

Cumberland Piedmont Network

National Park Service
Inventory and Monitoring Division



Standard Operating Procedure 8.0

Data Analysis—Version 2.0

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Summary

This SOP describes the process for conducting analyses of cave bats monitoring data and cave meteorological data collected at selected caves in the Cumberland Piedmont Network (CUPN). The tasks described in this SOP cover the period of time *from* when all digital data have been uploaded to the designated folders on the network's server; all manual data and data from photo/video analyses have been entered into the database; and all data verification, validation, and certification steps have been completed *to* the point of report writing. The steps for data handling and processing *prior to* data analysis are detailed in SOP—6: Post-field Sampling and SOP—7: Data Management. Report writing is detailed in SOP—9: Reporting. Analyses of summer and winter bat count data and analyses of cave meteorological data are described in this SOP.

Revision Log

Previous Version #	Revision Date	Author	Changes Made	Reason for Change	New Version #
1.0	Dec 2015	Steven Thomas	Changed analysis of summer bat data from a single-measure to a multiple-measures (hierarchical) approach in response to external peer review comments. Replaced linear regressions with additive models for analysis of winter bat and cave meteorological data. Minor edits made following external peer review and during database development.	Protocol Revision	2.0

Contents

	Page
Summary.....	1
Revision Log.....	1
Recommendations for Routine Data Summaries and Analysis	3
Summer Cave Roost Monitoring	3
Data Flow—Summer Bat Roost Counting	4
Data Analysis.....	4
Winter Cave Roost Monitoring.....	6
Data Flow—Winter Bat Roost Censusing.....	6
Cave Meteorological Monitoring.....	9
Data Flow—Cave Meteorological Sampling	10
Data Analysis.....	11
Opportunistic Grab Sampling.....	11
Continuous Sampling	17
Literature Cited	18

Recommendations for Routine Data Summaries and Analysis

Data from the CUPN cave-roosting bats monitoring project will be analyzed in multiple ways:

- Annual status summary of cave-roosting bats monitoring highlights,
- Analysis of changes (trends) in key measures over time, typically summarized every ten years (may be summarized every five years for the sub-set of summer bat monitoring data collected annually),
- Evaluations of relationships between key ecosystem drivers/attributes/stressors and key measures, including comparisons to regional datasets for a look at how cave bats using CUPN lands factor into the regional context, as resources become available to complete.

Table 6 in the “Variables and Measurements” section of the protocol narrative provides a list of the sampling methods and associated primary measures and variables that will be collected, used, or calculated for each of the three main field sampling categories in this protocol during data analysis. A brief description of how each variable will be determined is provided in the sections that follow.

Summer Cave Roost Monitoring

This section of the SOP outlines the data flow and expected analyses of summer bat emergence count data collected by implementing the CUPN cave-roosting bats monitoring protocol. The monitoring objective (below) and subsequent analyses of the supporting data address issues related to the status and trends in abundance of bats that roost in selected park caves during late spring and summer months. The protocol was designed to address the following monitoring objective (i.e., Monitoring Objective 1 of this protocol):

Estimate status and trend of summer cave-roosting bat abundance within selected caves in four parks in the Cumberland Piedmont Network during annual and rotating surveys.

This monitoring objective will be addressed using hierarchical models such as N-mixture (Royle 2004; Kéry et al. 2005; and Kéry and Royle 2010), in the R library called *unmarked* (Fiske and Chandler 2011), along with the maximum emergence statistic (to control for double-counting individual bats) to obtain abundance estimates (Loeb et al. 2015). The “maximum emergence” is the highest recorded net emergence (i.e., the total net number of bats out of the cave, that is, the number of bats that have left the cave minus the number of bats that have entered the cave) over a series of time intervals. An estimate of maximum emergence is obtained by calculating the maximum net bats out for each raw-data interval and adding to the net sum of bats for the preceding user defined intervals from that night. This produces the highest maximum emergence estimate for the night using the finest temporal scale available. With shorter time intervals in the raw data, higher values of maximum emergence can often be obtained (Appendix H). Results will be presented using tables or graphs in the Annual Summary and Trend Analysis reports.

Data Flow—Summer Bat Roost Counting

Multiple visit (two or more per sampling window) and multiple observer methods (two or more independent observers or two or more independent methods) will be employed to collect summer bat emergence (“multiple-measures”) data—this will allow the use of hierarchical models and estimation of detectability and will greatly increase the utility and longevity of the data (Loeb et al. 2015). Methods to collect data include direct (i.e., manual or visual counts) and passive (i.e., digital video) emergence counts (see SOP—3: Summer Cave Roost Sampling).

Data collected by summer bat sampling methods will be stored in the Microsoft Access database application developed by CUPN due to uncertainty regarding the BPD v.2. The data manager or project leader will follow retrieval procedures developed in the working database application in order to obtain raw data for performing analyses.

