Notes

Activity of Southeastern Bats Along Sandstone Cliffs Used for Rock Climbing

Susan C. Loeb,* Patrick G. R. Jodice

S.C. Loeb
U.S. Department of Agriculture Forest Service, Southern Research Station, 233 Lehotsky Hall, Clemson University, Clemson, South Carolina 29634

P.G.R. Jodice
U.S. Geological Survey, South Carolina Cooperative Fish and Wildlife Research Unit, 238 Lehotsky Hall, Clemson University, Clemson, South Carolina 29634

Abstract

Bats in the eastern United States are facing numerous threats and many species are in decline. Although several species of bats commonly roost in cliffs, researchers know little about use of cliffs for foraging and roosting. Because rock climbing is a rapidly growing sport and may cause disturbance to bats, our objectives were to examine use of cliff habitats by bats and to assess the effects of climbing on their activity. We used radiotelemetry to track small-footed bats *Myotis leibii* to day roosts, and Anabat SD2 detectors to compare bat activity between climbed and unclimbed areas of regularly climbed cliff faces, and between climbed and unclimbed cliffs. We tracked four adult male small-footed bats to nine day roosts, all of which were in various types of crevices including five cliff-face roosts (three on climbed and two on unclimbed faces). Bat activity was high along climbed cliffs and did not differ between climbed and unclimbed areas of climbed cliffs. In contrast, overall bat activity was significantly higher along climbed cliffs than unclimbed cliffs; species richness did not differ between climbed and unclimbed cliffs or areas. Lower activity along unclimbed cliffs may have been related to lower cliff heights and more clutter along these cliff faces. Due to limited access to unclimbed cliffs of comparable size to climbed cliffs, we could not thoroughly test the effects of climbing on bat foraging and roosting activity. However, the high overall use of climbed and unclimbed cliff faces for foraging and commuting that we observed suggests that cliffs may be important habitat for a number of bat species. Additional research on bats' use of cliff faces will improve our understanding of the factors that affect their use of this habitat including the impacts of climbing.

Keywords: small-footed bats; *Myotis leibii*; cliff faces; roosting habitat; foraging habitat; rock climbing; Obed Wild and Scenic River

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* Corresponding author: sloeb@fs.fed.us

Introduction

Bats in the eastern United States face numerous threats including habitat loss and fragmentation, mortality at industrial wind farms, climate change, and disease (Jones et al. 2009). For example, mortality from white-nose syndrome, an emerging infectious fungal disease, has caused severe declines in little brown bat *Myotis lucifugus*, northern long-eared bat *Myotis septentrionalis*, Indiana bat *Myotis sodalis*, and tricolored bat *Perimyotis subflavus* populations throughout eastern North America (Frick et al. 2010; Langwig et al. 2012).

Bat mortality due to collisions with wind turbines has increased greatly since 2000 (O'Shea 2016). Species most affected by industrial wind energy development include the eastern red bat *Lasiurus borealis*, hoary bat *Lasiurus cinereus*, and silver-haired bat *Lasionycteris noctivagans* (Arnett and Baerwald 2013). Habitat loss and fragmentation have likely had a negative impact on most of the other species found in the eastern United States (Mickleburgh et al. 2002). Thus, mitigating impacts from stressors such as further habitat loss, toxicants, and disturbance from humans is critical to offset losses from disease, wind turbines, and current habitat loss.

Several species of North American bats use cliffs for roosting, including eastern small-footed bats *Myotis leibii*, western long-eared bats *Myotis evotis*, fringed myotis *Myotis thysanodes*, little brown bats, and big brown bats *Eptesicus fuscus* (Cryan et al. 2001; Rancourt et al. 2005; Neubaum et al. 2006; Johnson and Gates 2008; Jung and Slough 2011; Randall et al. 2014). Species such as Virginia big-eared bats *Corynorhinus townsendii virginianus* use cliff faces for foraging as well as roosting (Adam et al. 1994; Burford and Lacki 1995). Although cliffs may be commonly used by bats, researchers know little about the extent to which bats use cliffs for foraging and roosting (Ancillotto et al. 2014).

