# WINTER ROOST SELECTION OF EASTERN RED BATS AND IMPACTS OF DORMANT SEASON PRESCRIBED FIRE ON FORAGING ACTIVITY OF FOREST ROOSTING BATS IN TENNESSEE

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## DEDICATION

For everyone who supported and believed in me while I chased this dream.

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## ABSTRACT

With an increase in wind energy development and continued deforestation and habitat degradation, eastern red bats (*Lasiurus borealis;* LABO) and other migratory foliage roosting bats (hoary bat [*Lasiurus cinereus;* LACI], silver-haired bat [*Lasionycteris noctivagans;* LANO]) are at risk of severe population declines, potentially leading to the need for protection under the Endangered Species Act. While studies have been done examining the ecology of these species, there is still a lack of research on winter roosting and foraging behaviors. This research aims to fill some of those knowledge gaps by 1) Examining roost use (i.e., trees vs. litter) and determining roost fidelity of LABO in forest stands during late fall, winter, and early spring, 2) Exploring winter roost selection by LABO at three spatial scales (roost, patch, and landscape), and 3) Examining the short-term effect of dormant season (October – April) prescribed fire on forest roosting bat activity in contrast with the activity in unburned stands by conducting acoustic monitoring of bat echolocation calls. During the winter of 2022/23 I tracked 9 radio-tagged LABO to 20 diurnal roosts, including 1 snag. While stand level characteristics did not appear to influence winter roost selection, bats roosted closer to forest edge than random roosts (101.8 $\pm$ 21.08; $P = 0.029$). Days spent in roosts increased as temperature decreased. From November 2022 to April 2023, we deployed SM4 mini bat acoustic detectors in 20 study sites to monitor bat activity in burned and unburned stands. Stands that had undergone prescribed burning had greater bat activity than stands that were not burned, with shelterwood release sites having a more significant increase in activity than savannas or native warm-season grass fields. While our research does provide some insight into winter roosting and foraging ecology of foliage roosting bats, more research is needed to fill knowledge gaps and conserve these species.

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## INTRODUCTION AND BACKGROUND

The eastern red bat (*Lasiurus borealis*; LABO) is a solitary, forest-dwelling bat species found across most of the southeastern United States (U.S.; Wilkins 1987, Walters et al. 2007, Perry 2018). It is one of 3 long-distance migratory bats, the other two being the hoary bat (*Lasiurus cinereus;* LACI) and silver-haired bat (*Lasionycteris noctivagans;* LANO) (Segers et al. 2013). Red bats are medium-sized bats that can be distinguished from other native bat species by their red/orange pelage with distinct white shoulder patches. They have a completely furred uropatagium, as well as fur on the wings along the length of the forearm. Eastern red bats are sexually dimorphic, with females and juvenile males having a more frosted appearance to the tips of the fur, while adult males are solid red in color with very minimal frosting. Hoary bats are also a solitary forest roosting bat, though much larger than LABO. They are the most widespread bat in the Americas, with their range stretching from southeastern Canada to Hawaii (Bat Conservation International 2023). They have distinct salt and pepper colored pelage and, like LABO, a completely furred uropatagium. Silver-haired bats form maternity colonies during the maternity season, but during the winter are a solitary forest roosting bat. They will often use tree cavities, snags, exfoliating bark, and wood piles as diurnal roost. They have dark gray to black fur with silver tips that make them easily distinguishable from other native bat species. Although historically common across their range, populations of LABO appear to have declined over the past several decades as a result of habitat degradation, deforestation, and fragmentation (Hutchinson and Lacki 2000, Carter et al. 2003, Winhold et al. 2008), as well as wind energy development, which has contributed heavily to the declines of LACI and LANO (Zimmerling and Francis 2016). Possible declines and a lack of prior research means studies investigating

factors that influence forest roosting bat habitat and behaviors are important for understanding their management requirements and conservation needs.

In the southeastern U.S., prescribed fire is a tool regularly used by land managers to achieve a variety of management objectives, including hazardous fuel removal, seed bed preparation, insect and disease control, ecological restoration, and wildlife habitat improvement (Waldrop and Goodrick 2012). Prescribed burns in this region are often conducted during the dormant season (October – April) to best achieve objectives and to avoid direct mortality of wildlife (Perry and McDaniel 2015). Many bat species hibernate in caves during winter and are therefore not present on the landscape, reducing their exposure to dormant season prescribed fires (Carter et al. 2002). However, LABO, LACI, and LANO roost exclusively in forests throughout the year and are still present on the landscape during the non-growing season when many prescribed burns are being conducted (Carter et al. 2002), meaning they may be affected by dormant season prescribed fire activities. During winter, when temperatures become colder, LABO, for example, will roost for short periods (i.e., days or weeks), often in trees or in leaf litter on the forest floor (Moorman et al. 1999, Hein et al. 2008, Flinn 2009, Perry 2012). When temperatures approach or go below 0° Celsius (C), this species has been found to abandon tree roosts in favor of leaf litter, which provides a more stable microclimate beneficial for energy conservation (Hutchinson and Lacki 2000, Mager and Nelson 2001, Moorman and Robbins 2006, Hein et al. 2008, Flinn 2009). Much of the prescribed burning conducted in the southeast is done with the goal of reducing fuels, including areas with heavy amounts of leaf litter. Because of this, bats roosting in leaf litter are potentially at risk from dormant season burns, especially those conducted in colder temperatures, as temperature may play a role in how quickly bats are

able to respond to stimuli such as smoke and heat to arouse from a state of torpor and flee the threat of an oncoming fire (Flinn 2009).

The benefits of prescribed burning to bats in the southeastern U.S. are often attributed to forest modifications that improve foraging conditions and increase arthropod prey abundance (Carter et al. 2002, Perry 2012). Fire may positively affect forest roosting bat foraging through reductions in structural vegetative clutter and opening-up of flight space under the canopy (Hayes et al. 2009, Knapp et al. 2009, Armitage and Ober 2012, Braun de Torez et al. 2018). Insect communities, prey for LABO, LACI, and LANO may be benefitted or harmed by prescribed burning. In the short-term, fire may reduce insect abundance through direct mortality and reduction in plant resources required for food, shelter, and oviposition. Alternatively, prescribed burning may result in short-term increases in insect abundance by attracting pyrophilous insects to freshly burned areas (Swengel 2001). Over the longer-term, insect abundance may increase because of the regrowth of herbaceous plants that attract recolonizing insects with fresh herbaceous vegetation to lay eggs as well as nectar producing plants for feeding (Swengel 2001, Lacki et al. 2009, Armitage and Ober 2012, Cox et al. 2016). Within forested areas, dormant season prescribed burning may reduce clutter, create more open areas, and increase insect abundance, at least in the short-term, allowing forest roosting bats to forage more effectively at a time when low temperatures mean food resources are scarcer (Swengel 2001, Armitage and Ober 2012, Cox et al. 2016). However, research has not been conducted examining forest roosting bat foraging activity following prescribed burning at this time of year, and whether dormant season fires benefit these species with regard to foraging is largely unknown.

State, federal, and non-governmental organizations (NGOs) conduct large-scale dormant season burning across the southern Appalachians, including forested areas across Tennessee. A lack of research and resulting uncertainty regarding the response of forest roosting bats to dormant season prescribed fire in the region precludes these agencies from developing prescribed fire prescriptions that that achieve objectives, while at the same time reducing unintentional negative impacts to LABO, LACI, or LANO. Land management partners have been scaling up fire across the southern Appalachians with a focus on pine and oak forests. Fire practitioners consider wildlife biology when developing fire management prescriptions, so understanding winter habitat requirements of this bat species in the southern Appalachians will allow regional agencies to adapt winter and spring burning to meet the species' needs, as well as other forest bat species that may be impacted by prescribed fire management activities. Results and products of this research will accelerate the awareness, understanding, and adoption of this fire science information by the partner and land management agencies; The Nature Conservancy, USDA Forest Service, Tennessee Wildlife Resources Agency, and the National Parks Service are just a few.

The objectives of this study are to 1) Examine roost use (i.e., trees vs. litter) and determine roost fidelity of LABO in forest stands during late fall, winter, and early spring, 2) Explore winter roost selection by LABO at three spatial scales (roost, patch, and landscape), and 3) examine the short-term effect of dormant season prescribed burning on forest roosting bat (LABO, LACI, LANO) activity in contrast with the activity in unburned stands by conducting acoustic monitoring of bat echolocation calls.

# CHAPTER 1

# WINTER ROOST SELECTION OF EASTERN RED BATS

## ABSTRACT

While eastern red bats (*Lasiurus borealis*) historically were considered common across their range, populations appear to have declined over the last several decades. While declines in populations are largely due to development of wind energy, habitat loss, deforestation, and fragmentation are also contributing to this loss. To make management decisions that can benefit this species, gaps in knowledge regarding roost selection, particularly in the winter, must be filled. The objectives of this study were to examine roost selection of eastern red bats in the winter to determine roost fidelity, and to characterize roosts selected by red bats during the late fall and winter to determine which local and/or landscape features best predict roost selection. Our results show that in our region, red bats appear to be generalists. Roosts varied in size, species, and location. While the local-level characteristics seem to be less important for roost selection, one landscape-level variable, distance to forest edge, appears to be have a significant influence in winter roost selection, with bats choosing to roost closer to forest edge. Red bats also chose roosts at the top of ridges on south-facing slopes. Roost fidelity was high with the average number of days spent in a roost negatively correlated with average daily temperature (as temperature decreased, number of days spent in a roost increased).


## INTRODUCTION

The eastern red bat (*Lasiurus borealis*; LABO) is a solitary, foliage roosting bat that is commonly found throughout much of the southeastern United States, including across the state of Tennessee (Wilkins 1987, Walters et al. 2007, Perry 2018). Despite being classified as "least concern" and historically being common across their range, populations of LABO appear to have declined over the past several decades as a result of habitat degradation, deforestation, and

fragmentation (Hutchinson and Lacki 2000, Carter et al. 2003, Winhold et al. 2008), as well as wind energy development (Zimmerling and Francis 2016). An increase in wind energy development has resulted in increased mortality of eastern red bats, particularly during their migration in the fall and spring, and is currently the biggest threat to populations of the species across their range. Red bat mortality accounts for 15% of annual bat related mortality at wind farms (Zimmerling and Francis 2016). Red bats are a small, solitary, cryptic, migratory species with a large geographic range, making studying them and getting accurate population estimates very difficult. These difficulties, as well as possible range-wide declines and a lack of prior research on the species means studies investigating factors that influence LABO habitat use and behaviors are important for understanding management requirements and conservation needs throughout their life-cycle.

In warmer months, the eastern red bat can be found roosting in large, canopy trees in the forest, often hanging on the edges of branches or near clusters of leaves. They can typically be found roosting near or on the ground, and commonly select roosts in forest edges that are adjacent or near to streams, open fields, and urban areas (Shump and Shump 1982). Roosting near water sources, roads, edge, and open patches can affect flight distances and energy expenditure of roosting bats (Perry et al. 2008). During the winter, when temperatures become colder, LABO are known to roost for short periods (i.e., days or weeks), often in trees or in leaf litter on the forest floor (Moorman et al. 1999, Hein et al. 2008, Flinn 2009, Perry 2012). The winter roosting behavior of LABO appears to be thermally dependent. Red bats do not roost in caves or buildings like many other species, and because trees do not offer much protection against extreme ambient temperatures, hibernation can be difficult for the species (Popa-Lisseanu 2009). When temperatures approach or go below 0°C (32° F), this species has been

found to abandon tree roosts in favor of leaf litter, which provides a more suitable and stable microclimate, beneficial for energy conservation (Hutchinson and Lacki 2000, Nager and Nelson 2001, Mormann and Robbins 2006, Hein et al. 2008, Flinn 2009). Mormann and Robbins (2007) examined LABO use of winter roosts in southwest Missouri, USA, and found tree roosts in eastern red cedars (*Juniperus virginiana)* and hardwoods. Tree roosts were located on the south side of trees on south-facing slopes and occurred more frequently in locations with low canopy cover. Litter roosts were predominately found in oak dominated leaf litter on south-facing slopes. Topography can affect microclimates and thus landscape attributes, such as slope, can be a determining factor in roost selection for a solitary, forest roosting species (Perry et al. 2008). In a 2008 study conducted by Perry et al., individual bats were observed roosting in multiple roosts within the same area (patch or stand) over a period of several days, indicating a higher rate of roost fidelity.