Data collected by video cameras will initially be stored in in the park’s raw videos directory folder on the external hard drive located at the following path (using CHCH as an example):

E:\Cave_Bats\Videos\CHCH\Raw_Videos\

Video files will be renamed following the process and naming convention described in the “Photo/Video Processing” section before being analyzed (i.e., bats in digital videos counted) using a procedure described in the “Performing Digital Video Analysis” section of SOP—6: Post-field Sampling. As a video file is being analyzed for a cave entrance, the number of bats exiting and entering for each time interval will be added to the original hardcopy field data form (or a blank form if additional space is needed), and, after database entry, the final form will be scanned, named, and stored following the process and convention described in the “Handling Field Data Forms” section of SOP—6.

Data Analysis

All forms of data collected under this protocol may be exported as comma delimited ASCII text or Microsoft Excel files. This data format is readily imported into statistical analysis software used at CUPN (e.g., SigmaPlot, R packages). An example of the proper format that summer bat emergence count data must be organized into (called a “data frame”) in order for R software to read it is shown in Table SOP8-1 (an Excel file exported from the database via a data query). This table has a total of three replicates (independent samples collected on one date at one site).

Abundance estimates via summer emergence counts are confounded when individual bats exit, then re-enter caves before the entire colony has emerged for the evening. This pattern of repeated passes through the entrance by individual bats results in “double counting,” where some individuals are counted more than once. Bats from outside the colony may also enter the cave for night-roosting, further confounding simple counts. In cases where all entrances and exits to a particular cave can be monitored simultaneously (thus accounting for differences in detection probabilities for individual bats due to unmonitored entrances/exits), this confounding may be ameliorated by estimating the maximum net emergence (Appendix H, Figure SOP8-2, blue lines only). The “maximum net emergence” statistic is calculated by carefully monitoring the difference between bat passes going in and passes going out of the cave during the nightly emergence cycle. At some point in the evening a

maximum net outward count is recorded that represents the largest number of bats simultaneously out from the colony, minus the number of bats who have arrived from elsewhere for night-roosting, and excluding the proportion of bats that are undetected. Assuming that the detection probability is equal for both inward and outward passes, the maximum net emergence reduces or eliminates double-counting (where individuals are counted more than once within a sampling event), allowing hierarchical models such as the N-mixture model (Royle 2004) to be utilized to estimate abundance when repeated measures—such as through multiple visits or multiple methods—are available (Loeb et al. 2015). Each visit and each method will be considered independent and not combined during analysis. N-mixture also provides explicit estimates of detection probability. The N-mixture model will be implemented in the R software package (R Development Core Team 2011), using the function *pcount*, available in the R library *unmarked* (Fiske and Chandler 2011).

Table SOP8-1. Example of proper format for a data frame from one sampling event at one cave entrance over 15 five-minute intervals using three independent methods to count entering and exiting bats. The data frame will be read by R software to estimate the maximum net emergence from the roost statistic.

Event Date	Interval Start Time	NV Goggles entry	NV Goggles exit	NV Video entry	NV Video exit	TIR Video entry	TIR Video exit
5/22/2015	19:45	0	1	0	1	0	1
5/22/2015	19:50	0	0	0	0	0	0
5/22/2015	19:55	0	3	0	2	0	2
5/22/2015	20:00	0	7	0	7	0	7
5/22/2015	20:05	0	13	0	14	0	14
5/22/2015	20:10	1	9	1	9	1	9
5/22/2015	20:15	1	4	1	4	1	4
5/22/2015	20:20	0	1	0	1	0	1
5/22/2015	20:25	1	2	1	2	1	2
5/22/2015	20:30	0	0	0	0	0	0
5/22/2015	20:35	0	1	0	1	0	1
5/22/2015	20:40	1	1	1	1	1	1
5/22/2015	20:45	0	0	0	0	0	0
5/22/2015	20:50	0	0	0	0	0	0
5/22/2015	20:55	0	0	0	0	0	0

Below is an example (Table SOP8-2) of a summer bat roost monitoring data summary table that represents the type of status information that may be included in the Annual Summary Reports. It was produced using the N-mixture model in the R software package *unmarked* via the maximum emergence statistic. The R code used to produce the maximum emergence statistic used to generate the results in Table SOP8-2 is given in Appendix I.

Table SOP8-2. Results of model-based population abundance estimates at individual caves via maximum emergence and N-mixture from Mammoth Cave National Park.

Cave Name	Estimate	Standard Error
Blight	64.43	0.13
Coke	99.12	0.17
Luna	73.40	0.18
Mossy Root	8.58	0.37
Cathedral	0.00	46.46
Dynamite Rock	6.10	0.43
Misty Hole	85.53	0.17
Total estimate	337.16	na
Estimated detection probability	na	0.76 (0.026 SE)

Winter Cave Roost Monitoring

This section of the SOP outlines the data flow and expected analyses of winter bat hibernacula census data collected under the CUPN cave-roosting bats monitoring protocol. The monitoring objective (below) and subsequent analyses of the supporting data address issues related to the status and trends in abundance of bats that roost in selected park caves during winter months, and the status and trends in winter bat distribution (use) within selected park caves. The protocol was designed to address the following monitoring objective (i.e., Monitoring Objective 2 of this protocol):

Determine status and trends of hibernating bat abundance and spatial distribution within selected hibernacula caves in four parks in the Cumberland Piedmont Network during biennial surveys.

