

Articles

Roost Selection by Male Indiana Myotis Following Forest Fires in Central Appalachian Hardwoods Forests

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Abstract

Despite the potential for prescribed fire and natural wildfire to increase snag abundance in hardwood forests, few studies have investigated effects of fire on bat roosting habitat, particularly that of the endangered Indiana myotis *Myotis sodalis*. From 2001 to 2009, we examined roost selection of Indiana myotis in burned and unburned forests in Tucker County, West Virginia. We radiotracked 15 male Indiana myotis to 50 roost trees; 16 in burned stands and 34 in unburned stands. Indiana myotis roosted in stands that had initially been burned 1–3 y prior to our observations. In burned stands, Indiana myotis roosted exclusively in fire-killed maples (*Acer* spp.). In unburned stands, they roosted in live trees, predominately hickories (*Carya* spp.), oaks (*Quercus* spp.), and maples. Roost trees in burned stands were surrounded by less basal area and by trees in advanced stages of decay, creating larger canopy gaps than at random trees in burned stands or actual roost trees located in unburned stands. Compared to random trees in unburned stands, roost trees in unburned stands were less decayed, had higher percent bark coverage, and were surrounded by less basal area, also resulting in larger canopy gaps. Roost-switching frequency and distances moved by Indiana myotis among roost trees were similar between burned and unburned stands. Our research indicates that use of fire for forest management purposes, at minimum provoked no response from Indiana myotis in terms of roost tree selection, and may create additional roost resources, depending on spatial context.

Keywords: Fernow Experimental Forest; forest fire; Indiana myotis; *Myotis sodalis*; prescribed fire; roost selection; West Virginia

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Introduction

Formerly discouraged as a forest management practice in many hardwood forest types, the use of prescribed fire has gained increasing acceptance among managers as a tool to help regenerate and retain hard-

mast-producing species such as oaks (*Quercus* spp.) and hickories (*Carya* spp.) in the Appalachian Mountains and Central Hardwoods forest regions (Brose et al. 1999, 2006). Although effects of fire have been examined mostly from a forest management perspective, including in the Appalachian Mountains (Keyser and Ford 2006), its



role is often overlooked relative to life histories and management strategies for wildlife species (Brennan et al. 1998). Depending upon season, severity, and micro-site conditions, fire can result in an increased abundance of dead and dying trees, which typically has positive implications for tree-dwelling wildlife species, including bats (Tucker et al. 2004; Blake 2005; Boyles and Aubrey 2006; Hayes and Loeb 2007). Recent research indicates that prescribed fires alter forest structure in a way that is favorable to bats that roost in tree cavities or under exfoliating bark (Boyles and Aubrey 2006; Johnson et al. 2009; Lacki et al. 2009). Whereas empirical data exist indicating that fire positively affects roosting habitat of common species such as evening bats *Nycticeius humeralis* and northern myotis *Myotis septentrionalis*, no work has specifically examined this condition relative to roost selection and habitat of Indiana myotis *M. sodalis*, a species listed as endangered pursuant to the U.S. Endangered Species Act (ESA) as amended (ESA 1973; *Federal Register*, 11 March 1967 [MacGregor et al. 1999; Gumbert 2001; Dickinson et al. 2009]). Typically, Indiana myotis roost under the exfoliating bark of live trees such as shagbark hickory *C. ovata* or dead trees that are taller and larger in diameter than surrounding trees (Menzel et al. 2001). During a fire event, bark of live trees tends to peel away from the sapwood from heated sap in the phloem–cambium layer (Barnes and Van Lear 1998), potentially providing an increased number of roosts for bats.

The geographic range of Indiana myotis largely overlaps oak-dominated forest communities in Midwest, mid-Atlantic, and northeastern United States (Braun 1950; Thomson 1982). Recent population stabilization and, in some cases, modest population increases are now being reversed by the rapidly spreading enzootic white-nose syndrome *Geomyces destructans*. Heretofore, successful efforts to promote species recovery have focused largely on protection of hibernacula (e.g., caves where Indiana myotis overwinter [Clawson 2002; USFWS 2007, 2009]). Following population declines due to white-nose syndrome, protection of critical summer habitat will also be important for species recovery.

