Distribution and Roost Site Selection of Eastern Small-footed Bats (*Myotis leibii*) in Mountains of West-central Arkansas

Valerie M. Kearny[1], Roger W. Perry[2], Thomas S. Risch[1,3], and Virginie Rolland[1,*]

Abstract – The Eastern Small-footed Bat (*Myotis leibii*) is a rare species in eastern North America that is threatened by habitat loss and white-nose syndrome. Although rare, this species cannot be adequately evaluated for listing on the Endangered Species Act because of data deficiencies, including about its distribution and roost habitat. Our objectives were to document the distribution of Eastern Small-footed Bats and determine landscape and local characteristics that influence their probability of presence in the mountains of west-central Arkansas. Using acoustic monitoring, visual searches of rock formations, and mist-netting, we found that presence of Eastern Small-footed Bats was more likely in regions with talus slopes and nearby forest cover. These features may benefit the species by providing abundant options for roost switching, unique thermal properties, and short distances to foraging habitat.

Introduction

Bats are essential to ecosystem functioning across the globe and provide billions of dollars in pest control every year in the US (Boyles et al. 2011, Kasso and Balakrishnan 2013). However, climate change, habitat loss, and disease threaten many bat species (Boyles et al. 2011, Gamfeldt et al. 2008). Specifically, the fungus causing white-nose syndrome (WNS) occurs in many hibernacula and has decimated several North American bat species. One species at risk from WNS is *Myotis leibii* (Audubon and Bachman) (Eastern Small-footed Bat; Cryan et al. 2010, Gargas et al. 2009, Turner et al. 2011). This species hibernates in caves but also roosts in rocky habitats (Best and Jennings 1997, Moosman et al. 2015). Therefore, destruction of rare rock habitats through mining or quarrying activities and shale-gas extraction may further threaten Eastern Small-footed Bats (Moran et al. 2015, Wickham et al. 2013) in parts of their range.

Eastern Small-footed Bats occur in eastern North America from lower Ontario to the Appalachian Mountains and south-westward toward eastern Oklahoma. Despite their considerable range, these bats are generally considered rare (Best and Jennings 1997). Although globally endangered (Solari 2018), the species is not being considered for federal listing as threatened or endangered because a lack of data on its distribution and abundance prevents an adequate assessment of its conservation status (USFWS 2013).

[1]Department of Biological Sciences, Arkansas State University, State University, AR 72467. [2]Forest Service Southern Research Station, Hot Springs, AR 71902. [3]Arkansas Biosciences Institute, Arkansas State University, State University, AR 72467. [*]Corresponding author - vrolland@astate.edu.

Manuscript Editor: Andrew Edelman

In addition to a lack of data on distribution and abundance, inconsistent estimates of rates of decline are another reason the species has not received federal protection status; the decline has been estimated at 12% from hibernacula surveys versus 68–84% from summer mist-netting data (Francl et al. 2012, Moosman et al. 2013, Turner et al. 2011). Furthermore, some decline estimates were as high as 96.6% for Eastern Small-footed Bats, based on modeling projections of potential WNS spread (Alves et al. 2014). However, traditional bat-survey methods often fail to detect Eastern Small-footed Bats. Moosman et al. (2015) suggested that hibernacula surveys likely overlook the microsites in which these bats roost, such as inconspicuous cracks and crevices or under rocks of caves and mines (Barbour and Davis 1969, Best and Jennings 1997, Mohr 1936). Furthermore, Eastern Small-footed Bats are not cave obligates and can roost in aboveground rock ledges, including during the winter months (Moosman et al. 2017). Similarly, summer mist-net surveys often do not capture Eastern Small-footed Bats because capture rates decrease with distance from rock formations, such as rock outcrops, talus slopes, cliff faces, and glades where these bats roost (Johnson et al. 2011, Moosman et al. 2015, Saugey et al. 1993). These challenges have led to new methods in monitoring this rock-roosting species. In some areas of the Eastern Small-footed Bat's range, flipping rocks or searching rock crevices with flashlights has proved to be a successful way to find individuals in their diurnal summer roosts (Moosman et al. 2020).

During hibernation, Eastern Small-footed Bats may roost in caves and mines, either in cool, relatively dry sections or near the entrance (Barbour and Davis 1969, Best and Jennings 1997, Gunier and Elder 1973, Mohr 1936). Eastern Small-footed Bats may also hibernate in rock-ledge cracks and may even retreat deeper into the crevices of talus slopes (i.e., rock rivers or boulder fields) in the winter (Moosman et al. 2017, Saugey et al. 1993). Upon spring emergence, these bats are suspected to travel only short distances (<1–20 km) between winter hibernacula and summer roost sites (Farney and Fleharty 1969, Johnson and Gates 2008). Based on wing morphology, the Eastern Small-footed Bat likely does not travel extensive distances and may roost near essential resources such as water, protective cover, and foraging areas (Farney and Fleharty 1969, Johnson et al. 2011). Summer roost sites are generally in open-canopy rock formations close to vegetation and water and consist of narrow cracks and crevices among rocks (Johnson et al. 2011, Moosman et al. 2015, Roble 2004, Whitby et al. 2013). In West Virginia, Johnson et al. (2011) found Eastern Small-footed Bat roosts to be <15 m from vegetation and <1 km from perennial water, and in sites with canopy cover <52%. In addition to short travel distances, sparse canopy cover may also maximize energy conservation through greater solar exposure that may help these bats to passively warm themselves, as previously suggested for *Myotis ciliolabrum* (Merriam) (Western Small-footed Bat), a closely related rock-crevice roosting bat (Lausen 2007). Similarly, timing and duration of solar radiation that are determined by site aspect may influence roost microclimates (Lausen 2007, Vaughan and O'Shea 1976). In Canada, Western Small-footed Bats use roosts with southern aspects during the reproduction season (Lausen 2007, Van Zyll De Jong 1984).