These studies offer some insight into the selection of winter roost sites of LABO; however, information is limited, and roost selection likely varies across the species range. As conservation of this species is of interest range-wide, identification of locally important roosting sites, both in trees and litter, is important to management, including the implementation of prescribed burning. When roosting in litter, forest managers conducting dormant season prescribed burns have observed bats flying from ground litter roosts in response to advancing prescribed fires (Saugey et al. 1989, Moorman et al. 1999, Rodrigue et al. 2001). In the southeastern U.S., prescribed fire is a tool regularly used by land managers to achieve a variety of management objectives, including hazardous fuel removal (including leaf litter where bats may roost), seed bed preparation, insect and disease control, ecological restoration, and wildlife habitat improvement (Waldrop and Goodrick 2012). These burns are often conducted during the

dormant season (October – April) to avoid direct mortality to other wildlife species, however, without an understanding of where LABO are selecting to roost, managers cannot develop burn strategies (i.e., timing of dormant season prescribed burns, firing patterns, vegetation types to be burned and when) that conserve the species.

The goal of this study is to examine the winter roosting behaviors of LABO in forested stands of Tennessee. This information will be used to fill some gaps in our knowledge of LABO life history in a way that allows development of dormant season prescribed fire activities that conserve the species and maintain and improve their habitat. Our specific objectives are to 1) Examine roost use (i.e., trees vs. litter) and determine roost fidelity of LABO in forest stands during late fall, winter, and early spring, and 2) Explore winter roost selection by LABO at three spatial scales (roost, patch, and landscape). Our hypotheses, based on previous studies conducted during the summer and winter, are 1) LABO will have high roost site fidelity, 2) Landscape attributes, such as slope, will be more important to roost selection than local-level characteristics, and 3) LABO will choose roosts closer in proximity to forest edge, roads/corridors (i.e., hiking/walking trails, logging roads, gravel roads, streams or creeks, dried streambeds, and firebreaks), water sources (i.e., ponds, lakes, streams, rivers), or open areas for foraging (i.e., food plots, pasture, fields, balds, clearcuts).

## METHODS

*Site Selection.* - For this study we conducted our research on public lands throughout East Tennessee. These areas include wildlife management areas (WMA's) and natural areas. Specifically, we conducted mist netting to capture LABO at Catoosa WMA in Cumberland County, TN, Chestnut Mountain Nature Reserve in White County, TN, and Buffalo Springs

WMA in Grainger County, TN (Figure 1; all tables and figures are listed in the appendix). Both Catoosa WMA and Buffalo Springs WMA are owned and managed by the Tennessee Wildlife Resources Agency (TWRA). Catoosa WMA is 38,850 hectares and encompasses portions of Morgan, Fentress, and Cumberland Counties in the Cumberland Plateau physiographic subregion of Tennessee. It is composed of both mature and young hardwood forests, as well as oak savanna restoration sites, and is bisected by the Obed Wild and Scenic River. Buffalo Springs WMA is 138 hectares located in Grainger County, Tennessee and is also managed by TWRA. It is comprised of mostly mixed hardwood forests, with openings of early successional vegetation and contains Buffalo Creek. It is surrounded by privately owned agricultural land. Chestnut Mountain Nature Reserve is managed by The Nature Conservancy (TNC) and is comprised of 2,332 hectares of mountain forest land located in White County, Tennessee in the Cumberland Plateau physiographic subregion. It is largely mixed hardwood forest with shortleaf pine and oak savanna, as well as small open patches of early successional vegetation.

Mist netting sites for LABO were chosen based on proximity to water, foraging areas including fields and wildlife food plots, proximity to travel corridors (i.e., roads, logging roads, hiking and walking trails, dried/ephemeral creek beds, game trails, etc.), and in wooded areas with available roost structures. Trail corridors and roads with dense vegetation along the edge and tall, overhanging trees were often chosen as they create “funnels” that prevent bats from flying over or around mist nets. Bats often use these corridors as flyways to get from roosts to foraging areas making them prime areas for capture. Each of these sites also contained well-maintained road systems that allowed for easy access and tracking of bats to roosts once captured.

*Capture.* - During winter and spring (15 October – 1 April) of 2022 and 2023, we attempted to capture LABO in forest stands (i.e., mixed hardwood forests, woodlands, oak-pine savanna) located on public lands for a total of 29 nights and used radio telemetry to track them to daytime roosts. To capture LABO we set polyester mist nets (38mm mesh size, Avinet, Inc. Dryden, New York) of varying lengths between 4m and 12m and varying heights between 2.6m and 7.8m. Mist nets were set in areas as described in *site selection.* Mist nets were opened 30 minutes before sunset and left open for up to 5 hours depending on weather and capture success. We checked mist nets for captures every 8 – 10 minutes. For each bat captured we recorded species, sex, weight, and right forearm length using protocols outlined in Kunz (1988) and attached a 2.4mm or 2.9mm forearm band (Porzana Ltd., United Kingdom) to all species except LABO and LASE. Bats in the genus *Lasiurus* have a propatagium that is more pronounced that in other bat species and are not typically banded due to the band potentially damaging this skin and possibility of impeding flight. We also made note of any wing damage or scarring for each bat captured, as well as noting presence of mites or other abnormalities.

To track bats to diurnal roosts, we outfitted captured LABO with a very high frequency (VHF) radio transmitter (0.47g; Holohil Systems Ltd., Ontario, Canada) with a 30-day battery life. Before applying the radio transmitter to a bat, we trimmed the fur from between the scapulae and cleaned the exposed skin using a disposable, one-time use alcohol pad. We attached the transmitter to the skin between the scapulae using non-toxic surgical adhesive (Osto-Bond, M.O.C.). The adhesive was applied to both the transmitter and the cleaned area of skin of the bat and allowed to dry to a tacky consistency (approximately 5 minutes) before being attached to the bat. After the transmitter was attached, we allowed the glue to dry for an additional 3 – 5 minutes to ensure security before then releasing the bat. The transmitter package, (i.e., transmitter plus

adhesive) weighed ≤5% of a bat's body weight (Aldridge and Brigham 1988). Each transmitter has an approximate battery life of 30 days.

*Roost Identification.* - After release, we tracked captured bats to their initial roosting locations and to each subsequent roosting location. To track bats to their diurnal roosts we used a Wildlife Materials receiver (TRX-1000WR Receiver; Wildlife Materials, Inc., Murphysboro, IL, USA), and a 3- or 5-element folding yagi directional antenna (Wildlife Materials, Inc., Murphysboro, IL, USA). We initially determined the direction and location of the roost from the capture site with a Wildlife Materials receiver and a 5-element yagi antenna. Once the bat's general location was determined, we then proceeded on foot with the Wildlife Materials receiver and a 3-element yagi antenna to locate the roost tree. We determined whether a roosting location was in a tree or beneath ground leaf litter based on transmitter signal strength. Each roost was confirmed by visual observation of the bat. Once roost location was confirmed via visual observation, we explored roost site selection by examining roost site characteristics at three spatial scales (roost tree (local), patch, and landscape; Jachowski 2016).

We reported the distance travelled from point of capture (mist netting site) to this initial roost. We continued to track each bat until the bat left the area or until transmitter failure, recording each roost used, number of days spent in each roost, and distance between each roost. To understand roost site fidelity, we detailed the number of days an individual was tracked, the number of unique roost sites used, the number of days the bat remained at each roost, and if the bat returned to any roost after switching to a new roost.

We used handling and transmitter application procedures consistent with guidelines of the American Society of Mammologists (Sikes et al. 2016). When conducting mist netting, we

followed all decontamination protocols outlined by the USFWS (USFWS 2016). All capture and handling methods have been approved by the University of Tennessee Institute of Animal Care and Use Committee (UTK-IACUC No. 2253-0317).

*Roost (Local level) Characteristics.* - To determine roost site characteristics at the local level, we collected data on each individual roost used by each bat. This included determining roost substrate (i.e., leaf clump, bark, ground leaf litter, etc.) and roost tree species. We then recorded roost tree height (m) using a clinometer, diameter at breast height (dbh; cm) using a loggers tape, percent canopy closure using a spherical densiometer at 5 meters from the roost in each of the 4 cardinal directions, elevation (m) using GPS, aspect, height of roost from ground (m) using a 100 m tape, height from roost to the top of the canopy (m) using a clinometer, and distance from the roost to the nearest deciduous and coniferous tree using a 100 m tape.

To determine roost site characteristics of the patch (Table 1; All tables for Chapter 1 are located in Appendix 1) we first established a 0.1-hectare (ha) plot using the roost as the center. For each tree in this 0.1 ha area, we recorded species, dbh (cm), and tree height (m). This was done for all overstory trees (≥10 cm dbh). We then recorded the number of mid-story stems in the plot. These included trees that had a dbh of 5 -10 cm and a height of at least 1m. The number of understory stems in the plot were also recorded. These included trees with a dbh 0 – 5 cm and a height less than 1 m. These counts were used to determine the mid- and understory density as number of trees per hectare. We then calculated means for the patch that included the mean overstory stem dbh (cm), mean overstory stem height (m), and the basal area of the patch ($m^2/ha$). Each roost tree was paired with a random tree for comparison. Random trees were located by walking a random azimuth a random distance between 50-150m from the roost to the

nearest canopy tree ≥10 cm dbh. Once the random tree was located, the same local-level characteristics were recorded.

*Landscape-level Characteristics.* – For each roost tree, global positioning system (GPS) coordinates were recorded with a handheld Garmin GPSmap 64 (Garmin International, Inc., Olathe, Kansas, USA). To determine roost site characteristics at the landscape scale (Table 2) we entered each GPS coordinate into ArcGIS Pro (ESRI, Redlands, CA) using a topographical base map with a TWRA huntable lands layer that outlined both Catoosa WMA and Buffalo Springs WMA. We used the near analysis tool to measure the distance from the roosts to features that may be important to red bat roost selection (i.e., water source, forest edge, open land cover, and roads/corridors). For random points at the landscape scale, we used a minimum convex polygon to create a 1005m buffer (the average distance a red bat is thought to travel between diurnal roosts and feeding sites) around each roost tree and then allowed the software to randomly generate random points with the site boundaries as the limit, choosing 1 random point for each roost mapped. We then measured the same landscape variables for each random point generated.

*Data Analysis.* - All statistical analyses were conducted using Rstudio (R Version 4.3.1, Posit Software, Boston, MA, USA). Due to our small sample size, we used roosts as the experimental unit rather than each individual bat, under the assumption that the observations were independent (Perry and Thill 2007). Similarly, we did not test for temporal variation across years.

Due to the small sample size, we elected to conduct Welch's *t*-tests with a Bonferroni correction for multiple comparisons to determine which local level variables were important for roost selection. We used $P<<0.05$ as our basis for showing statistical significance and possible

predictors for LABO roost selection, noting, however, that even variables that do not show statistical importance may still be biologically important for the species. This alpha value reflects the Bonferroni correction we used for our small sample size and to correct for running multiple comparisons on the same small dataset. We tested a total of 15 variables at the local level and 4 variables at the landscape level (Table 1 and Table 2). One bat used 3 different roosts that were all within 5m of each other, and so for analysis purposes, the distance between those roosts was averaged and one plot was created for all 3 of the roosts so that there was no overlap in vegetation data collection. Because of this, during the analysis roost count is 18 rather than 20.

## RESULTS

During the winter of 2022 we captured 11 bats over a total of 17 nights of mist netting. Red bats represented 63.6% of our captures, totaling 7 bats. Our catch per unit effort during the winter of 2022 was 0.28 bats per net night. We put out 2-4 nets per night, totaling 39 net nights for this season. Nets were open for 2-5 hours depending on weather and capture success, for a total of 231 mist net hours and an average number of mist net hours of 5.92 ($\pm$0.11hours). During the winter of 2023 we captured 16 bats over a total of 12 nights of mist netting. Red bats represented 75% of our captures, totaling 12 bats. Our catch per unit effort for this season was 0.64 bats per night. We put out 2-4 nets per night totaling 25 net nights for this season, and left nets open for 2-5 hours depending on weather and capture success. We had a total of 173 mist net hours and an average number of mist net hours of 6.92 ($\pm$0.16 hours). In total we captured 17 individual red bats, 15 males and 2 females. We applied transmitters to 16 of the 17 bats, one bat being released with no transmitter due to being underweight. Of the 16 bats, 9 were successfully tracked to diurnal roosts. Five bats were tagged at the same time as 5 other red bats that were

outfitted with Motus transmitters that were later discovered to have migrated through the area, thus we speculate our 5 missing bats were also migrating during the time of capture. All roost data collected and analyzed are from male bats, as the 2 female bats were also eliminated from analysis due to transmitter failure.