Many studies have focused on summer roosting habitat of Indiana myotis, but few have examined spring and autumn roosting habitat (Menzel et al. 2001; Brack 2006; Britzke et al. 2006; Carter 2006). Regardless of season, Indiana myotis generally select large-diameter trees and snags or live trees with exfoliating bark (Gardner et al. 1991; Callahan et al. 1997; MacGregor et al. 1999; Gumbert 2001; Menzel et al. 2001; Ford et al. 2002). Fire may negatively impact Indiana myotis roosting habitat by reducing roost availability or by creating unsuitable conditions at existing roost trees. Alternatively, fire may provide additional roosting resources for Indiana myotis and disturb a forest stand in a way similar to that in flooded forests, where snag abundance increases several-fold over preexisting conditions (Kurta et al. 1996; Carter et al. 2002; Carter 2006). Fire might be an effective tool to foster recovery of this species, because Indiana myotis may benefit from additional snags and canopy disturbances provided by active management (Carter et al. 2002; Carter 2006;

Keyser and Ford 2006). Nonrandom selection of roosts, roost-switching frequency, and distance traveled between successive roosts are indicators of roost availability, but have not been well-researched in the eastern United States (Wilkinson 1985; Crampton and Barclay 1998; Sedgeley and O'Donnell 1999; Kunz and Lumsden 2003; Chaverri et al. 2007).

Our objectives here were to: 1) compare roost tree selection of Indiana myotis in forest stands subjected to fire (wildfire and prescribed burning) to unburned stands in the central Appalachian Mountains based on physical characteristics of roost trees and random trees; and 2) examine roost tree abundance and availability by comparing roost-switching frequency and distances traveled between successive roosts located in burned and unburned forest stands. We predicted that Indiana myotis would select roost trees within forest gaps created by fire, and that roost-switching frequency would be higher and distances travelled to new roosts shorter in forest stands subjected to fire (Boyles and Aubrey 2006; Johnson et al. 2009), which is consistent with other bat species in the region and existing ecological observations of the Indiana myotis.

Methods

Study area

We conducted our research at the Fernow Experimental Forest (FEF) and Petit Farm in Tucker County, West Virginia (Figure 1). Both areas are located in the Unglaciated Allegheny Mountains subsection of the Appalachian Plateau Physiographic Province (Kochenderfer et al. 2007). American chestnut *Castanea dentata* and oak species, such as northern red oak *Q. rubra*, were historically significant components of the forest overstory at Petit Farm and FEF. Chestnut blight *Cryphonectria parasitica* and subsequent fire suppression, white-tailed deer *Odocoileus virginianus* herbivory, and use of uneven-aged harvesting systems has allowed forest composition to shift toward shade-tolerant tree species, such as maples and American beech *Fagus grandifolia* (Schuler and Fajvan 1999, Schuler 2004). Overall mean annual precipitation in the area is 145.8 cm, ranging from 9.7 cm in October to 14.4 cm in June. Mean annual temperature is 9.2°C, ranging from –18.0°C in January to 20.6°C in July (Kochenderfer 2006). The FEF is a 1,900-ha experimental forest managed by the U.S. Forest Service, Northern Research Station. Elevations range from 530 to 1,100 m at FEF, and nearly 1,300 m on portions of the surrounding national forest. Ellick Run, a 2.4-km fourth-order stream, roughly bisects the FEF from east to west. Approximately 5.5 km of dendritic intermittent and permanent streams feed into Ellick Run and incise the steep slopes and plateau-like ridgetops, providing all possible slope aspects (Madarish et al. 2002). Vegetation at FEF is largely a mosaic of second- and third-growth, mixed-mesophytic and northern hardwood forest. Forests on the FEF, largely resembling those in the surrounding region, have been managed by even (patch clearcut)- and uneven (single-tree selection)-aged silviculture since the mid-20th