Here, we aimed to (1) document the distribution of Eastern Small-footed Bats in the mountains of west-central Arkansas using 3 detection methods (acoustic, visual search, and mist-netting) and (2) determine local and landscape characteristics that influence the probability of presence of Eastern Small-footed Bats in the mountains of west-central Arkansas. We predicted that Eastern Small-footed Bats would select rock formations with specific landscape characteristics that minimize travel distances to foraging and drinking sites (e.g., <1 km from perennial water sources) and that maximize solar exposure in the roost for optimal thermoregulation (e.g., roosts with little canopy cover and on southern aspects).

Field-site Description

We conducted the study in the greater Ouachita Mountains of west-central Arkansas, representing the most southwestern portion of the Eastern Small-footed Bat's range (Best and Jennings 1997, Sasse et al. 2013). This area comprises the Arkansas Valley and Ouachita Mountains Level III Ecoregions (Fowler and Anderson 2015). The Ouachita Mountains were formed in the Paleozoic era through continental collide and consist of sandstone, shale, and chert (Fowler and Anderson 2015). This east–west trending mountain range is folded, rugged, and lithologically distinct from the Ozark Mountains to its north. Natural vegetation consists of mixed *Pinus echinata* Mill. (Shortleaf Pine), *Quercus* spp. (oak), and *Carya* spp. (hickory) forests with extensive areas of planted *Pinus taeda* L.(Loblolly Pine) (Fowler and Anderson 2015). The Arkansas River Valley, north of the Ouachita Mountain Ecoregion, contains a diverse transitional topography of terraces, mountains, hills, plains, and floodplains and is known for the oil-rich Arkoma Basin. The Arkansas Valley consists of a wide mix of both deciduous and coniferous forest lands and prairie habitats. Common land uses include poultry and livestock farming as well as planted hay fields (Fowler and Anderson 2015). Based on data collected from 15 weather stations across the study area from 2006 through 2020, total precipitation averaged 150.6 cm for the year. For the June–August period, total precipitation averaged 33.8 cm and mean temperature averaged 26.4 °C (NCEI and NOAA 2020).

We conducted our surveys at rock features (classified as sites) in the Rich Mountain–Black Fork Mountain, Caddo Mountain, Mount Magazine, Mount Nebo, Petit Jean Mountain, and Pinnacle Mountain regions of Polk, Scott, Montgomery, Logan, Yell, Conway, and Pulaski counties. We focused on 3 different types of rock features: outcroppings, glades, and talus slopes. Talus slopes are accumulated areas of loose rocks or boulders and are sometimes called rock rivers or boulder fields (Albjar et al. 1979, Saugey et al. 1993). Outcroppings mostly consist of large, exposed pieces of bedrock that are nearly vertical (Moosman et al. 2017). Finally, glades are areas of thin soil and exposed flat bedrock and are often called barrens (Jeffries 1985). The predominant type of rock feature in the Rich Mountain–Black Fork Mountain area is talus slopes appearing as "rock islands" dotted throughout the forest, whereas the Caddo Mountain area generally contains ridgelines of outcroppings and glades mosaicked with vegetation. Both Mount Magazine and Mount Nebo are plateaus ringed in cliff faces and talus slopes; however, Mount Magazine has more of both rock-feature types. Pinnacle Mountain has a bare rocky peak with rock outcroppings and a few talus slopes on the mountain sides (we surveyed only 1 talus slope site), whereas Petit Jean Mountain has extensive cliff faces and barren-like glades.

Methods

We used multiple sources of orthoimagery (ESRI 2020, NRCS 2006) to review and identify rock features. Each rock feature represented a potential site. For site selection in 2019, we reclassified orthoimagery (NRCS 2006) to show areas of brightness (i.e., spectral reflectance values ≥190 per pixel on a scale of 0 to 255) associated with rock. We used this method of reclassification to identify rocky areas where rock feature boundaries were not distinct, primarily an issue in the Caddo Mountains. We used these areas of brightness and with sparse canopy cover to delineate potential rock-feature sites (ESRI 2020, Moosman et al. 2015). We only reviewed orthoimagery for site selection in 2020 because reclassification from the 2019 survey was not discerning enough.

For the 2019 field season, which was focused on the Rich Mountain–Black Fork Mountain and Caddo Mountain area, we chose sites (separate rock features) ≥0.4 ha within 1 km of a road or hiking trail and with slopes <35% (ESRI 2019) that allowed accessibility by field personnel. For the 2020 field season, to compensate for the lack of accessible rock features in the Caddo Mountain area, we revisited some sites from 2019 in the Rich Mountain–Black Fork Mountain area and added sites in Mountain Magazine, Mount Nebo, Petit Jean Mountain, and Pinnacle Mountain areas. Additionally, we reduced constraints on site selection to include sites ≥0.2 ha, within 1.5 km of a road or hiking trail, with an access route on <35% slope. All chosen sites (which we assigned a unique ID) were ≥250 m apart to maintain independence because consecutive roosts can be up to 204 m apart, although most are within 70 m (Johnson et al. 2011).

General procedures and acoustic detection

We searched rock crevices visually with flashlights and used additional methods in a multi-tiered approach to detect the presence of Eastern Small-footed Bats at rock-feature sites. We used a combination of acoustic detectors, constrained visual searches, and mist-netting to increase detection probability. Unlike visual searches and mist-netting, acoustic detectors cannot confirm the presence of Eastern Small-footed Bats, although they are a helpful noninvasive monitoring tool (Britzke 2003, Britzke et al. 2002, Fenton and Bell 1981, Rydell et al. 2017). We only used mist-nets to survey for bats when acoustics indicated potential presence of *Myotis* but visual searches were unsuccessful. This tiered approach reduced labor costs while increasing detection probability by requiring only 1 method to confirm presence, but allowing for multiple chances to detect presence.