This monitoring objective will be addressed using a combination of summary statistics from bat counts among all survey sections within each cave monitored each year, and additive models for trend analysis. Additive models were selected over basic linear regressions because they enable modeling of a non-linear population trajectory rather than assuming a linear population trend (Ingersoll et al. 2013).

Data Flow—Winter Bat Roost Censusing

Up to four methods may be employed to collect winter bat hibernacula census data—direct visual counts, digital photography, quadrat/grid sampling, and LIDAR (see SOP—4: Winter Cave Roost Sampling). The total number of bats counted (or estimated if a grid or LIDAR is used) by species will be used for abundance status and time series trend analysis using additive models to produce population trajectories. Since census data will be recorded with reference to specific sections within the cave, trends in gross spatial distribution by species within the cave will be analyzed using generalized additive mixed models (GAMMs).

Data collected by winter bat sampling methods will be stored in the Microsoft® Access database application developed by CUPN. The data manager or project leader will follow retrieval procedures developed in the working database application in order to obtain raw data for performing analyses.

Data collected by digital cameras will initially be stored in in the park’s raw images directory folder on the external hard drive located at the following path (using CHCH as an example):

E:\Cave_Bats\Images\CHCH\Raw_Images\

Image files will be renamed following the process and naming convention described in the “Photo/Video Processing” section before being analyzed (i.e., bats in digital images identified and counted) using a procedure described in the “Performing Digital Photograph/Video Image Analysis” section of SOP—6: Post-field Sampling. After all image files have been analyzed for one section of a cave, the number of photo-counted bats for each species will be added to the hardcopy field data form, and, after database entry, the final form will be scanned, named, and stored following the process and convention described in the “Handling Field Data Forms” section of SOP—6.

Data Analysis

All forms of data collected under this protocol may be exported as comma delimited ASCII text or Microsoft® Excel files. This data format is readily imported into statistical analysis software used at CUPN (e.g., SigmaPlot, R packages). An example of a data summary table that may be included in an Annual Summary Report is shown in Table SOP8-3 (an Excel file exported from the database via a data query).

Table SOP 8-3. Winter bat roost monitoring annual data summary, by site, for Mammoth Cave National Park (WN—Whitenose).

Cave	Event Date	Species Common Name	Count Total	Dead Count Total	WN Count Total	Percent Dead	Percent WN
Currie Cave	07-Feb-2014	Rafinesque's big-eared bat	1	0	0	0	0
	07-Feb-2014	big brown bat	2	0	0	0	0
	07-Feb-2014	tri-colored bat	1	0	0	0	0
Haunted Cave	11-Feb-2014	Rafinesque's big-eared bat	58	0	0	0	0
	11-Feb-2014	big brown bat	4	0	0	0	0
	11-Feb-2014	tri-colored bat	2	0	0	0	0
Hickory Flat Cave	30-Jan-2014	Rafinesque's big-eared bat	1574	0	0	0	0
	30-Jan-2014	big brown bat	2	0	0	0	0
	30-Jan-2014	northern long-eared bat	1	0	0	0	0
	30-Jan-2014	tri-colored bat	4	0	0	0	0
J.T. Cave	21-Feb-2014	Rafinesque's big-eared bat	273	0	0	0	0
	21-Feb-2014	big brown bat	4	0	0	0	0
	21-Feb-2014	tri-colored bat	18	0	1	0	5.56
Wildcat Hollow Sink	13-Feb-2014	Rafinesque's big-eared bat	23	0	0	0	0
	13-Feb-2014	big brown bat	5	0	0	0	0

Additive models may be executed in the R software package (R Development Core Team 2011), using the R library *mgcv* (Wood 2008), with abundance estimates as a dependent variable, caves as a fixed-effect, and negative-binomial errors to account for overdispersion (Ingersoll et al. 2016). Independent variables may include bat-count, year, selected environmental covariates such as meteorological data, and spatial measurements such as colony clustering and correlation with previously observed colony location. Covariate models may be selected using Akaike's information criterion (AIC; Akaike 1973; Burnham and Anderson 2002). Details for analysis of bats counts using additive models and AIC are given by Ingersoll et al. (2013) and Ingersoll et al. (2016).

Below is an example (Figure SOP8-1) of winter bat roost monitoring data summaries, by site and year, that represent the type of graphical trajectory display that may be included in the eight-year Trend Analysis Reports.