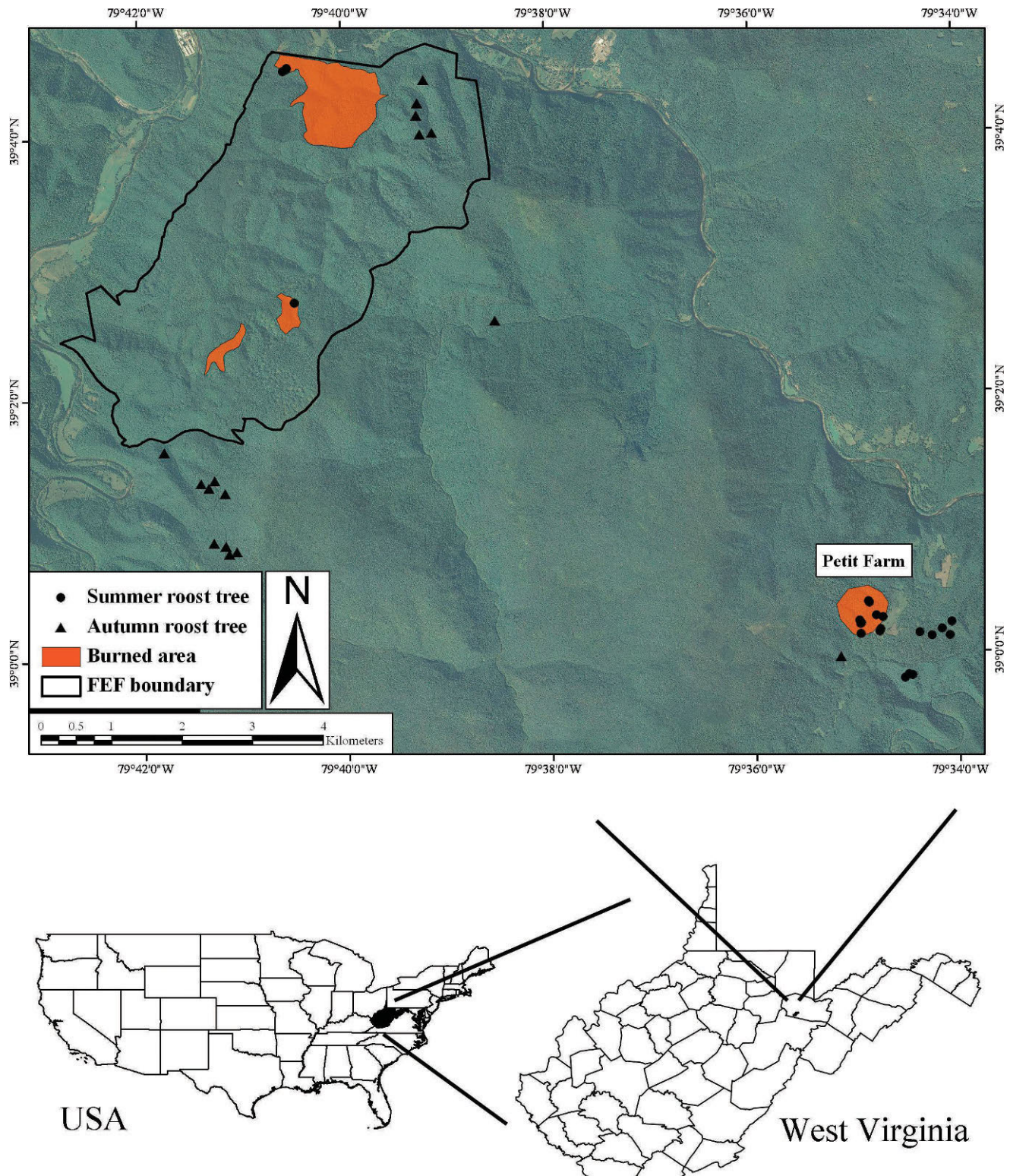


Figure 1. Indiana myotis *Myotis sodalis* roost tree locations within unburned areas and forest stands subjected to prescribed fire at Fernow Experimental Forest (FEF) and forest fires at Petit Farm, Tucker County, West Virginia, 2004–2009.

century, or has been left undisturbed following initial harvesting in the Ellick watershed from 1903 to 1911 (Schuler and Fajvan 1999). Prescribed fire has recently been used to promote oak regeneration in stands currently dominated by sugar maple *Acer saccharum*,

red maple *A. rubrum*, yellow-poplar *Liriodendron tulipifera*, black cherry *Prunus serotina*, American beech, sweet birch *Betula lenta*, and basswood *Tilia americana* (Schuler 2004). In spring (April or May) 2007–2009, prescribed fire treatments were conducted in three

management compartments (12-, 13-, and 121-ha areas) on FEF (Figure 1). The compartments were burned using strip head-fires, ignited with handheld drip torches. Actual flame heights and combustion varied from immediately dying out to >3.5 m high in some spots, due to variable leaf litter, slope, and aspect. Additionally, 48, 20-m-radius plots were randomly located in each of three management compartments, and all overstory or midstory trees, other than oak or hickory species, were treated with herbicides or girdled (T. Schuler, U.S. Department of Agriculture Forest Service, personal communication).

Petit Farm is located on private land, approximately 8 km southeast of FEF, and has elevations ranging from 750 to 1,000 m. Petit Farm contains several first- and second-order streams that drain into Gladly Fork. Slopes are less steep at Petit Farm than at FEF. Vegetation composition at Petit Farm is similar to that of FEF. However, small portions of forests at lower elevations were cleared for pastoral grazing and hay production, and in 2001, a diameter-limit harvesting occurred on much of the approximately 400-ha area. Northern red oak, black cherry, and sugar maple ≥ 46 cm diameter were harvested, whereas all red maple were retained. In March 2003, an escaped campfire burned through a portion of the forest stand that had been harvested in 2001. Fire intensity was variable, but flame heights and residual overstory mortality was greater than that observed at FEF, in large part due to abundant downed tops and slash from the recent logging (J. Rodrigue, U.S. Department of Agriculture Forest Service, unpublished data).