We deployed 2 acoustic detectors (Anabat SD2 or Anabat Swift; Titley Scientific, Columbia, MO) for 5 consecutive nights at each site. With microphones attached directly to detectors, we positioned detectors on rocks and at an angle of about 45° upward from the true horizontal but perpendicularly to the forest edges of a site such that detectors were directed toward the rock feature and not facing upslope or downslope. All detectors recorded from 2000 to 0600 h local time (i.e., Central Daylight Time). We classified echolocation calls into low-frequency calls (<30 kHz), mid-frequency calls (>30kHz and <60 kHz), and high frequency (>60 kHz) *Myotis* calls (Fenton and Bell 1981) using Bat Call Identification version 2.7d (BCID, Kansas City, MO). We only included calls with ≥5 pulses for analysis and considered group identification accurate if ≥75% of pulses were identified to group. We used either AnalookW version 4.3x or Anabat Insight version 1.8.3 (based on detector type used; Titley Scientific, Columbia, MO) to visually verify calls for which ≥75% of pulses were identified as *Myotis*. We considered *Myotis* calls as only indicating potential presence of Eastern Small-footed Bats, because we were unable to discern their calls from those of other *Myotis* species.

Constrained visual searches and mist-netting

Using the 'fishnet' tool on ArcGIS Pro 2.4.1 (ESRI 2019), we placed a grid with 10 m x 10 m cells over the rock-feature sites. The center of each cell represented the center of a potential 6-m radius plot for visual searches. We used a random number generator to randomly select 5 to 9 plot centers in each rock-feature site. We adopted an equal sampling approach of 5 plots per site in 2019 covering 0.4–13% of the area of a site (0.43–15.66 ha). To increase detection probability, we modified our sampling in 2020 so that a minimum of 5 plots were sampled for the smallest sites and proportionally more plots were sampled for larger sites (maximum of 9 plots), covering 2–18% of the area of a site (0.31–6.02 ha). At each site, we navigated to rocks that were as close as possible to the plot center point using a Garmin 64s handheld GPS (Garmin International Inc., Olathe, KS).

In each plot, a team of 2 (V.M. Kearny and 1 consistent assistant per year) searched every crack and crevice for bats with the same 800-lumen, pocket-sized flashlights (Lampo Optoelectronics Co., Ltd, Shenzhen, China; BYBlight, UK). The team conducted searches until either both observers were confident all cracks and crevices within the plot were examined or until an hour elapsed. Search time varied based on the number of open crevices (Whitby et al. 2013) in a plot (Moosman et al. 2015, 2020). We recorded Eastern Small-footed Bat roost locations and classified each plot as either bats present or not detected. To guard against a fatigue effect, breaks were taken between plots and no more than 6 plots were surveyed in a day.

When acoustic analyses indicated a *Myotis* call with ≥75% confidence but the constrained search did not yield any bats, we mist-netted at the site or at a potential flyway or water source as close as possible to the site. In 2020, field work was delayed because of precautions surrounding the SARS-CoV-2 pandemic and the possible risks associated with human–wildlife contact (Abdel-Moneim and Abdelwhab 2020). We used mist-nets of 2.6 m in height and 4, 6, 9, 12, or 18 m in length (Avinet, Portland, OR) depending on netting location. We often stacked nets using a pulley system to increase height and fill corridor openings or set up nets directly on rocks as an unstacked system. We deployed nets around 15 min before sunset when weather was favorable. When netting was possible at or close to the site, we left nets open for ≥2 h after sunset to capture bats as they emerged from their day roosts (Moosman et al. 2015). When the lack of accessibility forced us to net away from the site, we deployed nets for 3–4 h after sunset to catch bats as they began nightly foraging. We took appropriate measures to ensure animal safety (Sikes et al. 2016) as described in our IACUC (Institutional Animal Care and Use Committee) protocols and permits (A-State IACUC FY18-19-213, USFS IACUC 2019–006; AGFC Scientific Collection Permits 010820191 and 011420205; and Arkansas Department of Parks, Heritage and Tourism Collection Permit 068-2020).

Data analysis

We assessed the effectiveness of methods of detection in 2 ways. First, we conducted a McNemar's test using program R (Version 3.5.3; R Core Team 2019) to see if detection of *Myotis* at a site differed between the visual-search and acoustic-detection methods. Second, assuming that detection increases with abundance or activity, we ran a non-parametric Spearman correlation test using Program R between the number of Eastern Small-footed Bats visually confirmed at each site and an activity index for *Myotis* (Miller 2001) based on acoustic results from each site. We calculated the activity index for the *Myotis* group at each site by adding the number of 1-min intervals with at least 1 identifiable *Myotis* call divided by the sampling effort (number of detector-nights). We report mean *Myotis* activity index ± SE. For both tests, we accepted statistical differences at $\alpha = 0.05$.

We analyzed presence–absence data at 2 scales: landscape (site and beyond) and local (plot). For both scales, we used mixed-effects logistic regression (generalized linear mixed models [GLMMs]) with a binomial error distribution. We considered only visual-search data (landscape- and local-level analyses) and mist-netting data (landscape-level analysis only) in our analysis. We defined the response variable presence as 1 for plots (local-level analysis) or sites (landscape-level analysis) with an Eastern Small-footed Bat.

Fixed effects included 7 landscape-level and 7 local-level variables (Table 1). We treated aspect as a circular variable using the 'circular' package (Agostinelli and Lund 2017) in Program R (R Core Team 2019). To account for possible intra- and inter-observer effects (Moosman et al. 2020), we included week and year as random effects (slope and intercept, respectively) for both landscape-level and local-level models. We used site ID as an additional random effect in local-level models.