We tracked each tagged red bat for 5 - 24 days (15.8 ± 7.9 days; $\bar{x}$ ± SD) until the transmitter failed or the bat migrated, and a signal was no longer heard. Bats used between 1 – 4 roosts (2.2 ± 1.2 roosts), and a total of 20 unique roosts were recorded with 14 different species being used. Species used were mountain laurel (*Kalmia latifolia;* 1 roost), scarlet oak (*Quercus coccinea;* 1 roost), American holly (*Ilex opaca;* 3 roosts), American beech (*Fagus grandifolia;* 1 roost), red maple (*Acer rubrum;* 1 roost), sugar maple (*Acer sacchaurum;* 4 roosts), Virginia pine snag (*Pinus virginiana;* 1 roost), black walnut (*Juglans nigra;* 1 roost), sassafras (*Sassafras albidum;* 2 roosts), black tupelo (*Nyssa sylvatica;* 1 roost), hackberry (*Celtis occidentalis;* 1roost), multiflora rose (*Rosa multiflora;* 1 roost), and blackberry (*Rubus fruiticosus;* 1 roost). One bat was observed in a small *rubus* shrub that was used for 3 consecutive nights (Figure 1; All figures for Chapter 1 are located in Appendix 1). Another bat was observed using vines wrapped around a pine snag on 2 different occasions (Figure 2). To our knowledge this is the first time an eastern red bat has been documented using a snag as a diurnal roost. Diurnal roosts were 1.4 – 7.6 m off the ground (3.0 ± 1.8 m) (Figure 3). Diurnal roosts were between 267 – 1391 m from the capture site (690 ± 0.85 m), and distance between roosts for each individual bat were between 6.75 – 599.5 m (141.8 ± 0.67 m). Regardless of minimum nightly temperature, no bats were observed roosting on the ground beneath leaf litter.

The average nightly temperature during the tracking period was 11℃, with the highest temperature being 17.2℃ and the lowest temperature being -10℃. We found a negative

correlation between the minimum nightly temperature and the number of consecutive days that were spent in a roost. As the minimum temperature decreased, the number of consecutive days a bat spent in a roost increased (Figure 4). Bats spent 2 - 11 consecutive days in a roost (6.55 $\pm$ 2.56 days). Of the 18 roost plots (20 total roosts), 15 (83.3%) of these were found to be on south-facing slopes, compared to only 7 (38.8%) of the random roosts (Figure 5).

At the local level, none of the 15 variables measured showed statistical significance as influential in LABO roost selection (Table 1). However, 2 variables were, on average, less at the roost sites versus the random trees. Average basal area (BAEng) of the roost plots was less than in the random tree plots ($t = 1.881$, $P = 0.077$, d.f. = 17) (Tables 3 and 4). While this does not meet the $P << 0.05$ criteria, we speculate that a larger sample size may show significance in basal area of roost tree plots compared to random plots. The same is true for number of trees in a plot (NTrees) ($t = 1.9144$, $P = 0.07255$, d.f. 17) (Tables 3 and 4). At the landscape level, only 1 of the 4 variables was found to be a significant predictor of red bat roost selection. Distance to forest edge (edge) was, on average, less for roost trees than for random trees ($t = 2.349$, $P = 0.029$, d.f. 19) (Tables 5 and 6).

Overall, landscape level characteristics (Table 2) appear to be better predictors for red bat roost selection in the winter. However, due to our small sample size, these results may not be representative of the species across the entire Southeast. Considering our small sample size and the heterogeneity of our landscape, models created with our dataset may be overfit when transferred to other datasets or study areas. Knowing this and knowing that lack of statistical importance may not correlate to lack of biological importance of these characteristics, we are cautious to make absolute conclusions about red bat roost selection with our dataset alone.

## DISCUSSION

The results of our study suggest that eastern red bats may be generalists when it comes to roost selection during winter. None of the bats in our study chose roosts in a manner that suggested they were selecting for specific characteristics or choosing characteristics more than were available on the landscape. Bats roosted in trees in various states of defoliation, ranging from bare trees and trees with dead foliage, to broad-leaf evergreen species such as American holly and mountain laurel that had full foliage. Red bats are not a species that is adapted to flying well in areas that are dense with mid- and understory clutter due to high wing loading and aspect ratios, as well as their low frequency, narrowband echolocation calls (Armitage and Ober 2012). Because of this, areas with larger and fewer trees, but with a variety of species with various amounts of retained foliage may be biologically important in the winter. Less basal area and less number of trees would allow for more efficient flight and foraging, while a number of trees with residual foliage, dead or alive, would provide thermal cover during the winter when temperatures begin to drop. Although these variables did not prove statistically significant in our study, they may still be of particular biological importance in our region as none of the bats we tracked were observed abandoning tree roosts and moving to ground leaf-litter roosts.

While stand level characteristics in our study did not show statistical importance in roost selection, landscape level characteristics did. Perry et al. 2008 states that topography can affect microclimate, and so landscape attributes, such as slope, can be more influential in the roost selection of a solitary, forest roosting species such as the eastern red bat. All confirmed roosts in our study were located on or near the top of ridges, with a majority of those roosts on south-facing slopes, which is consistent with other studies examining roost selection of this species (Moorman and Robbins 2007, Perry et al. 2008). Roosting on the top of ridges that have south-

facing slopes increases solar exposure, especially in areas of low canopy cover (Moorman and Robbins 2007), which is common during the winter when trees defoliate. Roosting in areas of increased solar exposure means the ambient temperature will be higher and bats will not have to expend as much energy trying to keep warm.

Our analysis of other landscape level characteristics showed that bats in our study were choosing to roost closer to forest edge than random trees. This behavior has been observed in this species in the warmer months, where they have been found roosting in forest edges that are adjacent to water, open land, and even urban areas (Shump and Shump 1982). Roosting near these landscape features can affect the flight and energy expenditure of bats (Perry et al. 2008). Selecting roosts closer to edge, water, travel corridors, and open areas for foraging can help reduce the flight distance and therefore energy required to obtain food and water resources which is beneficial during the colder months when these resources are already scarce. In a 2008 study conducted by Perry et al., individual bats were observed selecting multiple roosts within the same area (patch or stand) over a period of several days, indicating a higher rate of roost site fidelity. Our study also observed bats roosting in the same roost for several consecutive days, and bats selecting multiple roosts stayed within the same stand.

In the winter when temperatures approach or drop below 0℃, red bats have been observed abandoning tree roosts in favor of leaf litter roosts. Roosting in leaf litter is believed to provide a more stable microclimate, allowing bats to conserve more energy while in torpor (Hutchinson and Lacki 2000, Nager and Nelson 2001, Mormann and Robbins 2006, Hein et al. 2008, Flinn 2009). While this behavior is frequently documented for this species across their range, none of the bats we tracked in this study were observed selecting ground leaf litter roosts, regardless of nightly temperature. While it is speculated that there could be regional variation in

roosting behavior within the species, we take caution in making generalized assumptions about the southeastern population of red bats with our results due to small sample size. Studies in other regions (Moorman and Robbins 2007, Perry et al. 2008) have reported leaf litter roosts being in predominately oak dominated forests and on south-facing slopes. While almost all our roosts were on south-facing slopes and there are large tracts of oak dominated mixed hardwood forests throughout the southeastern United States, we did not observe any bats choosing to abandon their tree roost for a ground litter roost even though oak dominated forest areas were largely available. If this does, in fact, suggest a regional difference in roost selection, use of dormant season prescribed fire as a management tool in this region could pose less of a threat to the red bats than is thought to be present in other areas. It is also important to note that all bats observed in our study were males, therefore we cannot determine if there is a difference between the roosting behavior of males versus females during the winter months.

Prescribed fire is a common practice in the southeast and is often conducted during the dormant season to avoid direct mortality to other wildlife species (Waldrop and Goodrick 2012). Burn practitioners have often observed bats flying up from ground litter roosts in response to advancing flame fronts (Saugey et al. 1989, Moorman et al. 1999, Rodrigue et al. 2001). It has been suggested that this may pose a threat to hibernating bats who have gone into torpor in litter roosts. However, our results suggest that, in our study area, this may not be an issue, and dormant season prescribed fire activities may actually benefit bats by opening up flight space and increasing prey abundance in the short-term (Chapter 2). Because red bats appear to be generalists when it comes to roost selection, managing forests in a manner that helps conserve the species may not require large-scale changes to management practices already in place. Managing for healthy forests with access to flight corridors, forest edge, open areas for

foraging, and a less dense mid- and understory that allows more open flight space could benefit these bats and help keep them common on the landscape.

# APPENDIX 1

Table 1: Description of stand scale covariates used in *t* - tests to describe eastern red bat (*Lasiurus borealis;* LABO) winter roost selection in Tennessee, USA, 2022 – 2023.

| Variable Abbreviation | Units | Description |
|---|---|---|
| ACC | % | Estimate of overstory canopy closure |
| DistDec | m | Distance from roost to nearest deciduous tree |
| DistCon | m | Distance from roost to nearest coniferous tree |
| AvgDBH | cm | Average diameter at breast height of trees in the stand |
| BAEng | $m^2$/ha | Total basal area of the stand |
| BAHard | $m^2$/ha | Basal area of hardwood trees in the stand |
| BASoft | $m^2$/ha | Basal area of softwood trees in the stand |
| NTrees | n | Total number of trees in a 0.1 ha plot |
| NTreeSp | n | Number of tree species in a 0.1 ha plot |
| StemsAcre | n/acre | Number of trees <10 cm dbh and >1m tall per acre |
| NOak | n | Number of oak trees in a 0.1 ha plot |
| NHick | n | Number of hickory trees in a 0.1 ha plot |
| NMaple | n | Number of maple trees in a 0.1 ha plot |
| NPine | n | Number of pine trees in a 0.1 ha plot |
| NOther | n | Number of other tree species in a 0.1 ha plot |

Table 2: Description of landscape level covariates - [a] used in *t* - tests to describe eastern red bat (*Lasiurus borealis*) winter roost selection in Tennessee, USA, 2022 – 2023.

| Variable Abbreviation | Description |
|---|---|
| distrd | Distance from roost to roads, trails, corridors, streambeds |
| distwater | Distance from roost to nearest water source |
| edge | Distance from roost to forest edge |
| open | Distance from roost to open area (field, food plot, pasture) |

[a] All units are in meters.