From spring through autumn, the extant bat community of both sites consists of northern myotis, little brown myotis *M. lucifugus*, big brown bats *Eptesicus fuscus*, tricolored bats *Perimyotis subflavus*, eastern red bats *Lasiurus borealis*, silver-haired bats *Lasionycteris noctivagans*, and hoary bats *Lasiurus cinereus* (Owen et al. 2004; Ford et al. 2005). A small number of endangered Indiana myotis and Virginia big-eared bats *Corynorhinus townsendii virginianus* that hibernate in cave systems on or near both FEF and Petit Farm remain in the area during summer (Owen et al. 2001; Ford et al. 2002).

Radiotelemetry

We captured bats in mist nets (Avinet, Inc., Dryden, NY) erected over stream corridors, small pools and ponds, and skidder trails, during summer 2004–2006 at Petit Farm and 2008–2009 at FEF. During autumn 2007–2008 at FEF, we used a harp trap to capture bats during the autumn swarm at Big Springs Cave, an Indiana myotis hibernaculum. For each captured bat, we determined species, sex, age, weight, forearm length, and reproductive condition (Menzel et al. 2002). We used Skin Bond® (Smith and Nephew, Largo, FL) surgical cement to affix a 0.35-g radiotransmitter (Model LB-2N; lifespan 1–3 wk; Holohil Systems Ltd., Carp, ON, Canada) between the scapulae of captured Indiana myotis. Bat capture and handling protocols were approved by the Animal Care and Use Committee of West Virginia University (Protocol No. 08-0504) and followed the guidelines of the American Society of

Mammalogists (ACUC 1998). We used a radio receiver and three-element Yagi antenna (Wildlife Materials, Inc., Murphysboro, IL) to attempt to locate roost trees daily. To record the geographic locations (± 10 m) of roost trees, we used global positioning units (various models).

Habitat variables

Using a point-quarter sampling method, we measured physical characteristics of each roost tree and those of four trees (>10 cm diameter at breast height [dbh]) nearest to the roost tree. Measurements were taken within a few weeks of bats roosting in a tree. For each roost tree, we determined tree species, dbh (cm) using a diameter tape, decay class (Cline et al. 1980; i.e., 1 = live, 2 = declining, 3 = recent dead, 4 = loose bark, 5 = no bark, 6 = broken top, 7 = broken bole), crown class (Nyland 1996; i.e., 1 = suppressed, 2 = intermediate, 3 = codominant, 4 = dominant), tree height (m) with a hypsometer, roost height when known, and visually estimated percent bark remaining on the tree. For each of four trees nearest to the roost tree, we determined tree species, dbh (cm), distance (m) to the roost tree, decay class, and crown class. For each roost tree, we averaged each variable for these four nearest trees irrespective of species. We measured percent canopy gap either with a densiometer at four cardinal directions surrounding the tree, or through photographic methods (Johnson et al. 2009). We recorded aspect with a compass, percent slope with a clinometer at the plot (11.3-m radius centered on the roost tree), and stand basal area with a 20-factor prism (m^2/ha).

Within each burned stand and in unburned areas, we located random roost trees at random coordinates generated with ArcMap (Version 9.2; Environmental Systems Research Institute, Redlands, CA). In burned stands and unburned areas, we located 6 and 15 random trees, respectively. We considered unburned areas to be any area outside areas within FEF where prescribed fires were used or the forest stand on Petit Farm where the wildfire occurred. Random trees were identified as any tree (>10 cm dbh) that had exfoliating bark that possibly could be used by an Indiana myotis as described by Menzel et al. (2001). We used a subset of random trees meeting Indiana myotis roosting requirements (e.g., exfoliating bark) from a separate study (Johnson et al. 2009). Therefore, we could not match random trees with roost trees in terms of sample size. We measured the same tree characteristics, with exception of roost height, at the random roost trees as we did at the actual roost trees.

In ArcMap, we determined the elevation for each roost and random tree and the distance of each roost and random tree from the closest permanent water source (Supplemental Material, Table S1, <http://dx.doi.org/10.3996/042010-JFWM-007.S1>). We also used ArcMap to determine straight-line distances that bats moved among successive roost trees (Supplemental Material, Table S2, <http://dx.doi.org/10.3996/042010-JFWM-007.S2>).



Table 1. Indiana myotis *Myotis sodalis* roost-tree use in burned and unburned forest stands at the Fernow Experimental Forest (FEF) and Petit Farm in Tucker County, West Virginia, 2004–2009.