We built multiple GLMMs with different fixed-effect combinations in the statistical program R using the 'lme4' package (Bates et al. 2015). We first identified the best random variable structure and then used it to determine the best fixed variables. To determine the best fixed-effect structure, we first tested models with only control variables. Then, we built models using the best control variable structure and combinations of the candidate variables. We calculated a variance inflation factor (VIF <2) to ensure models involving multiple predictor variables did not have collinearity issues. For each of these 3 steps, we conducted model selection at the landscape level and at the local level. For both the landscape and local levels, we used an information-theoretic approach to compare models based on an Akaike information criterion corrected for small samples (AIC_c) using the 'AICcmodavg' package in R (Burnham and Anderson 2002, Mazerolle 2019). We considered the model with the lowest AIC_c and ΔAIC_c <2 to be the best. However, if 2 models had ΔAIC_c <2, we selected the most parsimonious model (Burnham and Anderson 2002). We report the mean ± SE for each quantitative variable for plots where Eastern Small-footed Bats were visually observed and those where they were not, as well as the mean probability of presence and slope estimates at both the plot and site levels.

Results

Distribution of Eastern Small-footed Bats in west-central Arkansas

During this study, we visited 47 unique sites: 14 in 2019, 22 in 2020, and 11 in both years but at different plots. The 47 sites consisted of 10 glades, 8 outcroppings, and 29 talus slopes. Of the 11 sites searched in both years, 4 sites switched presence status between years; Eastern Small-footed Bats were detected at 25 (7 in 2019,

Table 1. Habitat variable names, descriptions, collection method, and data source. An asterisk (*) indicates a variable that was part of an a priori hypothesis, the other variables were treated as controls. GIS slope tool, aspect tool, and mosaic to new raster tool were all using the USGS National Elevation dataset (USGS 2019a).

Variables	Variable description	Source
Landscape-level		
Feature*	Rock feature category: talus slope, outcropping, or glade	In situ
Region	Mountain area: Rich-Black Fork, Caddo, Mt. Magazine, Mt. Nebo, Petit Jean, or Pinnacle	Geographic information systems (GIS)
Age	Geologic time period of bedrock (i.e., Silurian, Cretaceous)	GIS, using USGS geologic dataset (USGS 2000)
Stream*	Distance from center of site to perennial water (m)	GIS, using USGS National Hydrography dataset (USGS 2019b)
Road	Distance from center of site to closest road (m)	GIS, using ARDOT road data set (ARDOT 2014)
Area	Total area of rock feature site (ha)	GIS, geometric calculation
Distrock*	Distance from center of site to next closest rocky area (m)	GIS, using ESRI Living Atlas (ESRI 2020) orthoimagery
Local-level		
Vegamnt	Percentage of plot covered in vegetation	In situ, visual estimation
Vegtype	Dominant vegetation type in a plot: grass, tree, shrub, forb, or other	In situ, visual estimation
Canopy*	Percent canopy cover at plot center (%)	In situ, spherical densiometer
Edge*	Distance from plot center to rock-feature edge where forest vegetation begins (m)	GIS, measuring tool
Slope	Percentage of rise or fall of plot land surface (%)	GIS, Slope tool
Aspect*	Compass direction of the downhill slope of plot (°)	GIS, Aspect tool
Elevation	Height of plot above sea level (m)	GIS, Mosaic to new raster tool

18 in 2020) of the 47 sites (Figs. 1, 2). Of the 314 plots searched, 63 plots had 90 Eastern Small-footed Bat roosts that contained 149 total individuals (an additional bat was also found while traveling between plots in the Rich Mountain–Black Fork region; Table 2). In addition to bats found through visual searches, mist-netting yielded 1 Eastern Small-footed Bat at a Black Fork Mountain site in 2019 and 3

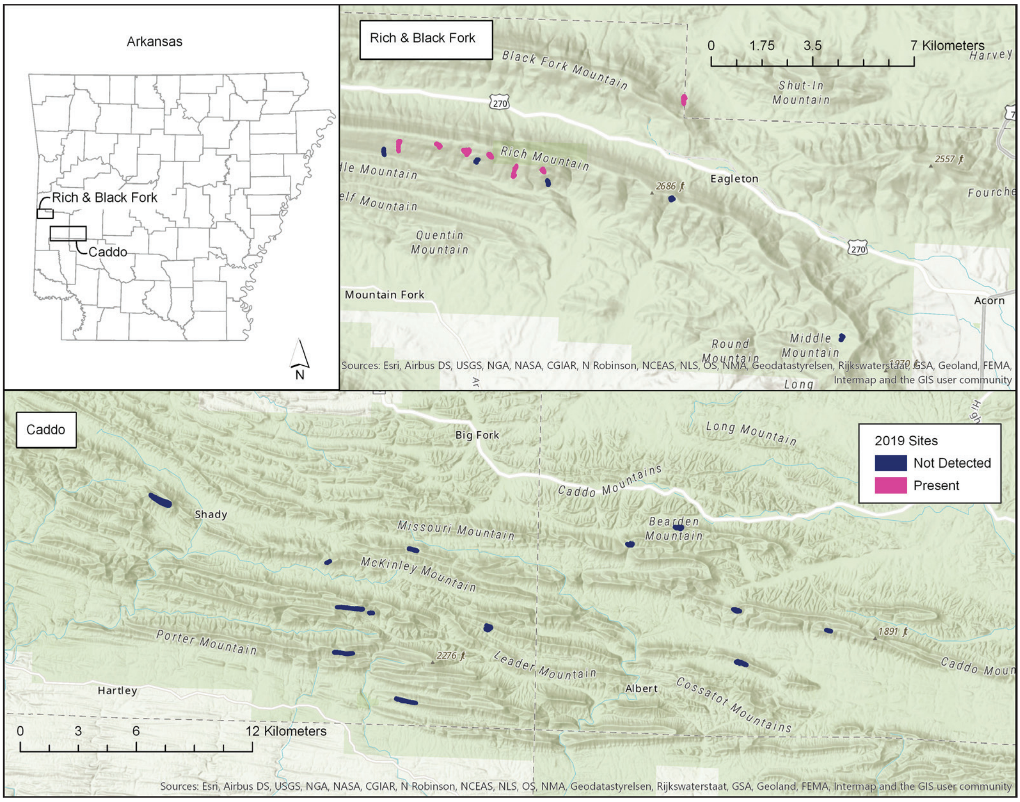

Figure 1. Locations of surveys and detections of Eastern Small-footed Bats (*Myotis leibii*) during summer 2019 in the Rich Mountain-Black Fork Mountains and Caddo Mountains, AR.

