed biodiversity surveys in 47 caves, documenting numerous previously unrecorded taxa, including rare and conservation-relevant species.

Preliminary analyses confirm expected patterns—e.g., temperature variability declines with distance from the entrance—while also showing substantial unexplained variation among caves with similar surface climates. These results indicate that cave entrance morphology, airflow, elevation, and forest cover interact to shape subterranean microclimates in ways not predictable from regional mean annual surface temperature alone. Final analyses will quantify the relative importance of these factors and the degree to which forest cover buffers internal cave temperatures.

To identify actionable management strategies, we conducted a systematic review of 1,617 abstracts and extracted data from 178 papers that evaluated drivers of cave microclimates. The literature strongly emphasizes temperature and humidity, with limited attention to extremes (freezing, drought) and minimal experimental tests of management actions. Combining partner expertise, newly collected datasets, and insights from the literature review, we developed a comprehensive "management toolbox" that outlines potential management interventions, their hypothesized mechanisms, evidence base, and implementation considerations.

This coordinated effort produced the first region-wide microclimate and biodiversity baselines for many high-priority caves in the Southeastern U.S. These datasets are already informing partner management decisions, providing pre-construction baselines, identifying new conservation targets, and enabling adaptive monitoring. Upcoming analyses will directly link forest cover and cave morphology to microclimate regimes and biodiversity patterns, and will culminate in peer-reviewed publications and partner-specific guidance documents.

SECTION 4. REPORT BODY

Purpose and Objectives:

Cave and karst ecosystems are ecologically, economically, and culturally important: they provide habitat for many species, act as CO_2 sinks, influence groundwater availability and quality, and provide cultural and recreational opportunities. These services might be threatened by climate change, but karst ecosystems are understudied, and data limitations complicate predictions and decision-making. For example, in an informal survey of cave managers in the Southeastern U.S. completed before our project, 100% self-reported having limited data on the historical or current microclimates and biodiversity patterns in the caves they manage; limited knowledge regarding how climate change might impact their caves; and uncertainty regarding which cave management strategies might create climate resilience. Given that the Southeastern U.S. is a subterranean biodiversity hotspot with a large stakeholder community, it is imperative that managers have a climate resilience toolbox (Fig. 1). Therefore, we originally proposed to collaborate with federal, state, and non-governmental organizations throughout the Southeastern U.S. to create and evaluate a portfolio of management options for improving cave ecosystem resilience during future climate change. We divided this task into three research objectives with immediate management implications: (Objective 1) Identify high priority caves; (Objective 2) quantify how much forest cover mediates microclimates; and (Objective 3) create a management toolbox. We have successfully completed data collection for all three objectives and expect to publish full analyses and results in 2026.

Organization and Approach:

Objective 1. Identify high priority caves

Site Selection:

A diverse community of managers and landowners oversee cave conservation in the Southeastern United States, which benefits an even broader and more diverse community of stakeholders. Our first project activity was to identify representatives from all management and stakeholder groups from across the region who would be willing to share their expertise, data, and/or caves with the project. We invited as many people as possible to participate, ranging from managers/owners of a single cave to managers/owners of hundreds of caves. This included managers/owners (hereafter “partners”) from federal and state governments, non-governmental organizations, and private properties (Table 1 in Management Applications). Over the course of the three-year project, we added some new partners and some original partners left the group due to career changes, but we estimate that at least 19 partner organizations and at least 72 individual partners were involved at some point in the project.

Given available time and funding, we estimated that we could include up to 60 caves in our study for microclimate monitoring, including visiting half of those caves for biodiversity surveys. To select these 60 caves from among the thousands of caves managed/owned by our partners across seven states (Figure 1), we first asked all partners to provide us with a list of caves that we could potentially include in our study, and designate any caves that were high priorities for them (e.g., those with data gaps, those with threatened species, those with ongoing or upcoming management actions). This resulted in a list of 285 caves that were potentially accessible for the study. Using this list, we performed stratified random sampling to select 60 caves that covered the full range of latitudes (~34–38) and forest cover (low < 60%, medium: 60–80%, and high > 80% forest cover) in the dataset. We examined the final list of 60 caves with each partner. If we could swab one of their low priority caves for a high priority cave with the same latitude and forest cover, we did. We also balanced the inclusion of partners who manage/own relatively few caves with partners who manage/own many caves—and thus had more caves randomly selected—by swapping some low priority caves from some partners with high priority caves from other partners, as long as the latitude and forest cover categories were the same. Finally, we randomly assigned the caves to those that would or would not receive biosurveys, excluding any caves where access was highly restricted due to endangered bats. From this initial list, a few caves had to later be removed from the study due to changes in landownership or access, resulting in a total of 56 caves included for microclimate monitoring and 28 caves included for biosurveys.