Table 3: Mean ($\bar{x}$), standard error (SE), minimum (Min), and maximum (Max) of stand level covariates of selected roost trees of eastern red bats (*Lasiurus borealis*) and random tree sites at Catoosa WMA in Cumberland County and Buffalo Springs WMA in Grainger County, Tennessee, USA, 2022 – 2023.

| **Stand Variable[a]** | **Selected Roost (n=20)** | | | | **Random Trees (n=20)** | | | |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ | **SE** | **Min** | **Max** | $\bar{x}$ | **SE** | **Min** | **Max** |
| ACC | 87.325 | 6.447 | 0 | 100 | 89.096 | 5.384 | 0 | 100 |
| DistDec | 1.866 | 0.895 | 0.35 | 4.7 | 2.305 | 0.267 | 0.25 | 17 |
| DistCon | 6.667 | 1.299 | 0.4 | 20 | 8.464 | 1.250 | 1.5 | 19.1 |
| AvgDBH | 23.690 | 1.658 | 18.756 | 37.629 | 27.291 | 1.851 | 13.983 | 43.975 |
| BAEng | 71.639 | 12.099 | 11.499 | 140.985 | 92.691 | 9.359 | 10.173 | 188.665 |
| BAHard | 66.233 | 13.316 | 9.213 | 139.764 | 83.374 | 9.224 | 4.384 | 188.665 |
| BASoft | 5.405 | 3.550 | 0 | 29.659 | 9.317 | 2.108 | 0 | 46.698 |
| NTrees | 27.333 | 4.806 | 0 | 53 | 32.166 | 3.786 | 2 | 80 |
| NTreeSp | 7.444 | 0.804 | 0 | 12 | 6.611 | 0.767 | 2 | 13 |
| StemsAcre | 485.555 | 84.671 | 40 | 1120 | 422.888 | 87.650 | 92 | 1344 |
| NOak | 9.833 | 3.242 | 0 | 36 | 12.944 | 2.348 | 0 | 29 |
| NHick | 1.833 | 0.657 | 0 | 11 | 1.555 | 0.672 | 0 | 10 |
| NMaple | 4.833 | 1.785 | 0 | 27 | 4.277 | 1.486 | 0 | 20 |
| NPine | 1.666 | 0.808 | 0 | 9 | 2.333 | 0.523 | 0 | 7 |
| NOther | 9.166 | 2.240 | 0 | 30 | 11.166 | 2.468 | 1 | 39 |

Table 4: Results of paired sample *t*-tests of stand level variables of eastern red bat (*Lasiurus borealis*) comparing roost trees to random trees at Catoosa WMA, Cumberland County and Buffalo Springs WMA, Grainger County, Tennessee, USA, 2022 - 2023.

| **Stand Variable** | **Test** | ***P* value** | **d.f.** |
|---|---|---|---|
| ACC | $t$ = -0.4 | 0.6941 | 17 |
| DistDec | $t$ = 0.514 | 0.6129 | 17 |
| DistCon | $t$ = 1.6132 | 0.1307 | 17 |
| AvgDBH | $t$ = 1.1898 | 0.2505 | 17 |
| BAEng | $t$ =1.881 | 0.077 | 17 |
| BAHard | $t$ = 1.5069 | 0.1502 | 17 |
| BASoft | $t$ = 1.0252 | 0.3196 | 17 |
| NTrees | $t$ = 1.9144 | 0.07255 | 17 |
| NTreeSp | $t$ = -1.1883 | 0.2511 | 17 |
| StemsAcre | $t$ = -0.62347 | 0.5412 | 17 |
| NOak | $t$ = 1.2864 | 0.2155 | 17 |
| NHick | $t$ = -0.47283 | 0.6423 | 17 |
| NMaple | $t$ = -0.33764 | 0.7398 | 17 |
| NPine | $t$ = 0.85973 | 0.4019 | 17 |
| NOther | $t$ = 0.8001 | 0.4347 | 17 |

Table 5: Mean ($\bar{x}$ ), standard error (SE), minimum distance (Min), and maximum distance (Max) of landscape level covariates - [a] of selected roost trees of eastern red bats (*Lasiurus borealis*) and random tree sites on Catoosa WMA in Cumberland County and Buffalo Springs WMA in Grainger County, Tennessee, USA, 2022 – 2023.

| **Landscape Variable[b]** | **Selected Roost (n=20)** | | | | **Random Trees (n=20)** | | | |
|---|---|---|---|---|---|---|---|---|
| | $\bar{x}$ | **SE** | **Min** | **Max** | $\bar{x}$ | **SE** | **Min** | **Max** |
| distrd | 200.623 | 38.4 | 27.44 | 501.28 | 300.001 | 76.62 | 13.36 | 1216.86 |
| distwater | 522.958 | 77.9 | 103.56 | 1510.79 | 1025.854 | 253.59 | 51.65 | 4507.83 |
| edge | 101.8 | 21.08 | 12.95 | 356.30 | 367.393 | 123.17 | 13.95 | 1786.4 |
| open | 200.022 | 27.54 | 0.00 | 434.41 | 444.824 | 131.37 | 0.00 | 1836.9 |

[a] All distances in meters

[b] Refer tables 1 and 2 for a description of each covariate

Table 6: Results of *t*-tests for landscape level variables of eastern red bat (*Lasiurus borealis*) roosts compared to random trees at Catoosa WMA, Cumberland County and Buffalo Springs WMA, Grainger County, Tennessee, USA, 2022 - 2023.

| **Landscape Variable** | **Test** | ***P* value** | **d.f** |
|---|---|---|---|
| distrd | $t = 1.906$ | 0.068 | 19 |
| distwater | $t = 1.896$ | 0.072 | 19 |
| edge | $t = 2.349$ | 0.029[a] | 19 |
| open | $t = 1.825$ | 0.083 | 19 |

[a] $P \ll 0.05$ level



Figure 1: *Rubus* shrub in an open field that an eastern red bat (*Lasiurus borealis*) was observed using as a diurnal roost for 3 consecutive days at Buffalo Springs WMA, Grainger County, Tennessee, USA, 2023.



Figure 2: An eastern red bat (*Lasiurus borealis*) using foliage wrapped around a pine snag as a diurnal roost at Buffalo Springs WMA, Grainger County, Tennessee, USA, 2023.



Figure 3: Various eastern red bat (*Lasiurus borealis*) roosts in Catoosa WMA in Cumberland County, Tennessee, and Buffalo Springs WMA in Grainger County, Tennessee, 2023.
Top Left: Roost in Mountain Laurel (*Kalmia latifolia*). Top Right: Roost in scarlet oak (*Quercus coccinea*) sapling. Bottom Left: Roost in American beech (*Fagus grandifolia*) foliage. Bottom Right: Roost in American holly (*Ilex opaca*) foliage.

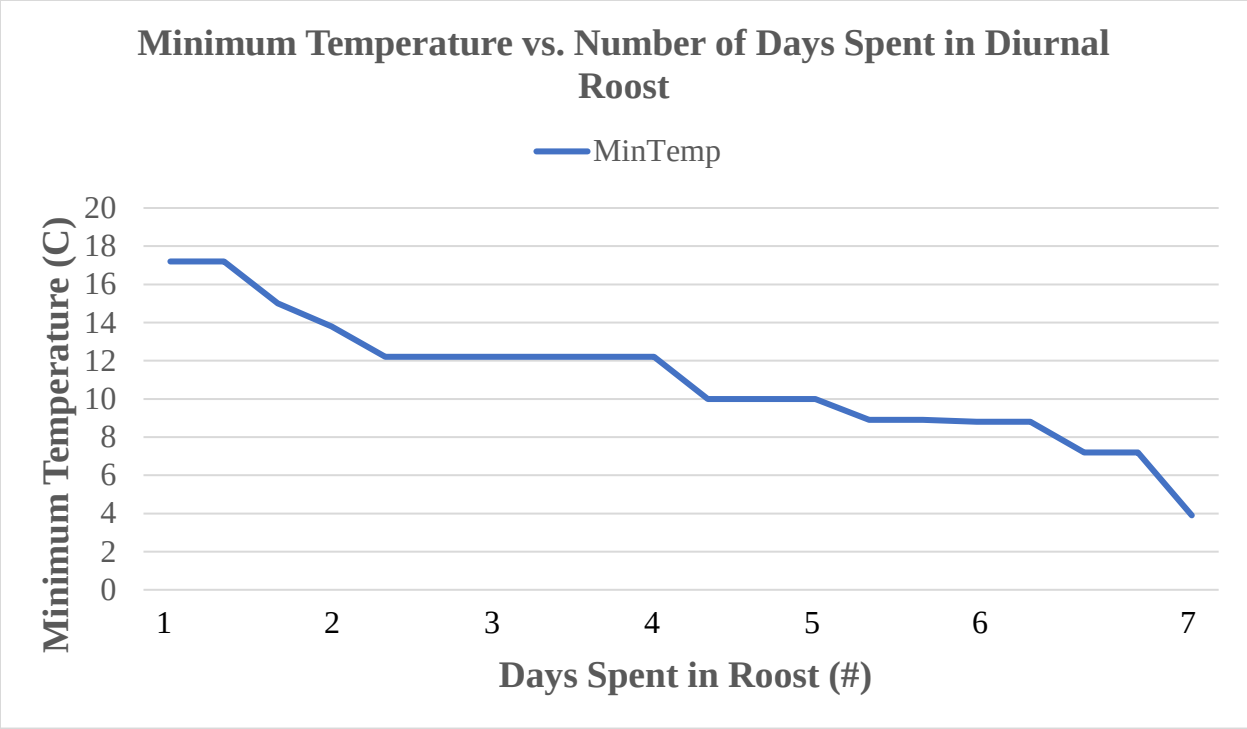



Figure 4: The relationship between the minimum daily temperature and number of days eastern red bats (*Lasiurus borealis*) spent in roosts at Catoosa WMA, Cumberland County and Buffalo Springs WMA, Grainger County, Tennessee, USA, 2022 – 2023.

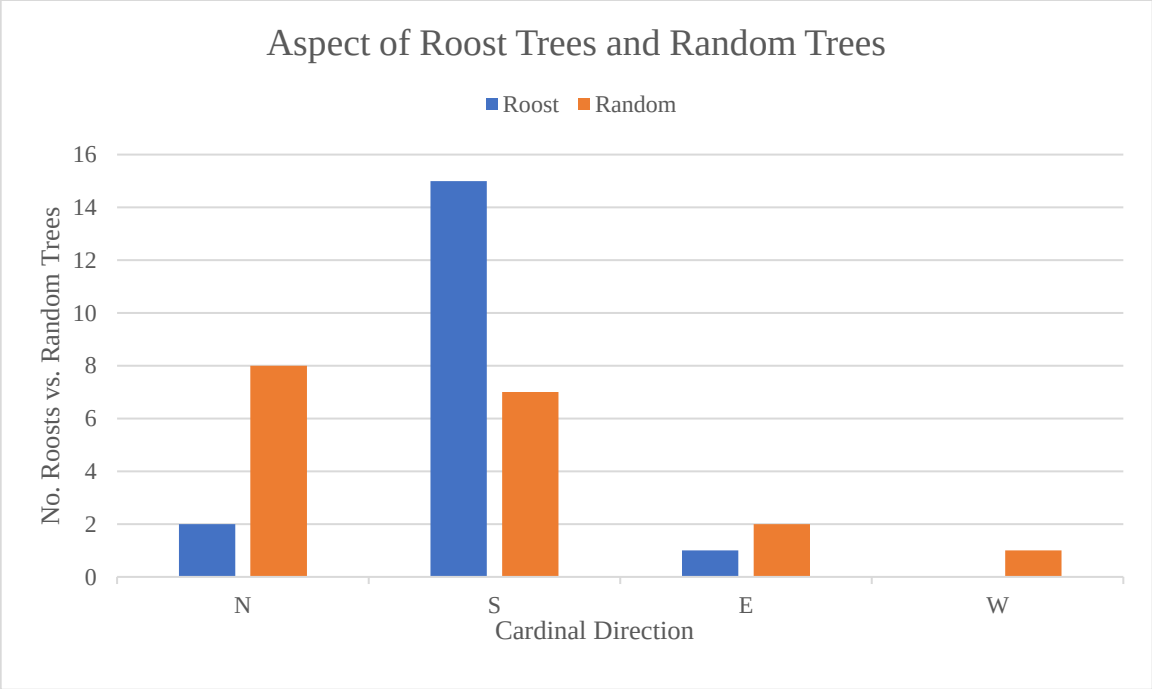



Figure 5: Number of eastern red bat (*Lasiurus borealis*) roosts selected on each aspect versus the number of random trees on each aspect at Catoosa WMA, Cumberland County and Buffalo Springs WMA, Grainger County, Tennessee, USA, 2022 – 2023.

# CHAPTER 2

# IMPACTS OF DORMANT SEASON PRESCRIBED FIRE ON THE FORAGING ACTIVITY OF FOREST ROOSTING BATS

## ABSTRACT

The benefits of prescribed burning to bats in the southeastern U.S. are often attributed to forest modifications that improve foraging conditions and increase arthropod prey abundance in both the short- and long-term. Fire may positively affect forest roosting bat foraging through reductions in structural vegetative clutter and opening-up of flight space under the canopy allowing more maneuverability for foraging. Our objectives for this study were to examine the short-term effect of dormant season prescribed burning on forest roosting bat foraging activity in contrast with the activity of these species in unburned stands by conducting acoustic monitoring of bat echolocation calls, and to determine how activity in different forest stand types changes with implementation of dormant season prescribed fire. We deployed Song Meter SM4 Mini Bat acoustic detectors in 20 study units (10 treatment and 10 control) in 3 shelterwood release cuts, 3 oak savannas, and 4 native warm-season grass fields. Our results show that dormant season prescribed fire increased bat activity in the treatment units compared to the control units, however this may be a result of vegetation rather than burning. We also showed that shelterwood release units had a higher increase in bat activity than savannas or native warm-season grass units, likely due to the opening of flight space post-fire. Savanna units also showed an increase in bat activity post fire. Our results suggest that bat activity in the winter is likely a result of changes to vegetation structure after implementation of prescribed fire.