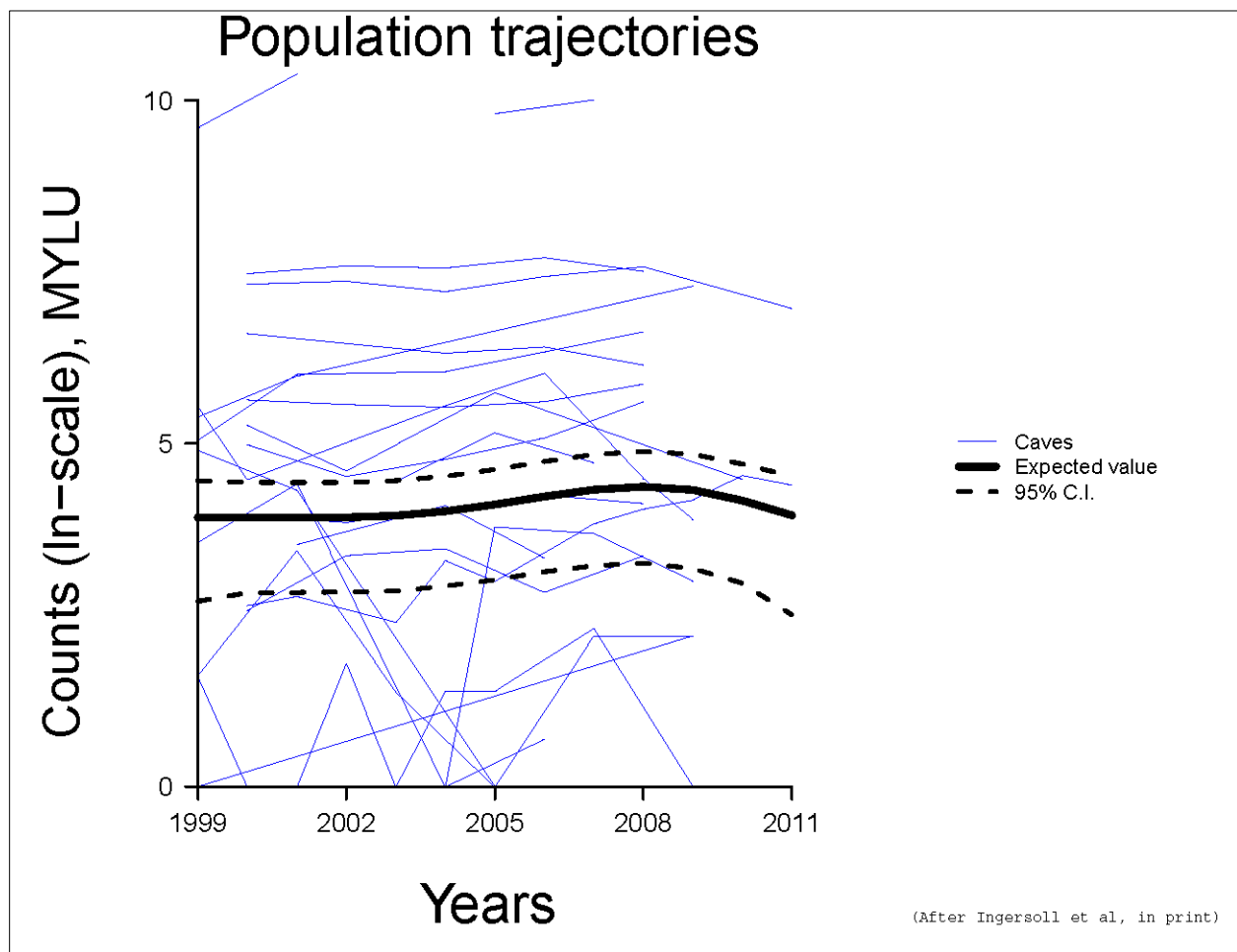


Figure SOP8-1. Example of population trajectories from winter bat roost monitoring for little brown bats at approximately 20 West Virginia caves over 12 years. Counts by direct observation and trajectories along individual survey routes over multiple years (blue lines). Expected value (solid black line) for a randomly selected route and its 95% confidence interval (dashed lines) as estimated with additive models (Ingersoll et al. 2016).

Cave Meteorological Monitoring

This section of the SOP outlines the data flow and expected analyses of the cave air temperature and relative humidity (RH) data collected within the CUPN cave-roosting bats monitoring protocol. The monitoring objective (below) and subsequent analyses of the supporting data address issues related to cave atmospheric conditions under which bats use caves. The protocol was designed to address the following monitoring objective (i.e., Monitoring Objective 3 of this protocol):

Determine status and trends of key habitat parameters (cave air temperature and relative humidity) within selected caves used by bats in four parks in the Cumberland Piedmont Network. This monitoring objective will be addressed using a combination of summary and descriptive statistics and graphic analysis. We will use additive models for trend analysis. Additive models were selected over basic linear regressions because they enable modeling of a non-linear trajectory rather than assuming a linear trend (Ingersoll et al. 2013). Additive models will show extrema, such as seasonal or daily maxima.

The relationship between bat activity and key habitat parameters may be established by modeling the relationship with generalized additive mixed models (GAMMs) and then using the GAMM to predict activity values at different habitat levels, as with the following relationship between temperature and fall emergence in Figure SOP8-2.