Figure 1. A map of the 56 caves that were included based on stratified random sampling, including 28 "logger only" caves (blue) and 28 biosurvey caves (orange).

Microclimate monitoring:
We deployed microclimate loggers in the 56 caves between June 2023 and February 2024, depending on access restrictions and partner availability. At the start of each trip, we measured the height and width of the cave entrance, because entrance size affects airflow and microclimates. We quantified wind speed at the entrance using a Btmeter BT-100 Digital Handheld Anemometer and measured surface temperature and surface relative humidity using a Protmex PT618 Temperature Humidity Meter (±1.5ºC, ±4.0% RH). We then placed one HOBO Pendant MX Temperature Logger (±0.5ºC) on the ground outside the cave entrance, positioning it away from direct sunlight and out of view of visitors, but still exposed to unrestricted surface air (i.e., not buried or covered). We programmed this logger to record outside air temperature every hour.

Inside the cave, we measured the length of the twilight zone from the entrance to the point where entrance light was no longer visible to the human eye. We noted any trash, graffiti, or broken formations. We mounted a HOBO Pendant MX Temperature Logger on the cave wall in direct contact with the substrate, always at least 1 meter above the floor and typically hidden from a visitor's direct line of sight. We programmed this twilight-zone logger to record air temperature every hour.

In the dark zone, we selected one location to install a wet-bulb psychrometer designed using a HOBO MX2303 Two External Temperature Sensors Data Logger (±0.2ºC). This logger recorded dry-bulb and wet-bulb temperatures every 3 hours, allowing us to calculate relative humidity from the evaporative cooling difference between the two bulbs. If relevant, we chose a site where bats or other priority cave species were likely to congregate to maximize the management relevance of the microclimate data. We suspended the psychrometer from a short chain attached to the wall or ceiling to maintain airflow around the wet bulb and to discourage rodents from chewing on the external wires. Finally, we recorded the psychrometer's distance from the cave entrance, as well as the passage height, width, and air speed.

Biosurveys:
Before visiting each site, we used Fiji, an image-processing software, to randomly generate up to 25 points on the cave map. We required points to be at least 10 m apart and restricted them to the first 2,000 m of human-accessible passage, ensuring that at least one point fell within the twilight zone. For each point, we measured the distance from the entrance in Fiji. If no cave map was available, we generated a list of random distances from the entrance and took that list to the cave. During field surveys, we used a laser distance meter to navigate as close as possible to each point based on this estimated distance. We visited points in order from closest to farthest from the entrance.

At each randomly selected point, we established a 10 m transect by measuring 5 m forward and 5 m backward along the passage. At the midpoint, start, and end of the transect, we measured passage height and width using a laser distance meter (±1/16 in). We took a central measurement of air temperature and relative humidity using a Protmex PT618 Temperature Humidity Meter (±1.5ºC, ±4.0% RH) and measured substrate temperature at three haphazardly selected locations on the walls or ceiling using a Fluke 64 MAX IR Thermometer (±1ºC). We completed these measurements as quickly as possible to minimize the influence of body heat on microclimates.

During constrained-area searches, 3–5 researchers surveyed the entire passage cross-section from the start to the end of the transect, including the ceiling, walls, floor, and any pools or streams. We recorded the number of researchers, the start time, and the end time (maximum 30 minutes) to control for search effort in analyses. We examined surfaces and crevices for small invertebrates and gently flipped and replaced small cover items such as rocks. We counted the number of observed individuals of each species and reported observations to a designated data recorder. When morphology did not allow clear identification, we photographed individuals for later examination and, in some cases, collected small invertebrates in ethanol for microscopic inspection or genetic sequencing.

Between each randomly selected survey station, we also conducted haphazard searches of the floor, walls, ceiling, pools, and streams to detect additional cave fauna. As in the constrained-area searches, we counted all individuals observed by species and collected photographs or specimens when needed for identification. For any opportunistic encounters, we recorded the nearest survey station.