## INTRODUCTION

Despite being classified as “least concern” and historically being common across their range, populations of forest roosting bats appear to have declined over the past several decades as a result of habitat degradation, deforestation, and fragmentation (Hutchinson and Lacki 2000,

Carter et al. 2003, Winhold et al. 2008), as well as wind energy development (Zimmerling and Francis 2016). An increase in wind energy development has resulted in increased mortality of eastern red bats (*Lasiurus borealis*; LABO), hoary bats (*Lasiurus cinereus*; LACI), and silver-haired bats (*Lasionycteris noctivagans*; LANO), particularly during their migration in the fall and spring, and is currently the biggest threat to these species across their range. Hoary bats, eastern red bats, and silver-haired bats make up 73% of all bat mortalities due to wind farms (Zimmerling and Francis 2016). Forest roosting bats are small, cryptic, solitary, and migratory, with a wide range of occurrence, making them difficult to study. However, with declines occurring in these species range-wide, research examining habitat use, particularly in the winter, is knowledge that can be used to help conserve these species.

Foraging conditions for bats can be influenced by prescribed fire (Lacki et al. 2007, Titchenell et al. 2011, Cox et al. 2016). In the southeast, prescribed fire is a tool commonly used by managers to achieve a variety of management objectives, including hazardous fuel removal, seed bed preparation, insect and disease control, ecological restoration, and wildlife habitat improvement (Waldrop and Goodrick 2012). These burns are often conducted during the dormant season (October – April) to avoid direct mortality to other wildlife species. Studies that have been conducted examining bat response to prescribed fire in other North American forest systems have found that the practice affects bat activity (relative use of an area for foraging) through changes in forest structure and availability of nocturnal flying insect prey (Loeb and Waldrop, 2008, Titchenell et al., 2011, Armitage and Ober, 2012, Cox et al., 2016). Abundance of lepidopterans have been observed decreasing after a fire, while abundance of dipterans increases (Johnson et al., 2019).

Changes in forest structure alter the degree of clutter (physical obstructions including foliage, branches, and stems, that impede flight and limit prey detection by reflecting echolocation calls) bats have to navigate (Lacki et al., 2007). Morphological variations in body size and wing shape, particularly wing loading (WL; mass of the bat divided by its total wing area) and aspect ratio (AR; length of the wing squared divided by its surface area), along with differences in echolocation call frequency and structure determine whether bats can fly and forage in clutter and, in turn, their use of and activity in a forest stand (Aldrich and Rautenbach, 1987, Norberg and Rayner, 1987). Larger-bodied bat species with high WLs or ARs, like forest roosting bats, tend to be less maneuverable and more adapted to flight in more open, less cluttered areas (Kingston et al., 2000, Lee and McCracken, 2004). Similarly, species with narrowband calls of low frequency, like LABO, LACI, and LANO are more suited to foraging in open locations (Neuweiler, 1983). However, while bats may use a forest stand for foraging based on their adaptations to that environment, the availability of nocturnal insect prey may also play an important role in determining use, and in turn, activity in an area (Erickson and West, 2003, Lacki et al., 2007).

Several studies have been conducted observing bat response to prescribed fire and have monitored activity in various vegetation communities. In 2016, Cox et al. conducted a similar study at Catoosa Wildlife Management Area (CWMA) during the summer, where they found that bat activity was greater in savanna stands subject to prescribed burning in the spring and fall compared to unburned savanna stands during the same seasons. They also observed greater LABO activity in spring burned savanna stands compared to control stands and fall burned savanna stands. Another study conducted in 2006 - 2007 observed how northern long-eared bats (*Myotis septentrionalis*) responded to prescribed fires conducted in the forests of eastern

Kentucky. Results showed that these bats responded to alterations to forest structure caused by prescribed fires by adjusting the location of their foraging sites based on changes to prey availability (Lacki et al., 2009).

Understanding how prescribed fire impacts bat activity can help us make inferences on how forest roosting bats are using the landscape after disturbance, and whether dormant season prescribed fire is a benefit to forest roosting species during the winter. The objective of our study is to examine the short-term effect of dormant season prescribed burning on forest roosting bat foraging activity in contrast with the activity of these species in unburned stands by conducting acoustic monitoring of bat echolocation calls. Our hypothesis is that the opening of flight space on the landscape by dormant season burning will cause an increase in LABO, LACI, and LANO activity in these areas. By exploring the response of forest roosting bats to dormant season prescribed fire activities, we can fill some gaps in our knowledge of the life history of these bats, which will provide managers and prescribed fire practitioners with information that supports place-based adaptive management and allows informed application of dormant season prescribed fire practices that contribute to the conservation of these species.

## METHODS

*Site Selection.* – To monitor bat activity, we chose to work on wildlife management areas (WMA's) that are regularly managed by prescribed fire activities. Our study sites were distributed between Catoosa WMA, Bridgestone-Firestone Centennial Wilderness area, and Mount Roosevelt WMA, all managed by the Tennessee Wildlife Resources Agency (TWRA). Catoosa WMA is 38,850 hectares and encompasses portions of Morgan, Fentress, and Cumberland Counties in the Cumberland Plateau physiographic subregion of Tennessee

(TWRA). It is composed of both mature and young hardwood forests, as well as oak savanna restoration sites, and is bisected by the Obed Wild and Scenic River. Along with prescribed fire, portions of this WMA are also managed with other forest management practices such as clear-cutting, thinning, and shelterwood release cuts. Of our 20 study sites (10 treatment and 10 control), 8 were located at Catoosa. Sites included oak savannas and shelterwood release cut stands.

Bridgestone-Firestone is over 4,047 hectares located in White County, Tennessee, and has a wide variety of habitats and vegetative structure. At the front of the property there are approximately 283 hectares of native warm-season grass that are regularly burned to create and maintain habitat for grassland species such as the northern bobwhite quail (*Colinus virginianus*). There are also second-growth mixed hardwood forests and some small pine plantations on the property. Of our 20 study sites, 10 were located at Bridgestone-Firestone. Sites included savannas and native warm-season grass (NWSG) fields.

Mount Roosevelt WMA is 4,452 hectares of mixed hardwood forests located in Roan, Morgan, and Cumberland Counties in Tennessee, a part of the Cumberland Plateau physiographic subregion of the state. Similar to the other 2 sites, it is also regularly managed with prescribed fire and other forest management activities including shelterwood release cuts. Of our 20 study sites, 2 were located at Mount Roosevelt in a shelterwood release cut stand. Study sites from all three WMA's were chosen by pre-determined burn rotation plans being carried out by managers on the property.

In total, we had 3 paired treatment and control units (6 total units) in oak savannas, 3 paired treatment and control units (6 total units) in shelterwood release cuts, and 4 paired treatment and control units (8 total units) in NWSG fields. The oak savanna units are grassy

plant communities scattered with open grown oaks. These savannas typically have a basal area (BA) ranging from 30-45 $ft^2$/acre. The shelterwood release units are units in which a shelterwood release cut was conducted with the goal of reducing the overall BA to regenerate an even-aged stand. These cuts were followed with prescribed fire to prepare the seedbed and aid in regeneration of desired species. The opening up of flight space in these areas along with the added fire disturbance make them ideal foraging areas for our forest roosting bat species. The NWSG fields are fields that are composed of native warm-season grasses and forbs with little to no BA or woody vegetation. They are open, making them frequently used as foraging areas for forest roosting bat species.

*Acoustic Detector Deployment*. – To monitor bat activity at each of the treatment sites and control units, we used full spectrum Song Meter SM4 Mini Bat acoustic detectors (Wildlife Acoustics, Maynard, MA, USA) with an external ultrasonic microphone to passively detect, record, and store full spectrum bat echolocation calls. Each unit was between 6 – 12 hectares, and detectors were placed in the center of each unit to reduce edge effect on sampling. We placed one detector in each of our units, following the protocol of one detector for every 20 hectares of land in the unit used in a similar study conducted by Cox et al., 2016. Detectors were attached to an extendable painter's pole and extended to 3 m above the ground. To maximize bat detections and the quality of recordings, we deployed detectors in open areas away from vegetative clutter, taking into consideration that each detector only has a recording power of approximately 10 m. We programmed detectors to record in full spectrum, starting at 30 minutes before sunset and ending 30 minutes after sunrise, and changed the time zone accordingly based on location. Otherwise, we used default recorder settings. After a unit was burned, we deployed detectors

within 14 days (Cox et al., 2016) and surveyed both the burn unit and paired control unit for 14 nights after burning (Table 7; All tables for Chapter 2 in Appendix 2). For each burn unit being monitored, we monitored a control of the same vegetation type (i.e., savanna, shelterwood, NWSG grass field) at the same time and for the same duration for comparison.

*Vegetation Sampling*. – We conducted vegetation sampling in each of the study units to categorize vegetation structure. We sampled at each detector, as well as at 4 randomly selected points within a 50m buffer around the center of the unit to reduce bias associated with edge effects. We chose 4 randomly selected points for each detector to get a representative sample of each unit, one random point in each of the 4 cardinal directions located 12.5m from the center (Figure 6; All figures for Chapter 2 in Appendix 2). This method assumes that the detector is representative of the entire unit by being placed in the center of the unit.

Because forest roosting bats are known to prefer open areas for foraging and are not adapted for flight in cluttered areas (Aldrich and Rautenbach, 1987, Norberg and Rayner, 1987, Lacki et al. 2007), we estimated clutter of each unit by measuring live overstory BA and midstory stem density, which have been found to be an effective measure of clutter (O'Keefe et al., 2014). We measured live overstory BA of each unit using a 10-factor prism in an 11.3m radius plot centered on the sampling point. We measured midstory stem density (stems/$m^2$) using a point-transect method at the detector and then at the 4, 3m radius subplots. At each 0.5m along the transect in each cardinal direction we counted all tree saplings, shrubs, woody vines, and semi-woody plants that were > 1m tall and with a diameter at breast height (dbh) <10cm.

*Analysis.* – We stored recorded bat passes on compact SDXC memory cards inside each detector before downloading them to an external hard-drive at the end of each 14-day recording period to be analyzed. To analyze bat passes, we used SonoBat 4 NA software with the North America, Southeastern bat classifiers (SonoBat Inc., Arcata, CA, USA). Bat passes were batch-processed through scrubbing to remove noise (non-bat ultrasound) and poor-quality files using default SonoBat scrub settings. To reduce species identification error (Lemen et al. 2015) and erroneous classification of lower quality bat calls (false positives and false negatives), we manually reviewed the spectrograms of all files classified by Sonobat as LABO, LACI, LANO, NoID, or noise, as well as all ambiguous files for which the software provides multiple species identifications that include LABO, LACI, and LANO that remained post-scrubbing. We used the default discriminant probability threshold for classification of 0.90 and acceptable call quality of 0.80. Calls meeting the ≥90% discriminant probability threshold were visually confirmed and kept as the number of bat files/night to be used as an index of bat foraging activity (Britzke et al. 1999, Tibbels and Kurta 2003, Davidai et al. 2015). We grouped bats into 4 categories; LABO, for calls meeting criteria that identified as eastern red bats, LACI, for calls meeting criteria that identified as hoary bats, LANO, for calls meeting criteria that identified as silver-haired bats, and Foliage, for calls that were identified as a forest roosting species, but could not be confirmed as specifically LABO, LACI, or LANO. There was also an "other" category, which included bats in the genus *Myotis* (little brown bat, Indiana bat, gray bat, eastern small-footed bat, and northern long-eared bat), big brown bats (*Eptesicus fuscus*), evening bats (*Nycticeius humeralis*), Rafinesque's big-eared bats (*Corynorhinus rafinesquii*), and tri-colored bats (*Perimyotis subfalvus*). We used recorded bat passes to calculate mean bat calls. Mean bat calls were then used as an estimate of bat activity (relative use of an area for foraging).