Table 2. Mountainous regions where rock-feature searches and mist-netting were conducted for Eastern Small-footed Bats (*Myotis leibii*) in west-central Arkansas, 2019–2020. Site probabilities, based on visual searches and mist net results, are from models with region as the predictor (see Table 1). Plot probabilities, based on visual searches of plots only. Searches resulted in 154 total visual observations (“positive”: 149 from plot searches, 4 from netting, 1 found while traveling between plots).

	Positive (total)		Probability of presence		Total *M. leibii*
Mountain region	Sites	Plots	Site	Plot	observed
Rich-Black Fork	16 (19)	39 (172)	0.614 ± 0.116	0.212 ± 0.053	83
Caddo	0 (13)	0 (65)	<0.001	<0.001	0
Mt. Magazine	6 (6)	22 (30)	1.000 ± 0.000	0.693 ± 0.114	65
Mt. Nebo	3 (3)	2 (16)	1.000 ± 0.000	0.100 ± 0.078	6
Petit Jean	0 (5)	0 (26)	<0.001	<0.001	0
Pinnacle	0 (1)	0 (5)	<0.001	<0.001	0

bats at 2 sites on Mount Nebo in 2020. We did not find Eastern Small-footed Bats in the Caddo area, where most rock features were inaccessible because of steep inclines. Of the 13 Caddo sites that were accessible, most had relatively few cracks and crevices in the rocks (outcroppings and glades).

Comparison among detection methods

We found a significant difference in detectability between methods ($\chi^2_1 = 14.06$, $P < 0.001$). Presence detected through visual searches was always corroborated by detection of *Myotis* via acoustic detectors ($n = 27$ sites). By contrast, acoustic detectors were more liberal at detecting *Myotis* presence than visual searches. At 21 sites, acoustic detectors recorded *Myotis* calls that were not confirmed visually, and follow-up mist-netting efforts confirmed the presence of Eastern Small-footed Bats at only 3 of those sites. Mist-netting generally did not produce Eastern Small-footed Bat captures, but in 2020, 4 additional sites (1 Pinnacle Mountain site, 1 Petit Jean site, and 2 Rich Mountain sites) that required netting events for confirmation after acoustic detection of *Myotis* could not be surveyed with nets due to labor and time constraints caused by the SARS-CoV-2 pandemic.

Across both years, activity index strongly and positively correlated with the number of Eastern Small-footed Bats confirmed visually ($\rho = 0.62$, $P < 0.001$). The

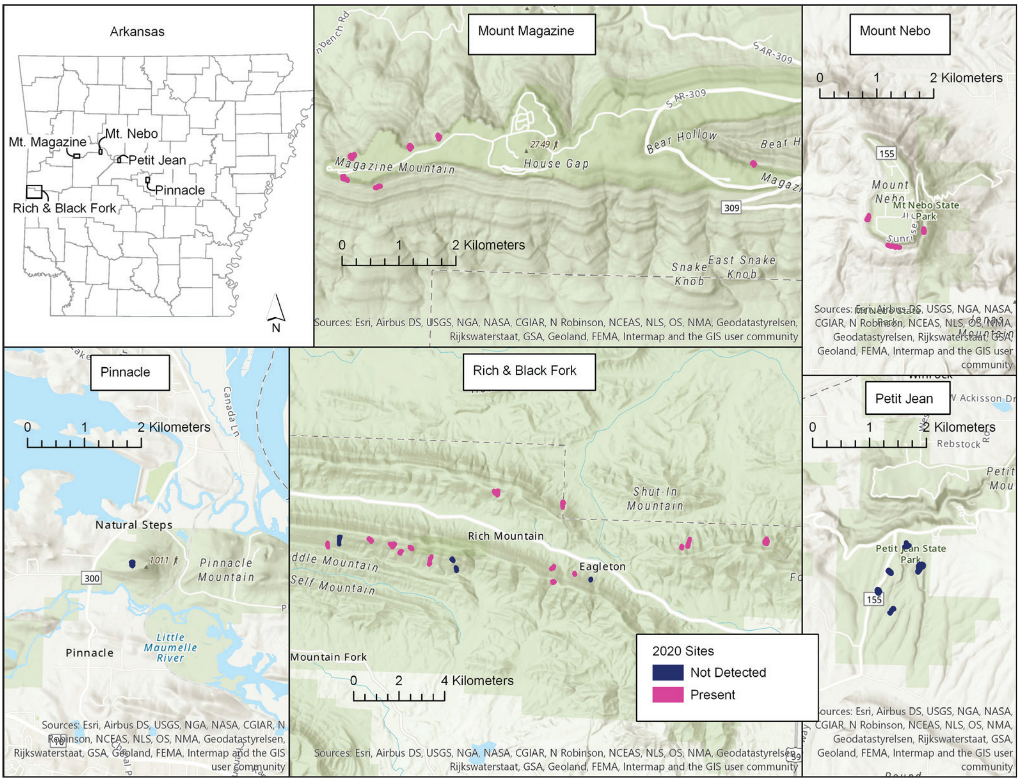

Figure 2. Locations of surveys and detections of Eastern Small-footed Bats (*Myotis leibii*) during summer 2020 in Mount Magazine, Mount Nebo, Pinnacle Mountain, Rich Mountain-Black Fork Mountains, and Petit Jean Mountain, AR.

average *Myotis* activity index was 4.82 ± 1.04, and only 8 sites (14.29% of total sites) had an activity index of 0.