We identified individuals to the finest possible taxonomic scale using genetic sequencing, standard taxonomic keys, and/or historical records and known species distributions. In many cases, taxonomic authorities for these cave fauna were so limited that the individual could not be identified to species, and thus we refer to them as morphospecies below.

Objective 2: Quantify how much forest cover mediates microclimates

We calculated the percent of surface land over each cave that was covered by forest using ArcGIS and the National Land Cover Database Tree Canopy Cover (TCC) raster layer from 2021 (Housman et al. 2021, U.S. Department of Agriculture, Forest Service, Geospatial Technology and Applications Center). The TCC layer provides the mean predicted tree canopy cover at a 30-meter spatial resolution, and we summed these values within polygons representing the area over each cave. We created four different kinds of polygons: (1) canopy cover over the surveyed area of the cave as indicated by the cave map or a straight line drawn from the entrance to the psychrometer location; (2) a circular buffer with a circular radius from the cave area; and (4) canopy cover over the watershed boundary where the cave is located. In early 2026, after retrieving our last data loggers, we will compare forest cover to the difference between the mean annual surface temperature in a region and the mean cave temperature to determine how much forest cover mediates microclimates relative to the expected mean.

Objective 3: Create a management toolbox

Partner Knowledge Synthesis:

At a virtual workshop, partner participated in break out group discussions and broader group discussions to create a list of all possible management actions that they do or could do that might intentionally or unintentionally influence (1) cave microclimates (e.g., gating, vegetation removal); (2) cave ecosystem resilience to climate change (e.g., gating or cave closures, animal translocations); or (3) management capacity for actions that impact microclimates or resilience (e.g., monitoring, developing management plans). We circulated the final list to all partners via email for additional opportunities to suggest management actions to add to the list.

Systematic Literature Review:

We performed a broad systematic literature review on Web of Science and PubMed to identify published papers that discuss or demonstrate factors that influence cave climates or microclimates, including management actions. The search terms included ("cave" OR "caves") AND (temperature* OR microclimate* OR climate*). We also excluded many terms that signaled that papers were not relevant to our study, including any terms found in papers about ice caves, caves on other planets, "caves" as a term used in materials science and metallurgy, caves from prehistoric times, studies specifically focused on using speleothems to reconstruct historical climates, and studies specifically focused on preserving historical cave art or dwellings. These searches resulted in a total of 1,617 abstracts.

Four people screened each abstract to determine whether the paper quantified or discussed relationships between external or internal factors (e.g., cave morphology, surface temperate) that influence cave microclimates. We kept all abstracts where >2 people rated the abstract for inclusion, resulting in a total of 263 papers for full text analysis. Two of these were not in English, reducing the total to 261 papers.