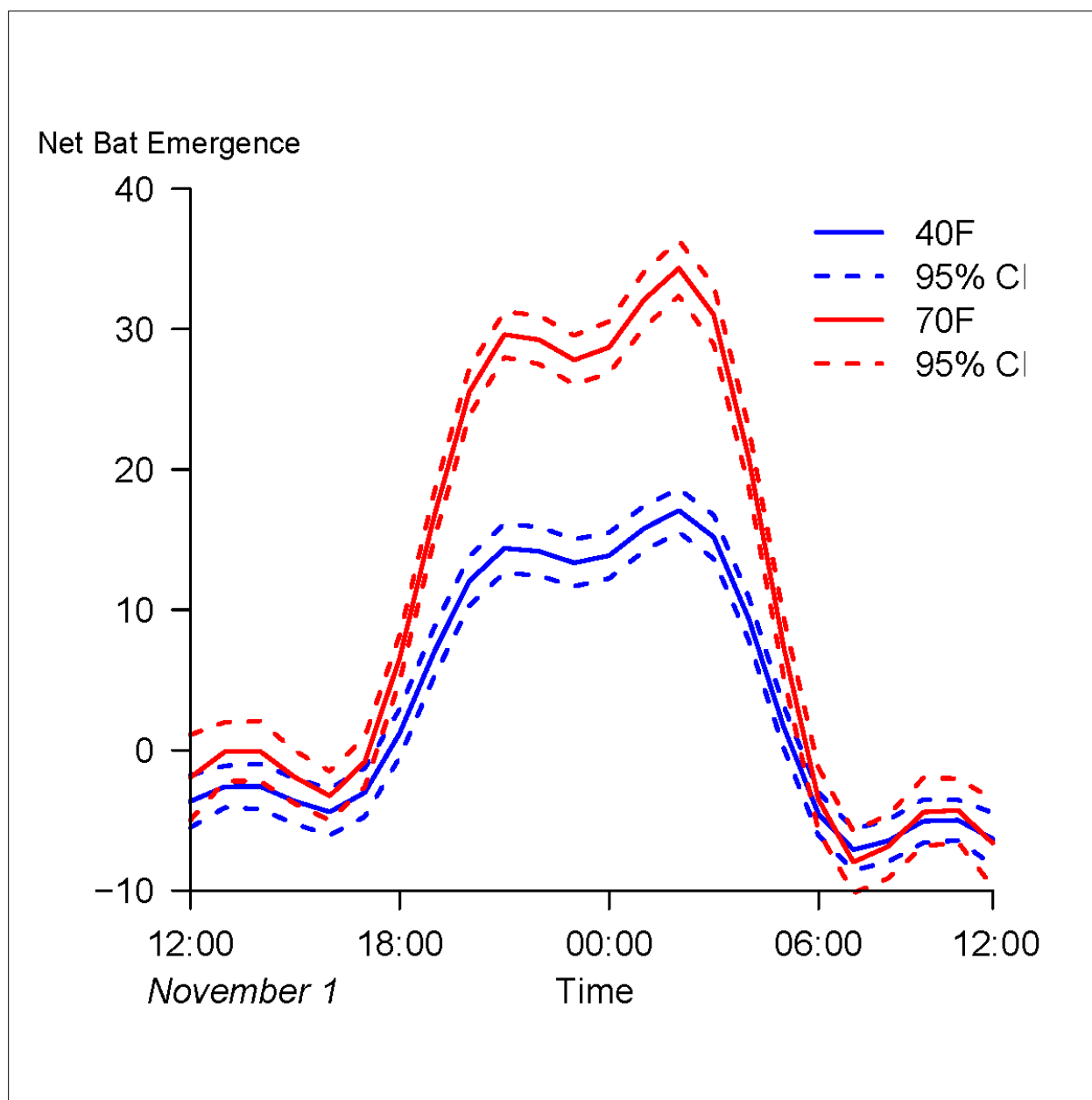


Figure SOP8-2. Example of predictive models of bat emergence from a roost during one day in November. Expected values (solid blue and red lines) for bat emergence at two different modeled ambient temperatures and their 95% confidence intervals (dashed lines) as estimated with AIC and additive models.

Data Flow—Cave Meteorological Sampling

Two methods (some simultaneously and some not) will be employed to collect cave meteorological data—opportunistic grab sampling and continuous sampling (see SOP—4: Winter Cave Roost Sampling and SOP—5: Cave Meteorological Sampling). Data collected by handheld sensors will be stored in the Microsoft Access database application developed by CUPN. The data manager or project leader will follow retrieval procedures developed in the working database application in order to obtain the raw data for performing analyses.

Data collected using automated data loggers will initially be stored in the park's "HOBO Offload" directory folder on the network's server located at the following path (using CHCH as an example): Z:\Vital_Signs\Vital_Signs_Prj\Cave_Air_Quality\Data\Working_Data\CHCH\HOBO_Offload.

HOBO data files will be checked for completeness (a quick quality check to look for missing data, failure, etc.) before being renamed and moved following the process and naming convention described in the "Processing Cave Meteorological Data Files" section of SOP—6: Post-field Sampling. The renamed and moved HOBO data files will be exported to a raw .csv file format in a temporary destination folder before being imported into a statistical package such as SigmaPlot or R for post-processing and validation. The final processed and validated .csv files will be saved and exported to the designated folder Z:\...\CHCH folder (in this example) for data analysis and archiving.