Factors associated with presence of Eastern Small-footed Bats

We visually confirmed Eastern Small-footed Bats at talus slope features in the Rich Mountain–Black Fork Mountain, Mount Magazine, and Mount Nebo regions, but we did not detect the species in the other regions. Accordingly, the top 2 overall models for the landscape-level analysis included region as a fixed effect (Table 3), with week and year as random slope and intercept, respectively. However, the best overall model did not include any of the candidate variables (Table 3). Moreover, the region and age variables were collinear (VIF >2), thus excluding all models with that combination of variables from analysis. Presence probability of Eastern Small-footed Bats was 0.17 ± 0.09 on average, but varied between 0 for the Caddo Mountain and 1 for Mount Nebo and Mount Magazine.

With the local-level analyses, the best random structure only included site ID and year as the random effects. The most parsimonious control variable structure

Table 3. Models with landscape-level control and candidate variables to determine probability of presence of Eastern Small-footed Bats (*Myotis leibii*) in the mountainous regions of west-central Arkansas, 2019–2020. Year and week were random intercept and slope effects, respectively, for all models. Intercept was included. Models involving region + age were excluded because of collinearity (variance inflation factor ≥2). See Table 1 for variable descriptions. AIC_c = Akaike information criterion corrected for small samples; ΔAIC_c = difference between AIC_c and lowest overall AIC_c; ω_i = AIC_c weight.

Models	AIC_c	ΔAIC_c	ω_i
Models with landscape-level controls			
Region + area	53.9	0.0	0.6
Region[A]	55.8	1.9	0.2
Region + road + area	56.8	2.9	0.1
region + road	57.4	3.5	0.1
Age	64.0	10.1	<0.1
Age + road	65.6	11.7	<0.1
Age + area	66.0	12.1	<0.1
Age + road + area	68.1	14.2	<0.1
Null	73.6	19.7	<0.1
Area	74.8	20.9	<0.1
Road	75.5	21.6	<0.1
Road + area	75.6	21.8	<0.1
Overall candidate models			
Region[B]	55.8	0.0	0.5
Distrock + region	58.0	2.2	0.2
Stream + region	58.6	2.8	0.1
Feature + region	59.3	3.5	0.1
Stream + distrock + region	61.0	5.2	<0.1
Feature + stream + region	62.4	6.6	<0.1
Feature + distrock + region	62.5	6.7	<0.1
Feature + stream + distrock + region	65.7	9.9	<0.1

[A]Most parsimonious control structure.
[B]Best overall model.

included elevation and vegetation amount, but the best overall model also included distance from feature edge (Table 4). The average presence probability was 0.13 ± 0.07 at the plot level. This probability increased with elevation (slope = 0.01 ± 0.002), decreased as the amount of vegetation cover within a plot increased (slope = -0.03 ± 0.01), and decreased as distance from forest edge increased (slope = -0.06 ± 0.03) (Fig. 3; Tables 4, 5).

Discussion

In Arkansas, the Eastern Small-footed Bat likely has an aggregated distribution across the landscape, restricted to areas where appropriate talus slope habitat occurs. Of the surveyed habitats, talus slopes were the only feature where we found the species. Many species have a discontinuous distribution across the landscape, most commonly to access a limiting factor on the landscape or because of their

Table 4. Models with local-level control and candidate variables to determine probability of presence of Eastern Small-footed Bats (*Myotis leibii*) in the mountainous regions of west-central Arkansas, 2019–2020. Site ID and year were random intercepts for all models. See Table 1 for variable descriptions. AIC_c = Akaike information criterion corrected for small samples; ΔAIC_c = difference between AIC_c and lowest overall AIC_c; ω_i = AIC_c weight.

Models	AIC_c	ΔAIC_c	ω_i
Models with local-level controls			
Elevation + vegamnt + slope	237.3	0.0	0.5
Elevation + vegamnt[A]	237.9	0.1	0.5
Elevation	241.9	4.6	<0.1
Elevation + slope	242.7	5.4	<0.1
Elevation + vegamnt + vegtype	245.8	8.5	<0.1
Elevation + vegtype	246.7	9.4	<0.1
Elevation + vegtype + slope	247.0	9.7	<0.1
Vegamnt + slope	271.0	33.7	<0.1
Vegamnt	272.0	34.7	<0.1
Vegamnt + vegtype + slope	276.0	38.7	<0.1
Elevation + vegamnt + vegtype + slope	276.0	38.7	<0.1
Vegamnt + vegtype	276.3	39.0	<0.1
Vegtype	279.1	41.8	<0.1
Vegtype + slope	279.4	42.1	<0.1
Slope	283.3	46.0	<0.1
Null	283.5	46.2	<0.1
Overall candidate models			
Edge + elevation + vegamnt[B]	233.3	0.0	0.5
Aspect + edge + elevation + vegamnt	235.3	2.0	0.2
Canopy + edge + elevation + vegamnt	235.3	2.0	0.2
Elevation + vegamnt	237.4	4.1	<0.1
Canopy + aspect + edge + elevation + vegamnt	237.4	4.1	<0.1
Canopy + elevation + vegamnt	239.1	5.8	<0.1
Aspect + elevation + vegamnt	239.5	6.2	<0.1
Canopy + aspect + elevation + vegamnt	241.2	7.9	<0.1

[A]Most parsimonious control structure model.
[B]Best overall model.

social biology (Brown and Orians 1970). Eastern Small-footed Bats likely have a discontinuous distribution because their preferred roosting habitat is aggregated or because of social behaviors with conspecifics (e.g., maternity clusters, fall swarming; Albjar et al. 1979, Cope and Humphrey 1977, Willis and Brigham 2007).