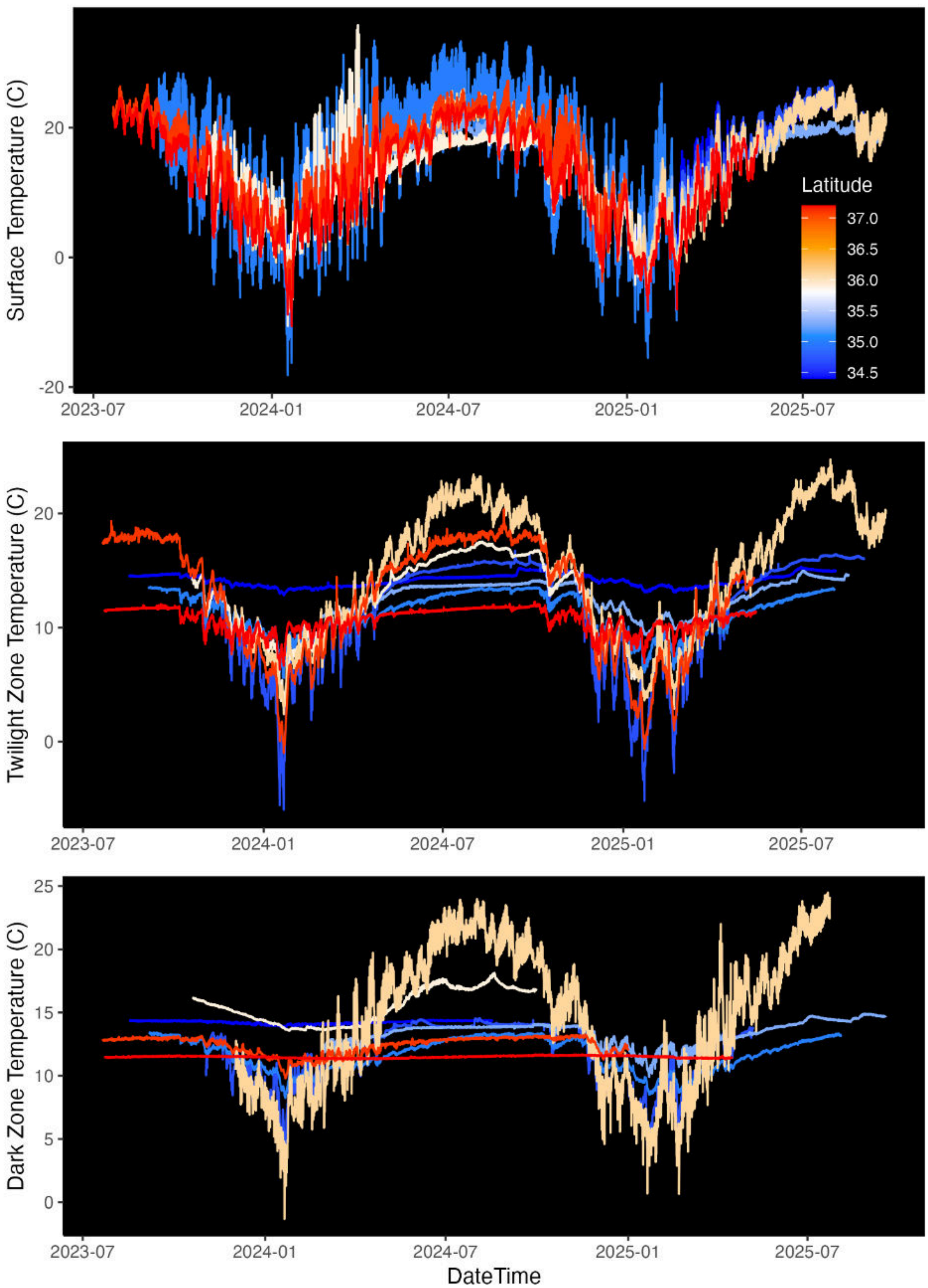
We developed a data extraction protocol that included variables related to metadata (e.g., primary vs secondary literature), microclimate variables that were measured or mentioned (e.g., air temperature variability, relative humidity), factors that were hypothesized or measured to demonstrate impacts on microclimates (e.g., cave visitation rates, gating, number of entrances), management relevance (e.g., was a management action discussed or tested), and spatiotemporal context (e.g., country, number of caves sampled, length of time series). We tested and refined this protocol by having teams of 4–5 people use the protocol on the same paper and comparing answers, discussing any discrepancies. We had at least two people perform data extraction on the first 150 papers, comparing answers and rectifying any discrepancies, until we were sure that we were all using the protocol consistently. For the remaining papers, a single researcher was assigned to each paper, but we flagged any papers that would benefit from a second review and comparison. After removing papers where the full text did not actually discuss or measure factors that influence microclimates, we had a final dataset of 178 papers.

Project Results, Analysis and Findings:
Microclimates:
Over the course of the project, loggers were lost due to cave flooding, vandalism or accidental removal by well-meaning cave visitors, theft or destruction by woodrats (*Neotoma* sp.), and technology failure (e.g., battery failure, moisture issues). This was not completely surprising, because we included many caves that did not have a frequent management presence that could check on loggers. This is important to note for future researchers, who can either plan to visit and download data more frequently (time and personnel intensive) or deploy extra loggers as an insurance policy for those that will go missing (funding intensive). Additionally, we suggest using metal twist ties or similar to secure small loggers in place in the twilight zone, to reduce theft by packrats. To date, we have retrieved multi-month datasets from 22 outside loggers, 28 twilight loggers, and 40 dark zone psychrometers. Some logger retrieval was delayed due to government disruptions and access restrictions related to bats, so we anticipate retrieving loggers from an additional ten caves in January/February 2026 during biennial bat survey trips.