We used multiple linear regression and an information theoretic approach to determine how forest clutter, temperature, and treatment affected forest roosting bat foraging activity. We developed *a priori* candidate models that included the variables overstory basal area, midstory stem density, site type, treatment, and average nightly temperature. Because forest roosting bat species are not adapted for flight in cluttered areas, we chose to use live overstory basal area and midstory density as an estimate of clutter. Quantitative measurements of liver overstory basal area and midstory density have been shown to be an effective surrogate for measuring clutter (O'Keefe et. Al. 2014). Each site type represents the different cover types (i.e., savanna, shelterwood, NWSG field) where acoustic detectors were deployed.

While forest roosting bats can be more active in the winter than other bat species, low nightly temperatures may reduce bat activity. Because we conducted this research in the winter, we determined that temperature is a variable that could affect bat foraging activity, and so deemed it necessary to include in analysis. We used Akiake's information criterion (AIC) adjusted for small sample sizes (AICc) to rank models and determine the importance of each of the variables tested. For each model we calculated the difference between the model with the lowest AICc and the AICc for the ith model ($\Delta$AICc) and considered models with a $\Delta AIC \leq 2$ to be supported models (Burnham and Anderson 2010). We then calculated the 95% confidence intervals and removed variables with confidence intervals that overlapped 0 as too weak to be informative. We considered the interaction between treatment and stand type when examining effect of prescribed fire on bat activity. All statistical analyses were conducted using Rstudio (R Version 4.3.1, Posit Software, Boston, MA, USA).

## RESULTS

We monitored bat activity within our 20 study areas for a total of 280 nights (14 nights/study area) from November 2022–April 2023 for a total of 3,360 hours (12hours/night). Over this sample period 12,058 bat passes were recorded, of which we identified 47.9% (n = 5,773) as belonging to the forest roosting bat group. Of calls identified to species, 12.1% (n = 699) were identified as LABO, 17.6% (n = 1,013) were identified as LACI, and 70.3% (n = 4,061) were identified as LANO. A total of 32.0% (n = 3,862) were grouped together as "other" but included species in the genus *Myotis* (little brown bat, Indiana bat, gray bat, eastern small-footed bat, and northern long-eared bat), big brown bats (*Eptesicus fuscus*), evening bats (*Nycticeius humeralis*), Rafinesque's big-eared bats (*Corynorhinus rafinesquii*), and tri-colored bats (*Perimyotis subfalvus*).

Mean bat activity was greater in burned shelterwood units than in unburned shelterwood control units (Table 8). Mean bat activity for NWSG fields was also greater in units that had been burned compared to the unburned control NWSG field units (Table 8). Mean bat activity was slightly less in burned savanna units than in unburned savanna control units (Table 8). When breaking down bat passes recorded by species, we observed a similar trend. For LABO and LACI, bat activity was greater after implementation of prescribed fire for both the shelterwood and native warm-season grass field units when compared to control units. In contrast, bat activity was slightly less in burned savanna units compared to control units (Table 9, Figure 7, Figure 8). However, LANO activity and activity of the forest roosting bat group was greater in all 3 units after burning compared to controls (Table 9, Figure 9, Figure 10).

For LABO, we ran all combinations of variables in models which resulted in 3 candidate models (Table 10). These models included the variables site, treatment, temperature, live

overstory basal area, and midstory density. Model averaging results indicated that site, temperature, and midstory density were informative explanatory variables in predicting LABO activity (i.e., confidence intervals did not overlap 0; Table 11). Live overstory basal area and treatment (i.e., dormant season prescribed fire) had confidence intervals that overlapped 0 indicating that these variables on their own have a weak effect on LABO activity in burned or unburned stands.

For LANO activity, all combinations of variables in models resulted in 2 candidate models (Table 10). These models included the variables site, treatment, live overstory basal area, and midstory density. Model averaging results for these models indicated that site was the only informative explanatory variable for predicting LANO activity (i.e, confidence interval did not overlap 0; Table 11). Silver-haired bat activity was two times higher in burned savannas compared to unburned controls, and three times higher in burned shelterwood units compared to unburned controls (Table 9). While treatment, live overstory basal area, and midstory density had a weak effect on predicting LANO activity, these variables did appear in each of the candidate models for this species, indicating that while they may not affect activity on their own, they may be informative explanatory variables when combined with other variables.

For LACI activity, all combinations of variables in models resulted in 2 candidate models (Table 10). These models included the same variables as those in the models for LANO activity, site, treatment, live overstory basal area, and midstory density. Model averaging indicated similar results for LACI activity as LANO activity. For LACI, only site was and informative explanatory variable (i.e., confidence interval does not overlap 0; Table 11). Similar to LANO, treatment, live overstory basal area, and midstory density appeared in all candidate models for the species as

well. These variables may not be informative on their own, but in combination with site type are informative in predicting LACI activity in burned and unburned stands.

For the forest roosting bat group, all combinations of variables in models resulted in 2 candidate models (Table 10). Variables included in these models were site, treatment, temperature, live overstory basal area, and midstory density. Of the 5 variables, site and temperature were indicated as informative explanatory variables (i.e., confidence intervals did not 0verlap 0; Table 11), for forest roosting bats. Bat activity was 2.5 times higher in burned shelterwood units compared to unburned control units, and only slightly higher in savanna and NWSG field units compared to the unburned controls. Bat activity was higher in stands when temperatures were warmer compared to colder temperatures that approached or fell below freezing (0℃). Treatment, live overstory basal area, and midstory density all had confidence intervals that included 0, indicating they, alone, had a weak effect on forest bat activity. However, these variables did appear in all candidate models for forest roosting bat activity, indicating that in combination with other variables they may be informative in predicting forest roosting bat activity in burned or unburned stands.

## DISCUSSION

Eastern red bats, hoary bats, and silver-haired bats are species that are known to be more active during the cold, winter months than other bat species, and the implementation of dormant season prescribed fire may drive some of this activity. Forest roosting bats (i.e., LABO, LACI, and LANO) are larger bodied bats with higher wing loadings and aspect ratios than other bat species, making flying through cluttered areas (areas with high basal area or high midstory and understory density) very difficult (Aldrich and Rautenbach, 1987, Norberg and Rayner, 1987).

Because of this morphology we can assume to have more activity of these species in areas such as savannas and NWSG fields where basal are and mid- and understory density are typically low, and there is more open space for flight and foraging (Neuweiler, 1983, Kingston et al., 2000, Lee and McCracken, 2004). While this held true for the savanna sites across all species in our study, this was not the case for the NWSG fields, which had lower activity than both the savanna sites and shelterwood release sites. This indicates that for savannas, amount of bat activity is likely an effect of vegetation type rather than fire. While bat activity did appear to increase in burned sites compared to control sites, our AIC candidate models did not provide evidence that dormant season prescribed fire was an important variable in determining bat activity.

Temperature appears in all AIC candidate models for each group and is a strong predictor for bat activity in all stand types. We can speculate that this is due to these bats going in and out of torpor throughout the season. During the colder nights, bats are likely going into torpor for days or weeks at a time (Moorman et al. 1999, Hein et al. 2008, Flinn 2009, Perry 2012). Once there are a few warmer nights, the bats may arouse and choose to take advantage of the weather and forage. Stands that have recently been burned can make this easier with providing a more open area for foraging. Our results are not comparable to those of other studies that have been done investigating the effects of fire and other silvicultural practices on bat activity, though those studies were conducted during summer, spring, and fall, rather than in the winter, and most were conducted in pine forests instead of mixed hardwood and open fields (Loeb and Waldrop 2008, Armitage and Ober 2012, Cox et al. 2016). These studies found a positive correlation between burning and mean bat activity, while we found that burning may be less important than temperature and vegetation in determining bat activity at this time of the year. A 2-way ANOVA test performed on the data presented in Table 9 showed no significance in treatment versus

control for any of the study units, suggesting vegetation, temperature, and other factors maybe more important at determining bat activity than prescribed fire during this time period.

Armitage and Ober (2012) found that bat activity was higher in Florida longleaf pine-wiregrass stands that had been recently burned and suggested that certain species are likely to benefit from this reduction in clutter, making these stands more available for efficient use than they would be otherwise. Loeb and Waldrop (2008) came to similar conclusions after increased bat activity in southern pine stands that had undergone thinning, leading to a reduction in clutter. Ford et al. (2006) and Loeb and O'Keefe (2006) found that eastern red bats are detected more in open habitats and in forests with less dense mid- and understory than in closed forests and forests with a dense mid- and understory.

All North American forest roosting bats are insectivorous in nature and rely on various orders of insects as prey. Studies that have been conducted examining bat response to prescribed fire in other North American forest systems have found that the practice affects bat activity (relative use of an area for foraging) through changes in forest structure and availability of nocturnal flying insect prey (Loeb and Waldrop, 2008, Titchenell et al., 2011, Armitage and Ober, 2012, Cox et al., 2016). While bats may use a forest stand for foraging based on their adaptations to that environment, such as wing loading, aspect ratio, and echolocation call frequency, the availability of nocturnal insect prey may also play an important role in determining use, and in turn, activity in an area (Erickson and West, 2003, Lacki et al., 2007). While our study did not investigate the change in insect biomass in our study sites after prescribed burning, other studies have shown that different silvicultural treatments, including prescribed fire, elicit a response in insect communities, often increasing abundance, though results are variable (Swengel 2001, Lacki et al. 2009).

Forest roosting bats are currently facing many threats to their populations including the development of wind energy facilities (Zimmerling and Francis 2016), habitat degradation, deforestation, and fragmentation (Hutchinson and Lacki 2000, Carter et al. 2003, Winhold et al. 2008). Because of these threats, understanding the full life cycle needs of these species are necessary for creating management plans that conserve the species. This includes understanding winter foraging behaviors and how our current land management practices can benefit bats during a difficult period in their life history. The results of our study show that forest roosting bats may show positive responses to non-growing season prescribed fire both in terms of roosting with the eastern red bat (Chapter 1) and foraging activity of eastern red bats, hoary bats, and silver-haired bats, as well as other species. Although our study provides insight into the foraging behavior of forest roosting bats during winter, more research is needed to understand how prescribed fire management activities impact insect communities in the winter and how bats may respond to those changes.

# APPENDIX 2

Table 7: Table details date when each treatment unit at each study site was burned during the field season, and date when SM4 MiniBat acoustic detectors were deployed after unit underwent treatment. All detectors were deployed for 14 days following treatment.

| Site | Unit | Date Burned | Date Detector Deployed |
|---|---|---|---|
| Mt. Roosevelt | Shelterwood 1 | 11/2/22 | 11/7/22 |
| Bridgestone Firestone | NWSG Field 1 | 11/2/22 | 11/7/22 |
| Bridgestone Firestone | NWSG Field 2 | 3/8/23 | 3/15/23 |
| Bridgestone Firestone | NWSG Field 3 | 3/1/23 | 3/15/23 |
| Bridgestone Firestone | NWSG Field 4 | 3/1/23 | 3/15/23 |
| Bridgestone Firestone | Savanna 1 | 3/8/23 | 3/15/23 |
| Catoosa | Savanna 2 | 3/8/23 | 3/22/23 |
| Catoosa | Savanna 3 | 3/8/23 | 3/22/23 |
| Catoosa | Shelterwood 2 | 4/1/23 | 4/6/23 |
| Catoosa | Shelterwood 3 | 4/1/23 | 4/6/23 |

Table 8: Comparison of total bat calls, bat calls per night, mean bat calls ($\bar{x}$), and standard deviation (SD) of bat calls between control units and treatment units managed with dormant season prescribed in each stand type at Catoosa, WMA, Cumberland County, Tennessee, Mount Roosevelt WMA, Roan County, Tennessee, and Bridgestone-Firestone Centennial Wilderness Area, White County, Tennessee, 2022 – 2023.

| **Stand Type** | **Control** | | | | **Treatment** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Total** | **Calls/night** | $\bar{x}$ | **SD** | **Total** | **Calls/night** | $\bar{x}$ | **SD** |
| Shelterwood[a] | 1834 | 43.67 | 611.33 | 17.51 | 3722 | 88.62 | 1240.67 | 29.71 |
| Savanna[b] | 2124 | 37.93 | 531.00 | 22.34 | 1996 | 35.64 | 499.00 | 17.92 |
| NWSG Field[c] | 1124 | 26.76 | 374.67 | 10.51 | 1258 | 29.95 | 419.33 | 10.04 |