Year	Radiotracked bats ^a	Tree species used	
		In burned area	In unburned area
2005	Petit Farm: 4 males in summer	<i>Acer rubrum</i> (n = 8)	<i>A. rubrum</i> (n = 2)
		<i>A. saccharum</i> (n = 2)	<i>Carya cordiformis</i> (n = 1)
			<i>Sassafras albidum</i> (n = 1)
			<i>Quercus rubra</i> (n = 1)
			<i>Q. prinus</i> (n = 1)
			<i>Betula lenta</i> (n = 1)
2006	Petit Farm: 3 males in summer	<i>A. rubrum</i> (n = 1) Undetermined (n = 1)	<i>A. saccharum</i> (n = 2)
			<i>A. rubrum</i> (n = 1)
			<i>B. lenta</i> (n = 1)
			<i>Q. rubra</i> (n = 1)
			<i>Robinia pseudoacacia</i> (n = 1)
			Undetermined (n = 1)
2007	FEF: 2 males in autumn	—	<i>C. ovata</i> (n = 4)
			<i>Fagus grandifolia</i> (n = 2)
			<i>Q. rubra</i> (n = 2)
			<i>Prunus serotina</i> (n = 1)
			<i>Liriodendron tulipifera</i> (n = 1)
2008	FEF: 1 male in summer, 3 males in autumn	—	Summer roosts:
			<i>C. glabra</i> (n = 1)
			<i>F. grandifolia</i> (n = 1)
			<i>A. rubrum</i> (n = 1)
			Autumn roosts:
			<i>C. ovata</i> (n = 4)
			<i>L. tulipifera</i> (n = 1)
			<i>A. saccharum</i> (n = 1)
2009	FEF: 2 males in summer	<i>A. rubrum</i> (n = 4)	<i>Ulmus rubra</i> (n = 1)
			—

^a We tracked 1 female Indiana myotis to a 31-cm-dbh, fire-killed red maple *Acer rubrum* on Petit Farm (data not shown), where it roosted with about 45 other bats (Keyser and Ford 2006).

Statistical analysis

We used Mann-Whitney tests (Proc Npar1way; SAS Institute, Inc. 2004) to make the following comparisons of tree characteristics: 1) roost trees located within burned areas to those in unburned areas, 2) roost trees in burned areas to random trees in burned areas, 3) roost trees in unburned areas to random trees in unburned areas, and 4) roost trees used in autumn to those used in summer. We made the four comparisons on appropriate subsets of the same data set. Although differences between FEF and Petit Farm probably exist in terms of topography and fire intensity, we combined data collected at both sites due to small sample sizes collected at either site. We used a Fisher's Exact Test (Proc Freq; SAS Institute, Inc. 2004) to determine whether roost trees were more frequently located on any slope aspects within burned and unburned areas. To determine roost tree availability, we used a Mann-Whitney test to compare the frequency with which Indiana myotis switched roosts (measured as the number of consecutive days spent in a roost tree, between burned and unburned areas) and to compare distances (m) travelled

between consecutive roost trees in the burned and unburned areas.

Results

From 2004 to 2009, we captured and radiotracked 15 male Indiana myotis, and located 50 roost trees ([mean = 3.3, 1 SE = 0.5, range = 1–5 roosts/bat] 24 at FEF and 26 at Petit Farm); 16 in burned areas and 34 in unburned areas. Ten bats were captured and tracked to roosts during summer (June–July); five bats were captured and tracked to roosts during autumn (September–October). All roost trees of bats captured at FEF during the autumn swarm were located on or near FEF except one roost located on Petit Farm, approximately 9 km from Big Springs Cave (Figure 1). In burned areas, Indiana myotis roosted exclusively in fire-killed sugar maple and red maple snags. In unburned areas, Indiana myotis roosted in a variety of live tree species, predominately hickories, oaks, and maples (Table 1). At FEF and Petit Farm, some Indiana myotis roosted in fire-killed trees in stands that had initially been burned 1–3 y prior to our observation (Table 1).

Table 2. Characteristics of roost trees used by Indiana myotis *Myotis sodalis* and random trees subjected and not subjected to fire in Tucker County, West Virginia, 2004–2009.

Fire roost (<i>n</i> = 16)			Fire random (<i>n</i> = 6)			
Variable ^a	Mean ^b	SE	Mean ^b	SE	<i>S</i> ^c	<i>P</i>
DBHR (cm)	41.37	2.54	26.63	4.85	35.0	0.018
HEIGHT (m)	21.65	1.11	12.92	2.17	28.0	0.004
DECAYN	3.54	0.31	2.21	0.42	39.5	0.042
GAP (%)	28.05	3.48	11.43	0.71	34.0	0.014
BASAL (m ² /ha)	11.82	2.83	26.86	3.63	91.5	0.017
SLOPE (%)	29.13	2.92	43.50	5.12	100.5	0.022
ELEV (m)	833.56	10.86	680.17	26.26	21.0	<0.001