In general, the temperature data from each cave follow the expected pattern for temperate cave systems, where the deeper cave zones have more stable (less variable) temperatures than the surface (Figure 2). Some caves had more or less variable temperatures in the twilight and dark zones, which is mostly a function of airflow and cave entrance morphology. In general, the mean annual cave temperature was similar to the mean annual surface temperature (MAST), which our literature review identified as one of the most commonly studied drivers of cave climates (see below).

However, our data show that other factors are as important or more important than MAST for determining cave climates and microclimates. For example, in Figure 2, we show eight caves across a latitudinal gradient. Although these caves range from Alabama to Kentucky, they have similar surface temperatures, due to a combination of elevation and forest cover. Despite similar surface temperatures, the twilight and dark zone temperatures differ dramatically, and not in ways that could be easily predicted by latitude. For example, one of the lowest latitude caves has the lowest winter temperatures, and one of the middle latitude caves has the most variable and extreme temperatures. This is an important reminder that many factors influence cave climates, including factors that managers control, and our final analyses will differentiate the roles of latitude, elevation, entrance size, cave size, and forest cover.

Figure 2. Example temperature time series from eight caves across a latitudinal gradient where all three loggers were successfully retrieved from each cave: surface logger, twilight zone logger, and dark zone logger.

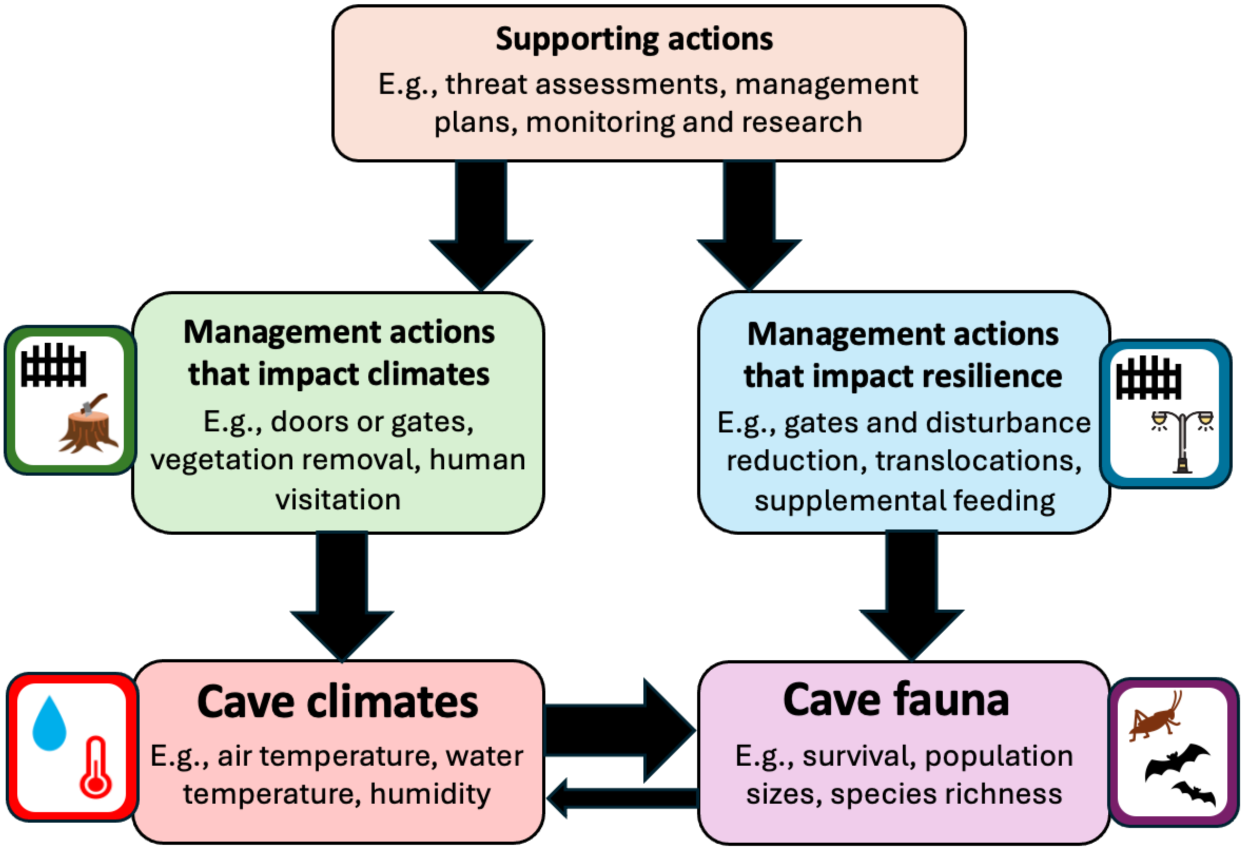

Surface Temperature (C)
Twilight Zone Temperature (C)
Dark Zone Temperature (C)
DateTime
Latitude
37.0
36.5
36.0
35.5
35.0
34.5
2023-07
2024-01
2024-07
2025-01
2025-07