Data Analysis

In instances where the statistical questions become increasingly complex, data will need to be exported out of the working database application to commercial off-the-shelf statistical packages or to free software packages like R. Network staff primarily utilize SigmaPlot for frequency distribution plots, testing for normality, analysis of variance, time series analysis, etc. In these instances, the data manager will work with the project leader and the physical scientist to format data for export. These data will be exported as comma delimited ASCII text or Microsoft Excel files.

Similar to winter bat monitoring, additive models may be executed in the R software package (R Development Core Team 2011), using the R library *mgcv* (Wood 2008), with abundance estimates as a dependent variable, caves as a fixed-effect, and negative-binomial errors to account for overdispersion (Ingersoll et al. 2016). Independent variables may include bat-count, year, and selected environmental covariates such as meteorological data. Covariate models may be selected or combined using AIC (Akaike 1973; Burnham and Anderson 2002).

Opportunistic Grab Sampling

Opportunistic grab (or spot) sampling will use handheld sensors to measure cave temperature and RH adjacent to concentrations of bats during biennial winter censuses. The specific questions that will be addressed are:

1. What is the cave air/rock temperature at locations where bats (sorted by species) hibernate in each section of a cave and in each cave (all sections pooled)? What is the trajectory over time?
2. What is the RH at locations where bats (sorted by species) hibernate in each section of a cave and in each cave (all sections pooled)? What is the trajectory over time?
3. What is the cave air/rock temperatures and RH at locations where bats (sorted by species) hibernate park-wide and across the four CUPN parks? What is the trajectory over time?

A fabricated example of data is shown in Tables SOP8-4a and b below. Notice that the data have been analyzed to answer the status-related portions of questions 1 and 2 from above. A fabricated

example of data that addresses the trajectory-related portions of questions 1 and 2 from above is shown in Table SOP8-5 and graphed using additive modeling in Figure SOP8-3. This figure represents the type of graphical trajectory display that may be included in the eight-year Trend Analysis Reports. Further, sample statistics (i.e., means) from the continuous sampling data loggers (HOBO) have been included in the spreadsheet as a gauge for antecedent conditions prior to the biennial bat censuses. Although not shown in the example (Table SOP8-4b), additional sample statistics such as minimum, maximum, and standard deviation, will be calculated from continuous sampling data. We chose a one-month (four-week) period from which to gauge antecedent conditions in hibernacula because it includes the period of time when bats switch roosts (within/among caves) the least, and the relative concentrations of bats could have been affected by those conditions. Except in cases where measurements cannot be obtained adjacent to bats hibernating out of reach, only data associated with relatively high concentrations of bats in each section of cave will be used in analyses. In cases where high concentrations of bats in a section are beyond reach of the instruments, data will be collected from medium or relatively low concentrations of bats, if available.

While the conditions determined may not be the preferred atmospheric conditions for these bats, they are at least conditions the bats will use, and they do provide insight into conditions the bats may prefer. Having target temperature/humidity ranges for hibernacula can help park managers determine whether a cave needs remediation (through actions like entrance modification) in order to restore particular hibernacula that have been used historically.

Table SOP8-4a. Mock-up example (from SigmaPlot software) of cave rock and cave air temperature and relative humidity measurements obtained from two sections within two caves during two separate sampling events by opportunistic grab sampling.

Cave Name	Section	Species	Cave Rock Temperature	Cave Air Temperature	Cave Relative Humidity	Sample Number
Fake Cave 1	1	<i>Myotis sodalis</i>	2.50	2.36	48.00	1
Fake Cave 1	1	<i>Myotis sodalis</i>	1.80	1.79	45.20	2
Fake Cave 1	1	<i>Myotis sodalis</i>	2.20	1.89	51.80	3
Fake Cave 1	1	<i>Myotis sodalis</i>	2.80	2.30	60.20	4
Fake Cave 1	1	<i>Myotis sodalis</i>	2.95	2.91	65.80	5
Fake Cave 1	1	<i>Myotis lucifigus</i>	1.70	1.38	70.50	6
Fake Cave 1	1	<i>Myotis lucifigus</i>	1.60	1.20	64.84	7
Fake Cave 1	2	<i>Myotis sodalis</i>	4.02	3.87	58.40	1
Fake Cave 1	2	<i>Myotis sodalis</i>	4.30	4.19	64.20	2
Fake Cave 1	2	<i>Myotis sodalis</i>	3.50	3.46	53.40	3
Fake Cave 1	2	<i>Myotis sodalis</i>	5.10	4.44	51.80	4
Fake Cave 1	2	<i>Myotis sodalis</i>	3.90	3.73	60.50	5
Fake Cave 2	1	<i>Myotis sodalis</i>	6.20	6.18	70.00	1
Fake Cave 2	1	<i>Myotis sodalis</i>	7.10	6.46	64.80	2
Fake Cave 2	1	<i>Myotis sodalis</i>	3.70	3.04	61.40	3
Fake Cave 2	1	<i>Myotis sodalis</i>	8.00	8.10	80.50	4
Fake Cave 2	1	<i>Myotis sodalis</i>	7.80	8.00	85.60	5
Fake Cave 2	1	<i>Myotis sodalis</i>	6.90	7.17	90.40	6
Fake Cave 2	2	<i>Perimyotis subflavus</i>	12.50	12.45	86.80	1
Fake Cave 2	2	<i>Perimyotis subflavus</i>	12.59	13.10	90.10	2
Fake Cave 2	2	<i>Perimyotis subflavus</i>	13.10	12.98	89.20	3
Fake Cave 2	2	<i>Perimyotis subflavus</i>	12.42	12.35	86.30	4