Fire roost (<i>n</i> = 16)			Nonfire roost (<i>n</i> = 34)			
Variable ^a	Mean ^b	SE	Mean ^b	SE	<i>S</i> ^c	<i>P</i>
BARK (%)	63.87	7.18	76.79	5.31	272.0	0.034
DBHN (cm)	24.87	1.54	30.79	1.54	257.0	0.014
DECAYN	3.54	0.31	1.54	0.14	561.5	<0.001
GAP (%)	28.05	3.48	14.63	3.10	90.0	0.005
BASAL (m ² /ha)	11.82	2.83	23.55	2.08	183.5	0.002
WATER (m)	74.88	18.81	272.97	47.70	288.5	0.013

Nonfire roost (<i>n</i> = 34)			Nonfire random (<i>n</i> = 15)			
Variable ^a	Mean ^b	SE	Mean ^b	SE	<i>S</i> ^c	<i>P</i>
DECAYR	2.95	0.29	4.27	0.36	481.5	0.010
BARK (%)	76.79	5.31	46.67	8.20	245.0	0.006
GAP (%)	14.63	3.10	8.49	0.45	167.0	<0.001
BASAL (m ² /ha)	23.55	2.08	32.52	3.29	400.0	0.041
ELEV (m)	812.59	16.66	721.27	20.58	231.5	0.002

Summer roost (<i>n</i> = 33)			Autumn roost (<i>n</i> = 17)			
Variable ^a	Mean ^b	SE	Mean ^b	SE	<i>S</i> ^c	<i>P</i>
BARK (%)	68.55	4.96	80.41	8.11	528.5	0.016
DBHN (cm)	26.60	1.32	33.20	2.18	521.5	0.024
DECAYN	2.63	0.26	1.32	0.11	272.5	0.002
GAP (%)	27.67	7.67	11.66	0.62	145.0	0.018
BASAL (m ² /ha)	16.15	2.64	24.34	2.15	438.5	0.030
SLOPE (%)	26.30	2.20	42.00	4.88	571.5	0.005
WATER (m)	121.33	38.41	380.88	52.56	650.0	<0.001

^a DBHR = diameter (cm) at breast height of roost or random tree; DECAYR = decay class of roost or random tree (Cline et al. 1980; 1 = live, 2 = declining, 3 = recent dead, 4 = loose bark, 5 = no bark, 6 = broken top, 7 = broken bole); HEIGHT = roost or random tree height (m); BARK = estimation of percent bark remaining on roost or random tree; SLOPE = percent slope; BASAL = stand basal area (m²/ha); ELEV = elevation of roost or random tree; WATER = distance of roost tree to closest permanent water source; GAP = percent canopy gap over roost or random tree; DBHN = average diameter (cm) at breast height of four trees nearest to roost or random tree; DECAYN = average decay class of four trees nearest to roost or random tree.

^b Mann–Whitney tests were performed on ranked values. Actual means and standard errors (SEs) are presented.

^c Mann–Whitney test statistic.

Roost trees in burned stands were surrounded by less basal area and by trees in more advanced stages of decay, resulting in larger canopy gaps than at random trees in burned stands and at roost trees located in unburned stands (Table 2). Compared to random trees in unburned stands, roost trees in unburned stands were less decayed, had higher percent bark coverage, and were surrounded by lower basal area, resulting in larger canopy gaps (Table 2). In burned areas, roost trees were not more frequently located on any slope aspects ($n = 22$, $df = 2$, $\chi^2 = 5.37$, Fisher's Exact test $P = 0.065$). In

unburned areas, roost trees were more frequently located on west- and south-facing slopes ($n = 49$, $df = 3$, $\chi^2 = 9.30$, Fisher's Exact test $P = 0.011$). Compared to summer roost trees, roost trees used in autumn had a higher percentage of bark coverage, were surrounded by greater basal area and by trees that were larger in diameter and less decayed, resulting in smaller canopy gaps surrounding these trees (Table 2). Roost trees used in summer were closer to water and on gentler slopes than roost trees used in autumn (Table 2).

Roost-switching frequency was similar (Mann–Whitney statistic = 229.5, $P = 0.945$) between burned ($n = 12$, mean = 1.25 d, SE = 0.25, switched every 1–4 d) and unburned areas ($n = 33$, mean = 1.08 d, SE = 0.06, switched every 1–2 d). Distances that Indiana myotis moved among roost trees was similar (Mann–Whitney statistic = 96, $P = 1.000$) between burned ($n = 8$, mean = 219.62 m, SE = 49.65, range = 21–435 m) and unburned ($n = 15$, mean = 476.95 m, SE = 177.23, range = 1–2,420 m) areas.