Biosurveys:
We conducted standardized biosurveys in 28 caves and opportunistic biosurveys in an additional 19 caves, for a total of 47 caves with new biosurvey data. We documented at least 360 unique taxa representing 7 phyla, 21 classes, 79 orders, 176 families, and 223 genera. This included 308 invertebrate taxa representing 6 phyla, 16 classes, 64 orders, 153 families, and 185 genera, and 52 vertebrate taxa, representing 5 classes, 15 orders, 23 families, and 38 genera. We documented at least 85 cave-obligate taxa, representing 5 phyla, 11 classes, 23 orders, 33 families, and 49 genera. At least seven taxa appear to be new to science. At least 32 taxa are of conservation concern at the state or federal level, highlighted by four federally listed species (two bats and two decapods). Specimens for some taxonomic groups have been sent to taxonomic specialists for additional species level identifications that will be communicated in the future.

Management toolbox:
Among the 178 papers included in the literature review, the most commonly measured climate variables were temperature or spatiotemporal temperature variability, with the next most common variable being humidity or vapor pressure. In contrast, relatively few papers measured airflow/windspeed or water temperature, and few to no papers measured risks/rates of freezing or droughts. The limited attention to climate extremes likely reflects the relatively short duration of most cave climate datasets, where only 28 papers included a time series longer than five years, and most time series were shorter than two years.

Several factors were measured to quantify their impacts on cave climates or microclimates, including [most to least commonly studied]: seasonality (104), mean annual surface temperature (92), distance from entrance (53), human visitation (42), air flow or windspeed (39), precipitation or snow melt (38), diurnal changes (35), depth (25), passage size or volume or orientation (17), water flow (14), gating (12), entrance elevation (10), surface winds or air pressure (<10), cave size or volume (9), entrance size or shape or orientation or number (8), artificial lighting (7), snow cover (7), geothermal sources (7), forest cover (6), solar radiation (6), bats and heat from their bodies or guano (5), entrance slope (5), height above floor (<5), waterfalls or other turbulent flows (4), percent impervious cover or urban cover (1), topography or roughness of ceiling or walls (1), and soil moisture over caves (1). Most of these tested relationships were correlational, and only 39 papers explicitly tested how a management action impacted cave climates or microclimates. The most common management actions tested were altering visitation rates and cave entrances or airflow.

Figure 3. A conceptual model of the cave management toolbox. Cave climates and microclimates directly impact cave fauna at the individual, population, species, and communities levels. Management actions can intentionally or unintentionally impact cave climates or impact species resilience to climate change and other stressors. Finally, supporting management actions may be needed to accomplish management actions related to climate or resilience.



Conclusions and Recommendations:
We collected new microclimate datasets from 43 caves and new biodiversity datasets from 47 caves (including 28 systematic surveys), with several additional datasets to be finalized in winter 2026. For many high-priority caves—identified directly by managers and landowners—these represent the first microclimate or biodiversity data ever recorded. Partners can now use these baseline datasets to inform management decisions, evaluate the effects of planned or ongoing actions, and establish long-term monitoring programs. In several cases, our surveys occurred before or during management interventions (e.g., surface construction or work inside the cave), providing critical pre-impact data for future comparison. We also documented previously unrecorded threatened species and species potentially new to science, enabling partners to take appropriate conservation measures.

By combining partner expertise with a systematic literature review, we compiled the most comprehensive list to date of management actions that may intentionally or unintentionally influence cave microclimates and climate resilience. While many proposed actions are grounded in theory or supported by correlational evidence, few have been tested through robust, replicated studies. This underscores the importance of ongoing monitoring, adaptive management, and knowledge sharing across partners and sectors. Managers can learn from their own experiences and from those of other partners as they work to conserve cave climates and subterranean biodiversity under changing environmental conditions.