Table SOP8-4b. Mock-up example (from SigmaPlot software) of summary data from cave rock and cave air temperature, relative humidity measurements obtained from two sections within two caves during two separate sampling events by opportunistic grab sampling and continuous sampling (air temp. and rel. humidity only). Concurrently collected Indiana bat (*Myotis sodalis*), little brown bat (*Myotis lucifigus*), and tri-colored bat (*Perimyotis subflavus*) winter counts are shown (“Bat Count”).

Cave Name	Section	Species	Mean Cave Rock Temp. ¹	Mean Cave Air Temp. ¹	Mean Cave Relative Humidity ¹	Bat Count ¹	Mean Air Temp. in Section for Previous 4 Weeks ²	Mean Relative Humidity in Section for Previous Weeks ²
Fake Cave 1	1	<i>Myotis sodalis</i>	2.45	2.25	54.20	50	2.58	55.4
Fake Cave 1	1	<i>Myotis lucifigus</i>	1.65	1.29	67.67	300	4.02	56.9
Fake Cave 1	2	<i>Myotis sodalis</i>	4.16	3.94	57.66	186	4.02	56.9
Fake Cave 2	1	<i>Myotis sodalis</i>	6.62	6.49	75.45	159	6.13	78.54
Fake Cave 2	2	<i>Perimyotis subflavus</i>	12.65	12.72	88.10	216	12.31	85.62

¹From Opportunistic Grab Sampling

²From Continuous Sampling

Table SOP8-4c. Mock-up example (from SigmaPlot software) of summary data from obtained from two sections within two caves during two separate sampling events by opportunistic grab sampling of collected Indiana bat (*Myotis sodalis*), little brown bat (*Myotis lucifigus*), and tri-colored bat (*Perimyotis subflavus*) winter counts are shown (“Bat Count”).

Data	Summary	Fake Cave 1: All Sections <i>M. sodalis</i>	Fake Cave 1: All Sections <i>M. lucifigus</i>	Fake Cave 2: All Sections <i>M. sodalis</i>	Fake Cave 2: All Sections <i>P. subflavus</i>	All Caves: All Sections <i>M. sodalis</i>	All Caves All Sections <i>M. lucifigus</i>	All Caves All Sections <i>P. subflavus</i>
Cave Rock Temperature	Mean	3.31	1.65	6.62	12.65	4.55	1.65	12.65
	Standard Deviation	1.034430063	0.070710678	1.568969938	0.306308668	2.05	0.070710678	0.306308668
	Minimum	1.80	1.60	3.70	12.42	1.80	1.60	12.42
	Maximum	5.10	1.70	8.00	13.10	8.00	1.70	13.10
Cave Air Temperature	Mean	3.09	1.29	6.49	12.72	4.37	1.29	12.72
	Standard Deviation	0.972204825	0.127279221	1.861938954	0.374966665	2.146799847	0.13	0.37
	Minimum	1.79	1.20	3.04	12.35	1.79	1.20	12.35
	Maximum	4.44	1.38	8.10	13.10	8.10	1.38	13.10
Cave Relative Humidity	Mean	55.93	67.67	75.45	88.10	63.25	67.67	88.10
	Standard Deviation	6.908617807	4.002224382	11.76906963	1.838477631	13.04090999	4.00	1.84
	Minimum	45.20	64.84	61.40	86.30	45.20	64.84	86.30
	Maximum	65.80	70.50	90.40	90.10	90.40	70.50	90.10

Table SOP8-5. Mock-up example of mean rock and air temperature, mean relative humidity, and biennial Indiana bat (*Myotis sodalis*) winter abundance based on hibernaculum counts in all sections (pooled) within one cave during 10 years. Cave meteorological data were collected by opportunistic grab sampling during biennial winter bat hibernaculum counts.

Cave	Year	Winter Bat Abundance	Mean Cave Rock Temperature (C ⁰)	Mean Cave Air Temperature (C ⁰)	Mean Cave Relative Humidity (%)
Fake Cave	2015	355	4.4	4.2	59.9
Fake Cave	2017	375	5.6	5.7	75.4
Fake Cave	2019	380	5.0	4.9	74.2
Fake Cave	2021	403	6.3	6.3	77.3
Fake Cave	2023	390	5.7	5.4	65.4
Fake Cave	2025	387	6.7	6.8	70.9
Fake Cave	2027	362	4.5	4.7	68.7
Fake Cave	2029	381	5.6	5.9	60.3
Fake Cave	2031	370	6.6	6.5	65.2
Fake Cave	2033	395	5.7	5.4	67.0