[a] Shelterwood sites had 3 replicates (6 total sites, 3 controls and 3 treatments)
[b] Savanna sites had 3 replicates (6 total sites, 3 controls and 3 treatments)
[c] NWSG Fields had 4 replicates (8 total sites, 4 controls and 4 treatments)

Table 9: Comparison of number of mean bat calls per night (calls/night ± SD) for each species in each stand type between control sites and treatment sites at Catoosa, WMA, Cumberland County, Tennessee, Mount Roosevelt WMA, Roan County, Tennessee, and Bridgestone-Firestone Centennial Wilderness Area, White County, Tennessee, 2022 – 2023.

| Species[a] Site | Control[b] | Treatment[c] |
|---|---|---|
| **LABO** | | |
| Field | 0.98±1.49 | 1.32 ±2.22 |
| Savanna | 4.19 ±6.07 | 2.45 ±3.61 |
| Shelterwood | 2.54 ±3.14 | 4.06 ±5.35 |
| **LANO** | | |
| Field | 9.30±16.44 | 9.96 ±18.02 |
| Savanna | 10.62 ±21.64 | 19.45 ±55.89 |
| Shelterwood | 9.56 ±11.21 | 30.10± 50.63 |
| **LACI** | | |
| Field | 1.43±2.00 | 3.43 ±6.00 |
| Savanna | 4.26 ±7.96 | 1.58 ±1.88 |
| Shelterwood | 3.17± 4.79 | 7.98 ±17.03 |
| **Forest** | | |
| Field | 11.72±18.28 | 14.70 ±20.33 |
| Savanna | 19.07 ±25.64 | 23.47 ±59.20 |
| Shelterwood | 15.28± 14.44 | 42.14± 60.56 |

[a] Species: LABO = eastern red bat (*Lasiurus borealis*), LACI = hoary bat (*Lasiurus cinereus*), LANO = silver-haired bat (*Lasionycteris noctivagans*), Foliage = total for all three species

[b] Control sites that were not burned before monitoring

[c] Treatment sites that were burned before monitoring

[d] Forest group is all bats SonoBat identified as a forest roosting bat without identifying species

Table 10: Akiake's Information Criterion corrected for small sample sizes ($AIC_c$), number of model parameters (*K*), log likelihood(LogLik), difference in $AIC_c$ between the *i*th and top-ranked model ($\Delta AIC_c$), and Akiake weight ($\omega_i$) for the confidence set of logistic regression models ($\Delta AIC_c < 2$) of variables explaining LABO, LACI, LANO, and forest roosting bat activity at Catoosa WMA, Cumberland County, Bridgestone-Firestone Centennial Wilderness Area, White, County, and Mount Roosevelt WMA, Roan County, Tennessee, USA, 2022 – 2023.

| Model | *K* | $AIC_c$ | $\Delta AIC_c$ | $\omega_i$ | LogLik |
|---|---|---|---|---|---|
| **LABO** | | | | | |
| Site + Treat + BA + Temp | 4 | 101.36 | 0.00 | 0.40 | -25.01 |
| Site + Treat + MSD + Temp | 4 | 101.46 | 0.09 | 0.38 | -25.06 |
| Site + Treat + BA + MSD | 4 | 102.66 | 1.29 | 0.24 | -25.66 |
| **LANO** | | | | | |
| Site + Treat + BA | 3 | 131.11 | 0.00 | 0.40 | -48.55 |
| Site + Treat + MSD | 3 | 132.28 | 1.16 | 0.27 | -49.64 |
| **LACI** | | | | | |
| Site + Treat + MSD | 3 | 60.41 | 0.00 | 0.40 | -13.70 |
| Site + Treat + BA | 3 | 61.09 | 0.67 | 0.29 | -14.04 |
| **Forest** | | | | | |
| Site + Treat + MSD + Temp | 4 | 139.34 | 0.00 | 0.40 | -44.01 |
| Site + Treat + BA + MSD | 4 | 140.22 | 0.87 | 0.36 | -44.44 |

[a]LABO = eastern red bat (*Lasiurus borealis*); LACI = hoary bat (*Lasiurus cinereus*); silver-haired bat (*Lasionycteris noctivagans*); Forest = all bats identified by SonoBat as a forest roosting bat without being identified down to species.

[b] Variables: Treat = treatment (dormant season prescribed fire); Type = stand type (shelterwood release, savanna, native warm-season grass field); Temp = minimum nightly temperature (℃); MSD = midstory density (stems/$m^2$); BA = live overstory basal area ($m^2$/ha).

Table 11: Model averaged parameter estimates, unconditional standard error, lower and upper confidence limits (CL) for 95% confidence intervals for confidence set of logistic regression models of variables predicting LABO, LACI, LANO, and forest roosting bat activity at Catoosa WMA, Cumberland County, Bridgestone-Firestone Centennial Wilderness Area, White, County, and Mount Roosevelt WMA, Roan County, Tennessee, USA, 2022 – 2023.

| Variable | Parameter Estimate | SE | Lower CL | Upper CL |
|---|---|---|---|---|
| **LABO** | | | | |
| Site | -5.558 | 6.743 | -3.983 | -0.762 |
| Treat | -0.662 | 4.371 | -12.799 | 11.474 |
| Temp | 0.112 | 0.138 | 0.062 | 0.136 |
| BA | 0.144 | 0.338 | -0.794 | 1.083 |
| MSD | -0.002 | 0.006 | 0.008 | 0.036 |
| **LANO** | | | | |
| Site | -17.943 | 30.034 | -35.893 | -9.261 |
| Treat | -16.222 | 19.469 | -70.277 | 37.832 |
| BA | 2.320 | 1.506 | -1.081 | 5.348 |
| MSD | -0.058 | 0.029 | -0.130 | 0.003 |
| **LACI** | | | | |
| Site | 2.670 | 1.952 | -6.353 | 0.873 |
| Treat | -2.646 | 1.265 | -6.161 | 0.868 |
| BA | 0.143 | 0.097 | -0.161 | 0.236 |
| MSD | -0.003 | 0.001 | -0.004 | 0.006 |
| **Forest** | | | | |
| Site | -20.831 | 28.511 | 1.618 | 21.815 |
| Treat | -19.531 | 18.481 | -70.844 | 31.781 |
| Temp | 1.162 | 0.585 | 0.717 | 3.011 |
| BA | 2.608 | 1.429 | -1.362 | 6.578 |
| MSD | -0.064 | 0.027 | -0.102 | 0.046 |

[a]LABO = eastern red bat (*Lasiurus borealis*); LACI = hoary bat (*Lasiurus cinereus*); silver-haired bat (*Lasionycteris noctivagans*); Forest = all bats identified by SonoBat as a forest roosting bat without being identified down to species.

[b] Variables: Treat = treatment (dormant season prescribed fire); Type = stand type (shelterwood release, savanna, native warm-season grass field); Temp = minimum nightly temperature (℃); MSD = midstory density (stems/$m^2$); BA = live overstory basal area ($m^2$/ha).

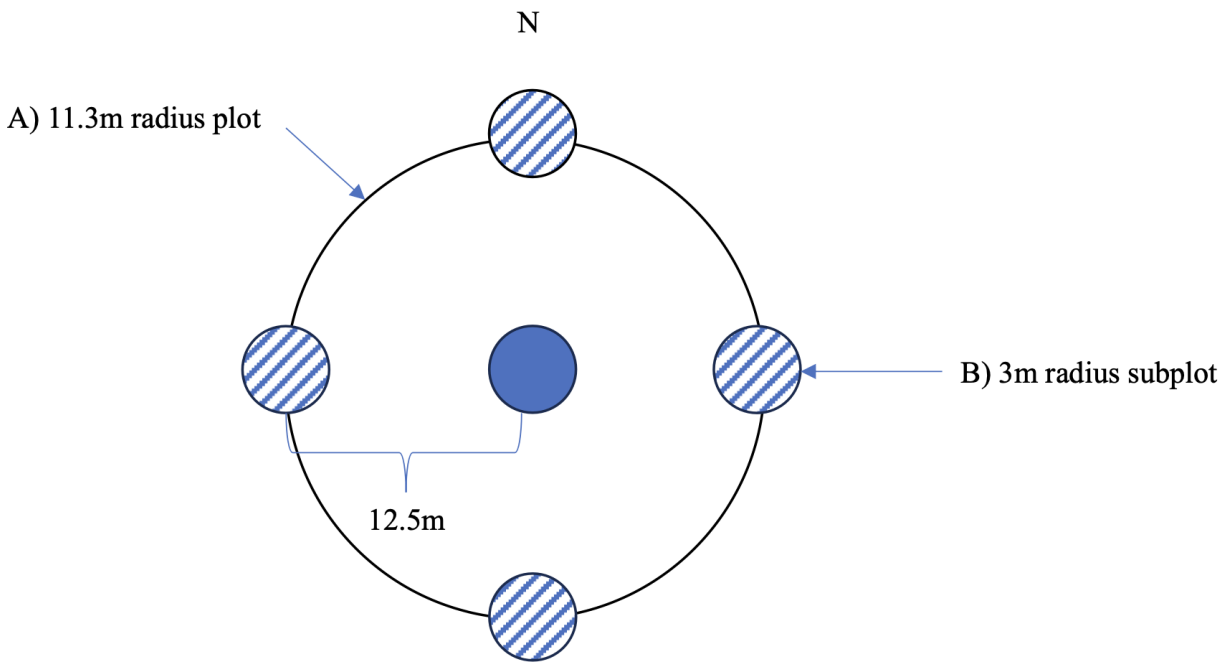



Figure 6: Sampling layout for assessing forest clutter in sampling units used to examine forest roosting bat foraging activity in forest stands subject to dormant season prescribed fire at Catoosa WMA, Cumberland County, Bridgestone-Firestone Centennial Wilderness Area, White, County, and Mount Roosevelt WMA, Roan County, Tennessee, USA, 2022 – 2023. A) An 11.3m radius plot used to estimate live overstory basal area (10 factor prism; $m^2$/ha). B) 3m radius sublots used to measure midstory stem density (stems >1m tall and <10cm dbh; stems/$m^2$).

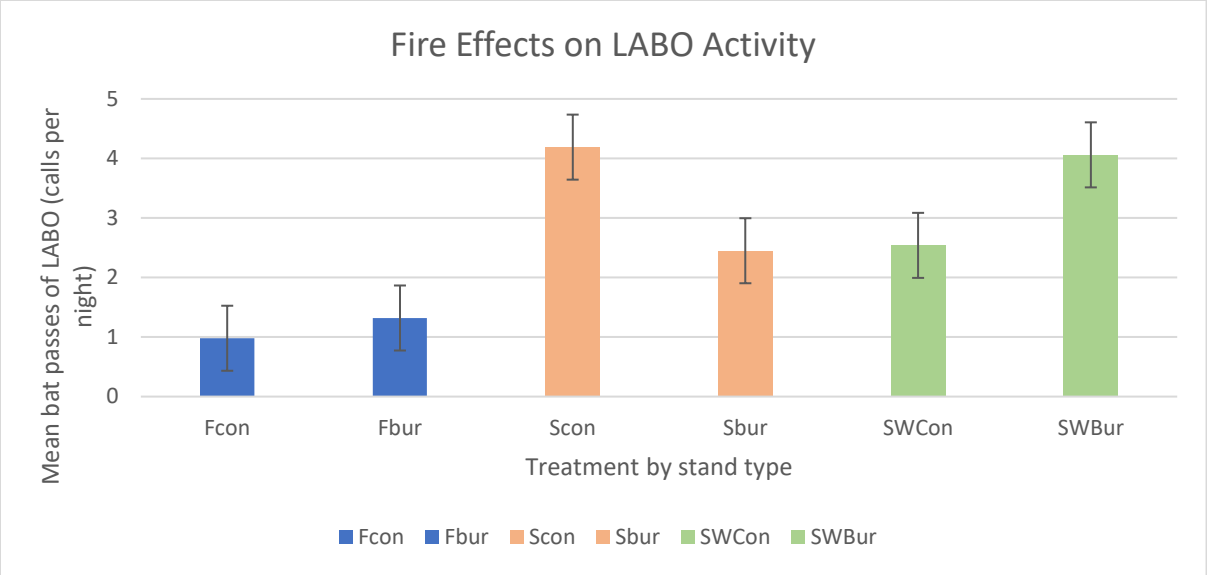



Figure 7: Effects of dormant season prescribed fire on eastern red bat (*Lasiurus borealis*; LABO) activity at Catoosa, WMA, Cumberland County, Tennessee, Mount Roosevelt WMA, Roan County, Tennessee, and Bridgestone-Firestone Centennial Wilderness Area, White County, Tennessee, 2022 – 2023. Treatments: Fcon = Field control, Fbur = Field Burn, Scon = Savanna control, Sbur = Savanna burn, SWCon = Shelterwood control, SWBur = shelterwood burn.