This project required close coordination with dozens of partners, who were critical for success, and it was not without challenges. Over the three-year period, we navigated landownership changes, access restrictions related to endangered bats, staff turnover within partner organizations, logger losses due to storms, vandalism, wildlife interference, and federal government shutdowns that resulted in two missed field seasons. These realities illustrate why large-scale cave climate studies remain rare—and why the datasets produced here are exceptionally valuable for the region.

Several components of the project are still underway. Before 2027, we will complete analyses relating microclimates to forest cover and to cave community composition. These results will be submitted in at least two peer-reviewed publications. We will also finalize individualized reports for partners, including a formal report for the National Park Service summarizing findings from Mammoth Cave National Park.

Management Applications and Products:
At the start of the project, we surveyed our partnering cave managers/owners, and found that 0% of them were explicitly managing caves for climate resilience. Some partners told us that climate resilience was a priority for their organization, but they did not know what management actions could support climate resilience. Other partners told us that climate resilience was not a priority for their organization given the other demands on their time, but they would consider actions that improve climate resilience if they were compatible with their other management responsibilities. Our final management toolbox supports all cave managers/owners but listing all possible management activities that might intentionally or unintentionally influence cave climates or cave ecosystem resilience to climate change, enabling them to make more informed management decisions.

In total, we partnered with 19 organizations and some private landowners, working with more than 70 partners across the organizations (Table 1). Our partners were involved in all aspects of study design, permitting and access coordination, and data collection. Most partners participated in our virtual “partner summit” meetings (see Outreach and Products section), where they provided ideas and feedback related to study design and methodology. Outside of those meetings, all partners contributed their ideas and management needs during the site selection process via emails or individual meetings with the academic team. Most partners assisted with data collection, either by accompanying the academic team on cave trips to deploy loggers or survey biodiversity, or by deploying or retrieving loggers without the academic team. All partners will continue to be involved with data analysis and dissemination in 2026.

Below are a few quotes from our partners illustrating how they have or will use the data and products from this study:

“By collaborating on this project, KNLT has been able to collect data to evaluate how the installation of a bat gate could impact the cave microclimate and biodiversity. The data collected before and after the gate construction will allow for better management of the cave species and the protection of this unique habitat within one of the most biodiverse temperate regions on Earth.” – Derrick Lindsay, Stewardship Coordinator, Kentucky Natural Lands Trust

“Both the biological data and the microclimate data that was collected from these sites help establish a baseline of conditions that occur in these caves, and this information is critical to understanding how these communities may change in the future as climate conditions shift. We expect to use the information to help us develop strategies to ensure these cave communities, subterranean habitats, and surface habitats are managed to support their continued existence. This information is particularly important for the endemic and or endangered species found exclusively in these habitats.” – Mike Slay, Ozark Karst Program Director, The Nature Conservancy

“Participating in the microclimate/biodiversity study has enhanced our understanding of how climate impacts the unique ecosystems of our Nature Preserves. From this collaboration, we are also encouraged to continue data collection as citizen scientists, thus ensuring sustained support for our management practices.” – Julie Schenck-Brown, Preserves & Acquisitions Chair, Landowner Relations Chair, National Speleological Society

Table 1. Partners involved in the Southeast Cave Microclimate Project from 2023 to 2025.

State	Organization	Number of Partners	Summit Participation or Project Design	Data Collection
AL	Alabama Department. of Conservation and Natural Resources	3	x	x
AL	Bankhead National Forest	4	x	x
AL	National Park Service (Natchez Trace Parkway)	1	x	
AL	Redstone Arsenal, United States Army	3	x	
AL	The Nature Conservancy in Arkansas (Paint Rock Research Center)	3	x	x

AR	The Nature Conservancy in Arkansas	2	x	x
KY	Kentucky National Park Service	5	x	x
KY	Kentucky Natural Lands Trust	5	x	x
KY	Kentucky Nature Preserves	2	x	
NC	North Carolina Wildlife Resources Commission	3	x	x
TN	Tennessee Department of Environment and Conservation (TDEC)	8	x	x
TN	TN Ecological Services Field Office (USFWS)	2	x	
TN	Tennessee Valley Authority	7	x	x
TN	Tennessee Wildlife Resources Agency	7	x	x
TN	The Nature Conservancy in Tennessee	1	x	x
TN	Cumberland Caverns (privately owned)	2	x	x
Multiple	National Park Service	1	x	
Multiple	National Speleological Society	9	x	x
Multiple	Southeastern Cave Conservancy, Inc.	4	x	