We detected Eastern Small-footed Bats in 3 mountain regions of west-central Arkansas: Rich Mountain–Black Fork Mountains, Mount Magazine, and Mount Nebo. The first 2 regions are associated with previous detections of Eastern Small-footed Bats (Sasse et al. 2013). However, we detected Eastern Small-footed Bats at Mount Nebo where Saugey (2005) previously failed to document the species. Although we did not visually confirm the species on Pinnacle Mountain, we had a positive acoustic detection for *Myotis* but were not able to conduct mist-netting; we recommend this area be further searched for presence of Eastern Small-footed Bats before inferring species absence. Similarly, although we surveyed all the accessible rock features we found in aerial imagery, there may be Eastern Small-footed Bats present in other locations. Overall, our study provides

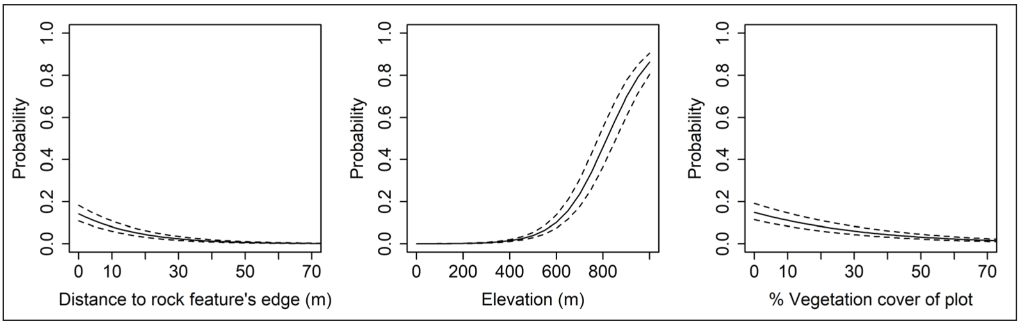

Figure 3. Probability of Eastern Small-footed Bat (*Myotis leibii*) presence at the local level estimated with a generalized linear mixed model based on distance from plot to rock feature edge, elevation, and vegetation cover (%) in west-central Arkansas, summers 2019–2020.

Table 5. Habitat characteristics (mean ± SE) for plots where Eastern Small-footed Bats (*Myotis leibii*) were detected and not detected during visual searches of rock features in west-central Arkansas, 2019–2020.

Variable	Detected	Not detected
Landscape level		
Distance to stream (m)	587 ± 37	390 ± 14
Distance to road (m)	610 ± 78	587 ± 31
Distance to closest rock feature (m)	188 ± 19	210 ± 11
Total site area (ha)	0.6 ± 0.1	0.8 ± 0.1
Local level		
% canopy cover	15 ± 1	17 ± 1
% vegetation cover	10 ± 2	25 ± 1
Distance to edge (m)	9.4 ± 0.9	12.2 ± 0.6
Aspect (°)	177 ± 13	173 ± 5
% slope	37 ± 2	33 ± 1
Elevation (m)	679 ± 11	541 ± 9

support for visual searches of rock features (Moosman et al. 2020) and acoustic monitoring as effective detection methods.

Visual searches may have a higher chance for false negative results because Eastern Small-footed Bats may be present but not detected. Absence of detection does not always indicate absence of species (MacKenzie et al. 2017, Pellet and Schmidt 2005). For example, 4 of the 11 sites surveyed in both years were associated with a detection in one year but not the other, possibly because of variation among plots (Moosman et al. 2020). However, the use of mist-nets helped confirm the presence of Eastern Small-footed Bats at only 3 sites following an acoustic detection, suggesting that visual searches in plots are associated with high probabilities of detection at talus slopes (Moosman et al. 2020).

All rock-feature sites where we visually observed Eastern Small-footed Bats in west-central Arkansas were talus slopes. We did not detect them at non-talus slope features. Other studies reported this species roosting occasionally in other types of rock features, such as cliff faces in West Virginia (Johnson et al. 2011), and rock ledges in Virginia (Moosman et al. 2017). Whitby et al. (2013) is the only study to report Eastern Small-footed Bats roosting exclusively under rocks at barren-like glade features in Illinois. Either this species was less likely to use glades and outcroppings in Arkansas, or visual searches are not as effective for these non-talus slope features. We were unable to survey many inaccessible rock features such as cliff faces, but our lack of detection in cliffs does not mean this species does not occupy this type of rock feature (Loeb and Jodice 2018, Saugey 2007). We also only surveyed 10 glades and 8 outcroppings; thus, we cannot conclusively say Eastern Small-footed Bats are not using these or other rock features in west-central Arkansas. For these non-talus slope features, mist-netting may be an appropriate method following acoustic surveys where travel corridors are available (Ford et al. 2005). However, acoustic and mist-netting results should be interpreted with caution because netting bats during foraging hours could mean the bats may have been roosting somewhere other than the target site. We only captured Eastern Small-footed Bats in mist-nets placed at roost sites or in travel corridors directly adjacent to rock-feature sites, corroborating the idea that capture rates decrease with increasing distance from rocky areas (Johnson et al. 2011).

Although the best landscape-level model did not include rock-feature type, we did not find Eastern Small-footed Bats at other rock features. Therefore, talus slopes may provide unique thermoregulatory opportunities with deep crevices that may offer winter hibernacula (Moosman et al. 2015, Saugey et al. 1993). For instance, *Ochotona princeps* (Richardson) (American Pika) in the Colorado Rocky Mountains use the distinctive thermal properties of talus slopes to persist (Benedict et al. 2020). Furthermore, talus slopes may be preferred over glades and outcroppings because they represent a concentrated area of small crevices that allows ample options for roost switching. We suggest conducting surveys at talus slopes in the early spring and late fall to determine the timeline of Eastern Small-footed Bats' use of talus slopes in Arkansas, following Moosman et al. (2015) in Virginia.