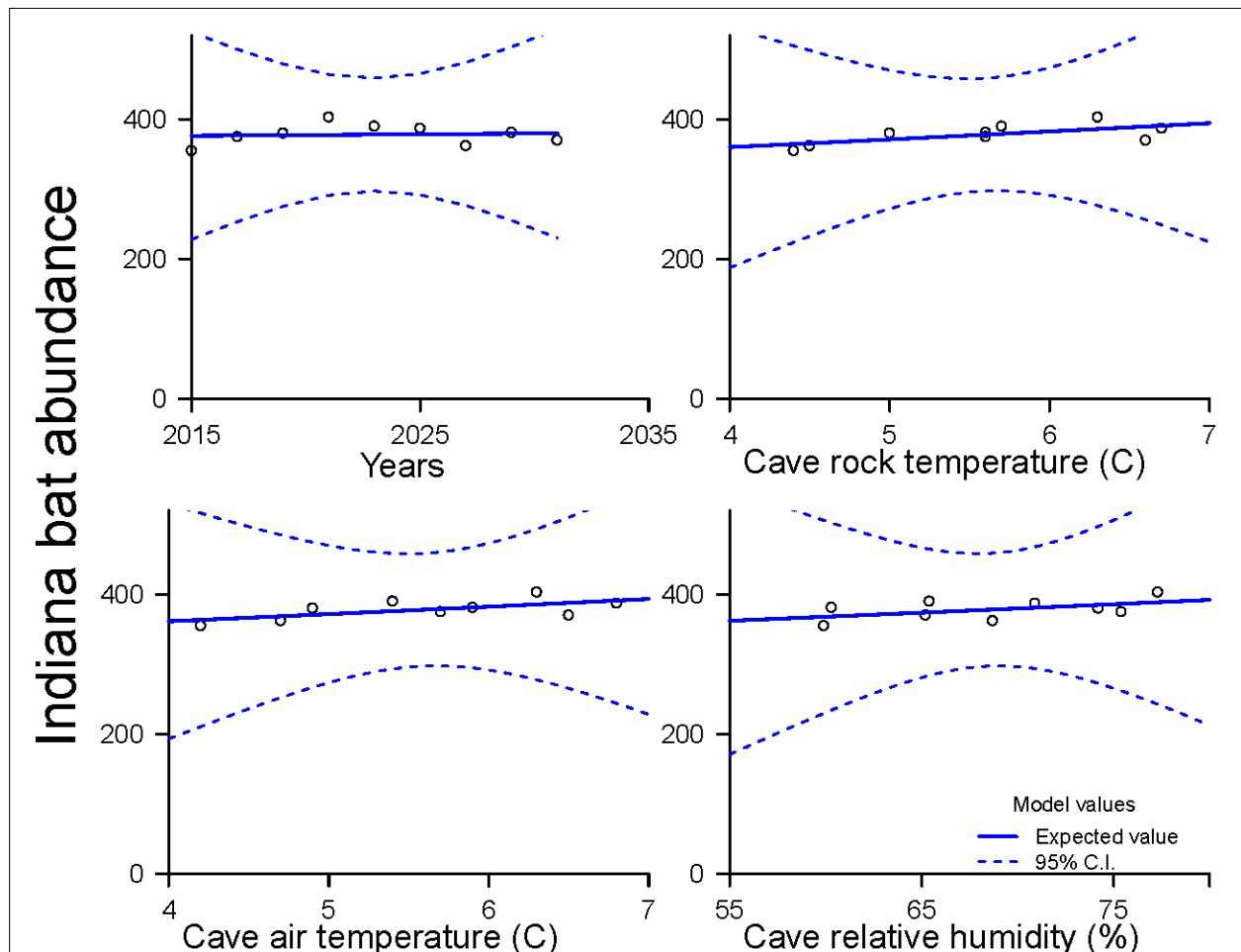


Figure SOP8-3. Generalized additive models for a simulated population of hibernating Indiana bats (*Myotis sodalis*) demonstrating abundance trajectories in relation to year, rock temperature, air temperature, and relative humidity.

Continuous Sampling

Continuous sampling will use automated data loggers placed in sampled caves (at summer roosts and winter hibernacula) to collect temperature and RH measurements every two hours throughout the year indefinitely. Sampling will follow methods outlined in Woodman et al. (2011). For each cave, additive models will be used to explore the relationship between cave air temperature/RH with bat abundance. For example, if a particular cave shows air temperature increasing over time and summer bat abundance estimates decreasing over time, then additive modeling of those data could document a correlation between temperature and abundance estimates and suggest that additional research should be considered.

Summer bat abundance estimates can only be analyzed at the species level for caves in which only one species is known to roost. This is because it is very difficult to distinguish among most bat species exiting a cave at night—especially among *Myotis* species. For all other summer roost caves, bat abundance estimates will include all bat species pooled.

For analysis of summer cave roosts, HOBO measurements collected 48-hours prior to (and including) the summer bat roost emergence count will be used to gauge cave atmospheric conditions that could influence the number of individual bats within the cave. We chose the 48-hour (2-day) interval in summer bat caves because bats tend to switch roosts frequently during that season, and we did not choose less than 48-hours in order to have a large enough sample size to reduce random error associated with individual temperature and humidity measurements.

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