Discussion

Our observations suggest that Indiana myotis may respond favorably to structural changes in forests caused by fire. Although it is unclear whether Indiana myotis roosted in burned areas prior to fires, the fact that Indiana myotis roosted in spaces under exfoliating bark of fire-killed sugar and red maples, indicates that the bats may benefit from forest alterations due to fire (Brose et al. 1999). Characteristics of roost trees and surrounding trees in burned areas were important in roost selection.

Within burned areas, Indiana myotis selected trees that were taller and larger in diameter than surrounding trees, similar to that reported by others (Menzel et al. 2001). Roost trees were surrounded by trees that were in more advanced stages of decay, possibly providing additional roosting structure. Also, the forced senescence of roost trees and surrounding trees resulted in an enlarged canopy gap, allowing more solar radiation to reach the roost trees (Johnson et al. 2009). In burned areas, canopy gaps were larger than those in unburned areas. From our observations, mean canopy gap size at roost trees in burned areas and those used during summer were >30%, but it remains unclear whether enlarged canopy gaps such as those in burned areas provide actual fitness benefits (e.g., increased recruitment success) for Indiana myotis beyond roost use in unburned areas.

Roost trees in unburned areas occurred in naturally existing canopy gaps. However, roost trees were less decayed than random trees in unburned areas, and were comprised of a larger number of species than in burned areas. Although we did not investigate tree species selection, the diversity of tree species used in unburned areas was more typical of previous observations of Indiana myotis roosts (Menzel et al. 2001). In unburned areas, Indiana myotis selected trees surrounded by less basal area than random trees, and occurred in larger canopy gaps.

During autumn, male Indiana myotis selected roost trees that were less decayed, and in smaller canopy gaps than roost trees used during summer. Also, Indiana myotis roosted in trees that occurred mostly on southern or southwestern slopes, augmenting solar exposure. In the mountains of western Virginia, almost half of roost trees used during autumn were shagbark hickory (Brack 2006). Although we documented no bats roosting in burned areas during autumn, Indiana myotis have been reported roosting in burned areas in Kentucky in autumn, although it is unclear whether those bats

roosted in fire-killed trees (Gumbert 2001). In that study, summer and autumn roost areas also were similar in terms of canopy gap, aspect, slope, and distance to water. We found that most differences in site characteristics, including slope and distance to water likely were attributable to differences between Petit Farm and FEF rather than selection per se, because the majority of autumn roost trees were located in or near the FEF and the majority of summer roost trees were located at Petit Farm. Also, fire intensity and forest harvesting (basal area removal) at Petit Farm were greater than at FEF (J. Rodrigue, unpublished data). Compared to autumn roost trees, the larger canopy gaps at summer roost trees were due to more summer roosts being located in burned areas. Although differences were probably attributable to different study areas where roosts were found between the two seasons, other studies suggest there are real and tangible physiological benefits to roosting in less open sites during autumn. During autumn, when insect availability may be unstable, male Indiana myotis may select relatively shaded, cooler roosts that allow them to conserve energy by lowering their body temperature near ambient air temperatures to a state of torpor (Henshaw and Folk 1966). Conversely, during summer, insect availability may be more consistent, allowing male Indiana myotis to maintain a higher body temperature during the day by selecting warm trees in canopy gaps on favorable aspects. Therefore, the benefits of fire may be limited to summer roosting habitat, possibly at the detriment of autumn roosting habitat. However, prescribed fires typically create a heterogeneous canopy layer with various gap sizes from which to select in summer and autumn (Johnson et al. 2009).

In Virginia, Brack (2006) found that males and females sometimes shared roost trees during autumn. Because our study included data from only one female Indiana myotis, we were unable to make any substantive male–female roost-selection comparisons (Menzel et al. 2001). Despite known differences between roost selection of male and female bats (Kunz and Lumsden 2003), roost trees of males in our study are very similar to those reported for Indiana myotis maternity colonies elsewhere within the species' distribution (Menzel et al. 2001; Britzke et al. 2003; Carter and Feldhamer 2005; Carter 2006; Watrous et al. 2006; Johnson and Gates 2010).

Although it is unknown whether there is a minimum density of roost trees required for Indiana myotis occupancy of an area, our roost-switching data and that of others suggest that there may be a sufficient number of roost trees in burned and unburned stands (Menzel et al. 2001; Gumbert et al. 2002; Kurta et al. 2002; Britzke et al. 2006). We caution that areas we studied included small patches of burned forest, and roost densities in areas adjacent to our study areas were unknown. Fire may be important in creating additional roost resources. Fire-killed trees may be suitable Indiana myotis roosts for an unknown number of years. Nonetheless, the ephemeral existence of roost trees remains to be quantified, depending on species and site conditions (i.e., susceptibility to wind-throw).