Region was collinear with geologic age and both variables may indicate where talus slopes formed across the landscape. Probability of presence was greatest at Mount Magazine, which appeared to have the greatest concentration of talus slopes, and lower in regions with lower concentrations of talus slopes. Greater concentrations of rocky areas could allow for roost switching without traveling long distances and could foster social interactions (Cope and Humphrey 1977, Johnson and Gates 2008, Johnson et al. 2011, Willis and Brigham 2007). Frequent roost switching has been observed in other bat populations, including Eastern Small-footed Bats, and may aid in predator and parasite avoidance (Chruszcz and Barclay 2002, Lausen 2007, Lausen and Barclay 2002). We hypothesize that the probability of Eastern Small-footed Bat presence may be greater at Mount Magazine than at other surveyed regions because Mount Magazine's greater number of cliff faces and talus slopes provide abundant roost habitat to support larger local populations (Loeb and Jodice 2018, Saugey 2007).

Distance from streams did not appear in our landscape-level model selection, and sites occupied by Eastern Small-footed Bats tended to be farther from streams than sites where bats were not detected. This result is opposite of our prediction that occupied sites would be closer to water than random sites, most likely because bat presence increased with elevation and higher-elevation sites tended to be farther from streams. Although sites where Eastern Small-footed Bats were detected were on average ≤1 km from perennial water, 2 occupied sites were >1 km (1.05 km and 1.26 km) from perennial water. Additionally, the average distance to streams was greater for sites where the presence of Eastern Small-footed Bats was confirmed than for other sites. However, distance to perennial streams does not equate to distance from water because smaller upland water sources most likely provide enough water to the species and may be an important unquantified factor in roost selection (Johnson et al. 2009, 2011; Wilhide et al. 1998).

The Eastern Small-footed Bat's association with high elevations in our study is corroborated by other studies (Johnson et al. 2011, Moosman et al. 2015, O'Keefe and LaVoie 2011, Thomson 2013). Elevation is inherently related to geologic age (House et al. 1998), which is specific to each of the regions included in this study, and region was an important predictor of presence in the site-level model selection. Similarly, talus availability may be associated with high elevations as they form from weathering of cliffs and other geologic processes associated with mountains (Albjar et al. 1979). Unfortunately, higher-elevation, rocky habitats can be threatened by mining or quarrying, as is the case on Pinnacle Mountain (Ellison 2009, Wickham et al. 2013).

Distance to rock-feature edge where protective forest cover begins was also an important factor influencing probability of presence. As predicted, we found Eastern Small-footed Bats roosting <15 m from protective vegetation cover. Although this result may be an artifact of the small size of talus slopes (0.3–15.7 ha), the analysis indicated a higher probability of bat presence in plots close to the edge than plots more central within a talus slope. Considering the species' small home-range size and association with foraging in cluttered forests (Johnson et al. 2009), it is not surprising that they would favor roost sites close to their foraging habitat. Reducing the time spent in an open area without protective cover also reduces predation potential (Thurber et al. 1994). Furthermore, roosts closer to the forest edge may provide a different microclimate than rock crevices closer to the center of the feature. Trees may cast shadows across the edges of these rocky habitats, thus retaining morning dew longer or cooling roosts during hotter times of the day (Davies-Colley et al. 2000). Aspect can also influence microclimate. The aspect variable did not appear in the best model for presence of Eastern Small-footed Bats, but most surveyed sites were on southern aspects. Similarly, canopy cover was not included in our best local-level model; sites both with and without Eastern Small-footed Bats had similar sparse canopy coverage. We found Eastern Small-footed Bats roosting under sparse canopy cover (<52% as predicted), but lack of canopy was an innate trait of all the rock features surveyed.

Less vegetation cover in a plot was associated with a higher probability of presence, likely because less vegetation means more rock area and more potential roosts available. Talus slopes generally had plots with less vegetation cover than sites with mosaics of outcroppings and glades. However, many talus slope edges were engulfed in vines, and we observed instances of vine expansion from the previous summer. Although succession of plants is natural, succession may threaten rare talus slope features in Arkansas (Daubenmire and Slipp 1943). We suggest exploring potential practices that stall succession of talus sites without disturbing bats, such as clearing vines engulfing talus slope edges by hand or with herbicides. Controlled burns may not be feasible in the rugged terrain and remote setting of many of the rock-feature sites we surveyed (Rogers 1996).

Overall, the Eastern Small-footed Bat is present in regions providing talus slopes with adjacent protective cover and ample solar exposure. However, based on our review of orthoimagery of the Ouachita Mountains, talus slopes appear to be a relatively rare habitat type and a potentially limiting factor for the species. We suggest monitoring abundance of Eastern Small-footed Bats across years to aid in the evaluation of their conservation status. To maintain availability of talus slopes, we recommend exploring practices that reduce vegetation growth at talus slopes. Furthermore, considering the species' spotty distribution and strong association with a relatively rare habitat type, preventing loss of roosting habitat and providing artificial roost structures could support continued persistence of Eastern Small-footed Bat populations in Arkansas. For example, riprap (rock-covered embankments used to prevent erosion) often seen along roads, appear to mimic natural talus slopes and could be used as a mitigation technique (Thomson 2013).

Acknowledgments

This project was funded in part by the State Wildlife Grants program (Grant #AR-T-F18AF01171) of the US Fish and Wildlife Service through an agreement with the Arkansas Game and Fish Commission. Additional funding was provided by the Arkansas Audubon Society. We also thank the US Forest Service for their logistical support, as well as Samantha Burnett and Cameron Rhoden for their assistance in the field. Furthermore, Blake Sasse was helpful in providing edits during manuscript preparation.

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