Outreach and Products:
Project-related conference presentations, seminars, webinars, or workshops:
Hopkins, S.R., E. Foy, E. Maxwell, Z. Gajewski, B. Cramphorn, M.E. Slay, R. Toomey, C. Holliday, B. Peterson, A. Hinkle, M. Niemiller. 2025. Assessing patterns of subterranean biodiversity and microclimates to inform cave management and conservation. Tennessee Bat Working Group, Chapel Hill, Tennessee.

Hopkins, S.R., E. Foy, E. Maxwell, Z. Gajewski, B. Cramphorn, M.E. Slay, R. Toomey, C. Holliday, B. Peterson, A. Hinkle, M. Niemiller. 2025. Assessing patterns of subterranean biodiversity and microclimates to inform cave management and conservation. 2025 SE CASC Regional Science Symposium, Asheville, North Carolina.

Hopkins, S.R., E. Foy, E. Maxwell, Z. Gajewski, B. Cramphorn, M.E. Slay, R. Toomey, C. Holliday, B. Peterson, A. Hinkle, M. Niemiller. 2025. Assessing patterns of subterranean biodiversity and microclimates to inform cave management and conservation. Mammoth Cave 12th Research Symposium, Cave City, Kentucky.

Hopkins, S.R., E. Foy, E. Maxwell, Z. Gajewski, B. Cramphorn, M.E. Slay, R. Toomey, C. Holliday, B. Peterson, A. Hinkle, M. Niemiller. 2024. Assessing patterns of subterranean biodiversity and microclimates to inform cave management and conservation. Karst Interest Group Workshop, Nashville, TN.

Niemiller, M., E. Foy, E. Maxwell, Z. Gajewski, B. Cramphorn, M. Slay, R. Toomey, C. Holliday, B. Peterson, A. Hinkle, and S. Hopkins. 2023. Assessing Patterns of Subterranean Biodiversity & Microclimates to Inform Cave Management & Conservation. National Cave & Karst Management Symposium, Chattanooga, TN.

Communications with decision-makers:
We had five virtual partner summit meetings during the project period, during which partners helped us to design and revise methods to ensure that we were meeting individual and collective data needs.

Partner Summit #1
Date: 6 December 2022
Attendance: 28 partners + academic team
Topics: Introductions and networking; shared project goals; site selection procedures

Partner Summit #2
Date: 3 May 2023
Attendance: 14 partners + academic team
Topics: site selection results; discussing and designing methods for logger deployment and biosurveys

Partner Summit #3
Date: 27 October 2023
Attendance: 16 partners + academic team
Topics: updates on biosurveys; group effort to brainstorm a list of management actions for toolbox

Partner Summit #4
Date: 1 February 2024
Attendance: 9 partners + academic team (only partners interested in bats attended)

Topics: biosurvey updates; new funding for a tricolored bat study

Partner Summit #5
Date: 6 November 2024
Attendance: 19 partners + academic team
Topics: plans for logger retrieval; updates on systematic literature review

Table 1. Partners involved in the Southeast Cave Microclimate Project from 2023 to 2025.

State	Organization	Number of Partners
AL	Alabama Department. of Conservation and Natural Resources	3
AL	Bankhead National Forest	4
AL	National Park Service (Natchez Trace Parkway)	1
AL	Redstone Arsenal, United States Army	3
AL	The Nature Conservancy in Arkansas (Paint Rock Research Center)	3
AR	The Nature Conservancy in Arkansas	2
KY	Kentucky National Park Service	5
KY	Kentucky Natural Lands Trust	5
KY	Kentucky Nature Preserves	2
NC	North Carolina Wildlife Resources Commission	3
TN	Tennessee Department of Environment and Conservation (TDEC)	8
TN	TN Ecological Services Field Office (USFWS)	2
TN	Tennessee Valley Authority	7
TN	Tennessee Wildlife Resources Agency	7
TN	The Nature Conservancy in Tennessee	1
TN	Cumberland Caverns (privately owned)	2
Multiple	National Park Service	1
Multiple	National Speleological Society	9
Multiple	Southeastern Cave Conservancy, Inc.	4