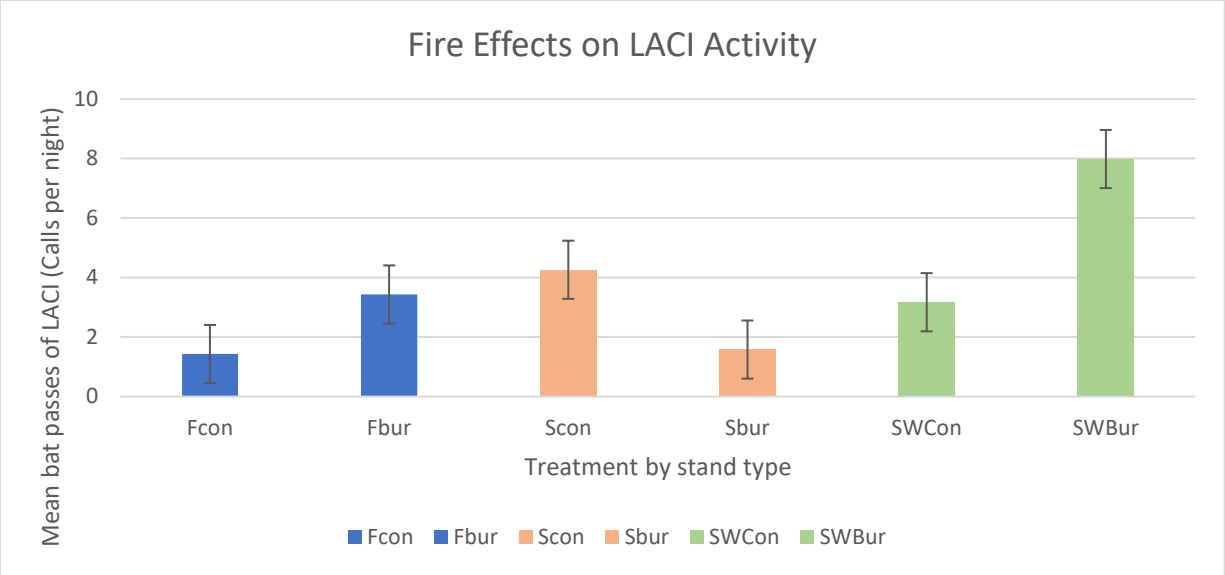



Figure 8: Effects of dormant season prescribed fire on hoary bat (*Lasiurus cinereus*; LACI) activity at Catoosa, WMA, Cumberland County, Tennessee, Mount Roosevelt WMA, Roan County, Tennessee, and Bridgestone-Firestone Centennial Wilderness Area, White County, Tennessee, 2022 – 2023. Treatments: Fcon = Field control, Fbur = Field Burn, Scon = Savanna control, Sbur = Savanna burn, SWCon = Shelterwood control, SWBur = shelterwood burn.

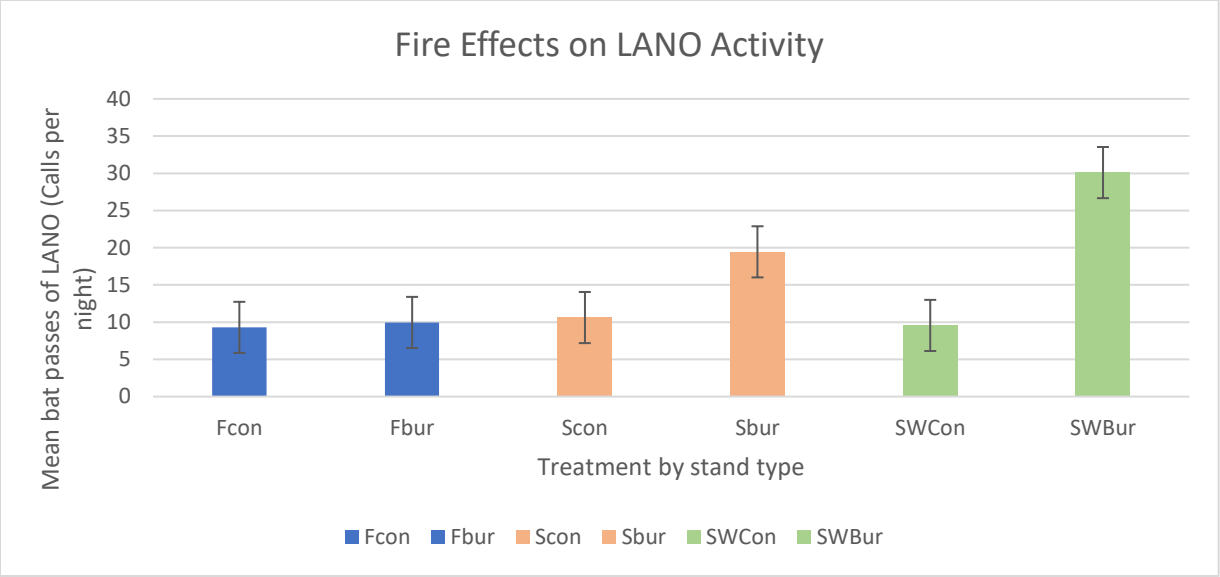



Figure 9: Effects of dormant season prescribed fire on silver-haired bat (*Lasionycteris noctivagans*; LANO) activity at Catoosa, WMA, Cumberland County, Tennessee, Mount Roosevelt WMA, Roan County, Tennessee, and Bridgestone-Firestone Centennial Wilderness Area, White County, Tennessee, 2022 – 2023. Treatments: Fcon = Field control, Fbur = Field Burn, Scon = Savanna control, Sbur = Savanna burn, SWCon = Shelterwood control, SWBur = shelterwood burn.

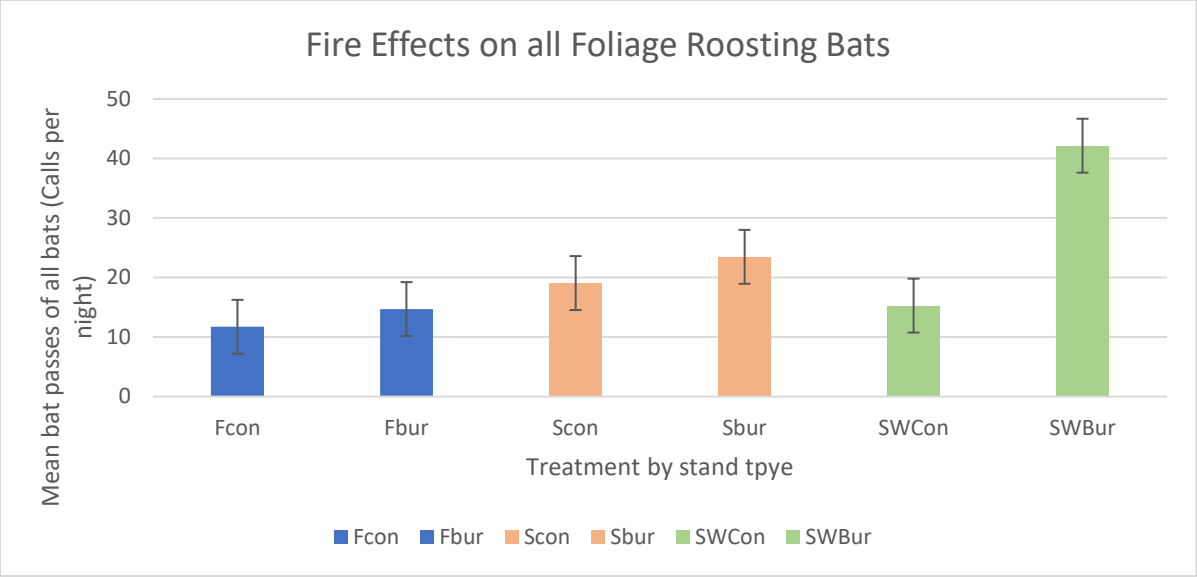



Figure 10: Effects of dormant season prescribed fire on forest roosting bat activity (bats identified as a forest roosting bat without species) at Catoosa, WMA, Cumberland County, Tennessee, Mount Roosevelt WMA, Roan County, Tennessee, and Bridgestone-Firestone Centennial Wilderness Area, White County, Tennessee, 2022 – 2023. Treatments: Fcon = Field control, Fbur = Field Burn, Scon = Savanna control, Sbur = Savanna burn, SWCon = Shelterwood control, SWBur = shelterwood burn.

## CONCLUSIONS

While eastern red bats have frequently been observed roosting on the ground beneath leaf litter during periods of cold winter temperatures, our study indicates that this could be a regional phenomenon. Even when temperatures dropped below freezing (0 ℃), bats in our study areas remained in their tree roosts during the cold period. Our study also showed that eastern red bats may be generalists when it comes to winter roost selection. Roost and stand level characteristics do not appear to be indicators of roost selection, and bats were observed using a variety of species in various states of defoliation. However, landscape attributes such as slope do appear to be important in roost selection, with bats frequently selecting roosts that are on south facing slopes. This is likely due to the increased solar exposure bats would get by roosting on the south side of a ridge. Bats in our study also chose roosts that were close to forest edge.

It is thought that dormant season prescribed fire could be harmful to roosting eastern red bats. If they are in torpor and on the ground, they may not arouse in time to flee the oncoming flame front. However, our results do not provide evidence that this is the case. In fact, it may be that dormant season prescribed fire is benefitting this species by opening flight space under the canopy. Because these bats are more generalists when it comes to roost selection, management of the species in this region may only require us to continue managing for healthy, mature, mixed hardwood forests with plenty of edge, and a mosaic landscape that includes open areas for foraging.

Forest roosting bats (eastern red bats, hoary bats, and silver-haired bats) are often more active during the winter that many other species. They are frequently observed coming out on warmer nights to forage. Dormant season prescribed fire can have many benefits to these forest roosting species. Benefits of dormant season prescribed burning may include reduction of clutter

and opening up of flight space below the canopy, making navigating through forested areas less taxing, and an increase in insect prey availability during a period when food resources are typically scarce. Our results show that forest roosting species are using forest stands that have been treated with a dormant season prescribed burn more than untreated forest stands, especially on warmer winter nights. For some species, like eastern red bats and silver-haired bats, the reduction of clutter makes foraging in these areas more efficient, allowing them to conserve energy during the winter. Continuing to manage forest stands with dormant season prescribed fire can provide forest roosting species more opportunities for winter foraging, as well as create the mosaic landscape that these species require for roosting. By continuing to manage our forests for healthy, mature, mixed hardwood forests we can help to conserve the species and prevent further declines in populations.

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## VITA

Ashley Epstein is from Baltimore, Maryland. She graduated from Bedford Senior Highschool in Bedford, Pennsylvania in 2009. Ashley worked as a veterinary technician in Florida before deciding to pursue a career in wildlife and fisheries science. Ashley moved to Knoxville in November of 2016, and began working on her bachelor's degree at the University of Tennessee, Knoxville in the fall semester of 2018. While working on her undergraduate degree, Ashley worked as a field technician for graduate students in the Willcox Small Mammal Ecology Lab, aiding with various projects including those researching bats and eastern spotted skunks. Ashley graduated with her bachelor's degree in wildlife and fisheries science with a concentration in management in the spring of 2021. In the summer after graduation, Ashley continued to gain field experience by working with other graduate students and developed and conducted a pilot study examining the presence and range of Appalachian cottontails in east Tennessee. Ashley joined the Willcox Small Mammal Ecology Lab in the fall of 2021 to study the roosting behavior of eastern red bats and foraging ecology of foliage roosting bats in Tennessee.