Our results indicate that Indiana myotis respond to effects of fire on forest stands, roosting in fire-killed trees 1–3 y postfire. This quick response to effects of fire allows the bats to maximize the time period of roost suitability for the newly created roost trees, because these trees will eventually become unsuitable. The mechanisms behind the initial use of a roost tree remain unclear (Wilkinson 1992; Ruczyński et al. 2009), but our observations indicate that Indiana myotis likely were using trees in or near the areas impacted by fires prior to the disturbances (Ford et al. 2002). Although we did not observe the same individuals for multiple years, the fact that Indiana myotis roosted in fire-killed trees in burned areas suggests that they selected these new roost trees over those used in previous years, (i.e., roost selection took precedence over roost fidelity). The exfoliating bark on fire-killed trees will gradually or quickly slough from the trees depending on species (Hallett et al. 2001), eventually rendering the tree unsuitable for Indiana myotis. Therefore, the intermediate- to longer term (>10 y after fire event) benefits of fire are uncertain for Indiana myotis.

Roost densities may return to or decline below prefire densities in absence of additional disturbance as fire-killed roost trees lose their bark and, therefore, much of their Indiana myotis roost-specific suitability. However, adjacent or nearby forest stands can be burned, or herbicided, or girdled to create additional roost trees in the short term. Systematic rotation of fire treatments among adjacent forest stands would maintain or increase density of roost trees for Indiana myotis populations at stand to landscape scales. By temporally staggering prescribed fire treatments among adjacent forest stands, potential roost trees could be maintained in an area (Rudolph and Conner 1996). Moreover, maintaining a heterogeneous canopy layer across the landscape would provide unshaded roost trees used during summer and relatively shaded roosts that are used during autumn.

In the long-term, canopy gap creation and reduction or elimination of fire-sensitive tree species due to fires will favor an oak-dominated forest that is beneficial to many other wildlife species (McShea and Healy 2002). However, this will also aid in the regeneration and retention of hickories, a preferred roost tree genera of Indiana myotis (Brose et al. 1999; Nowacki and Abrams 2008). Because it could take several decades for shagbark hickories to reach roost tree size, burning adjacent stands on systematic rotation will create and retain snags and other large trees with exfoliating bark in the interim. Certainly, additional research is needed to fully assess the spatial and temporal dynamics of snags and burning in relation to Indiana myotis roosting habitat requirements relative to foreseeable management regimes in the central Appalachians and elsewhere.

Conclusions

We believe that efforts to manage forests with prescribed fire to enhance oak regeneration appear to be compatible with Indiana myotis habitat management. Immediate effects of prescribed fires conducted in spring

are minimal in terms of disturbance to bats roosting in trees within a burned stand, but may affect species (e.g., eastern red bats) that roost in forest leaf litter (Rodrigue et al. 2001; Dickinson et al. 2009). However, further research is necessary examining the effects of wildfire on bats during summer. Short-term (<10 y) effects of forest fires include the increase in roost tree abundance resulting in more trees with exfoliating bark and favorable conditions such as enlarged canopy gaps at trees that may have been previously unsuitable for Indiana myotis. These conditions will gradually change as canopy gaps close and exfoliating bark is lost. Relative to bat-roosting habitat, effects of fire on upland hardwood forest stands are perhaps functionally similar to the disturbance impacts following flood damage and mortality in bottomland and riparian forests, as many trees are killed and become suitable snags for roosts, with surrounding dead trees and canopy gaps (Kurta et al. 1996; Carter 2006). In the Midwest, for example, Indiana myotis maternity colonies often use snags within floodplains or in ponds created by beavers *Castor canadensis*. Forest fires in upland stands may mimic effects of floods in systems in terms of snags (i.e., roost creation and forest structure change; Carter et al. 2002; Carter 2006). However, floods may be more spatially extensive, providing a more abundant source of snag resources than forest fires, which may be less extensive over the montane landscape where our study occurred. Although some aspects of Indiana myotis roost selection may differ among regions, disturbance regimes that increase roost resources may evoke similar responses from this species.

Supplemental Material

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Table S1. Characteristics of Indiana myotis roost trees and random trees in burned and unburned forest stands at the Fernow Experimental Forest (FEF) and Petit Farm in Tucker County, West Virginia, 2004–2009.

Found at DOI: 10.3996/042010-JFWM-007.S1 (114 KB XLS).

Table S2. Roost-switching distances of Indiana myotis in burned and unburned forest stands at the Fernow Experimental Forest (FEF) and Petit Farm in Tucker County, West Virginia, 2004–2009.

Found at DOI: 10.3996/042010-JFWM-007.S2 (27 KB XLS).

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