Cliff faces are also important recreational sites. For example, technical rock climbing (i.e., use of a rope and either fixed or removable anchors for protection from falls) and bouldering (i.e., unroped climbing within a few meters of the ground) are rapidly growing sports in the United States. In 2016, approximately 7.5 million people participated in technical climbing (Outdoor Foundation 2017). While several studies have examined the effects of climbing on vegetation (e.g., McMillan and Larson 2002; Müller et al. 2004; Vogler and Reisch 2011), only a few published studies have examined the effects of climbing on animals and in most cases, the impacts have been negative (Camp and Knight 1998; McMillan et al. 2003; Brambilla et al. 2004). The lack of information on the interactions between climbing, natural resource management, and conservation has led to discussions regarding cliff management practices (e.g., Jodice et al. 1999; Krajick 1999), the development of climbing management guidelines (Attarian and Keith 2008), and increased awareness about the opportunity to balance recreation and conservation interests in protected areas such as national parks (Burgin and Hardiman 2012). We are unaware of any published studies that have examined the effects of rock climbing on bats.

Given the lack of information on bat use of cliffs and other climbing habitats such as boulders, and the potential for interactions between climbers and bat conservation, our objectives were to examine use of cliff habitats by bats and to evaluate the presence of climbing activities on bats. Specifically, we aimed to 1) document bat use and activity during the summer months in technical climbing and bouldering areas in Obed Wild and Scenic River, Tennessee, and compare these with areas not used for climbing, and 2) examine roost use of small-footed bats in relation to the presence of climbing routes. We focused on small-footed bats because they are a species of concern in many states and use cliff faces for roosting (Amelon and Burhans 2006).

Methods

Study area

Obed Wild and Scenic River (OBRI) is a National Park located in Morgan County, Tennessee. It is in the Cumberland Plateau physiographic region with elevations ranging from 366 to 610 m. The park consists of river gorges and adjacent uplands and protects 68.4 km of river and riparian habitat along the Obed River, Clear Creek, Daddy's Creek, and Emory River. Due to its steep terrain and the texture of its rock, OBRI is a popular area for rock climbers from around the world. Climbing is only allowed along five cliff faces or bands within OBRI (Lilly Bluff, Obed River, North Clear, South Clear, and Y-12 Wall) and one cliff band just outside the park boundary (Little Clear). Cliff bands are approximately 0.3–1.3 km long. There are approximately 475 climbing routes along these bands with the number of routes per band ranging from approximately 40 to 150 (Brown 2011). Routes were often clustered with areas devoid of climbing between the clusters of climbing routes. Bouldering is also popular but is concentrated in a 1.27-ha area.

The park is in the Mixed Mesophytic Forest Region and forest types within the park based on the dominant species are river birch *Betula nigra*, beech *Fagus grandifolia*–tulip poplar *Liriodendron tulipifera*, tulip poplar, white oak *Quercus alba*, hemlock *Tsuga canadensis*, sweet birch *Betula lenta*–hemlock–chestnut oak *Quercus prinus*, chestnut oak–white oak, white pine *Pinus strobus*–white oak–chestnut oak, white oak–scarlet oak *Quercus coccinea*, and Virginia pine *Pinus virginiana* (Schmalzer 1988). Underlying rock consists of limestone, shale, coal, and sandstone. Mean air temperatures at the closest weather station (Crossville, Tennessee; 42 km from the park) were 22.0°C in June, 23.2°C in July, and 21.5°C August 1–21 (the end date of this study). Rainfall amounts were 13.9 cm in June, 23.3 cm in July, and 16.6 cm from August 1 to 21. Britzke (2006) documented nine species of bats in the park.

Acoustic surveys

Because it was difficult to access many of the unclimbed cliffs at OBRI, we compared bat activity between climbed and unclimbed zones at two scales: 1) areas with and without climbing routes within the same cliff band (hereafter climbed and unclimbed areas, respectively), and 2) cliffs with climbing routes and cliffs without climbing routes (hereafter climbed and unclimbed cliffs). We used a paired sampling regime in which we surveyed a climbed site and an unclimbed site simultaneously to control for temporal variation in bat activity (Hayes 1997, 2000). Because Anabat SD2 detectors have a range of approximately 15 m (Adams et al. 2012), climbed and unclimbed sites along climbed cliffs were $\geq$ 30 m from each other. At each site we

placed two Anabat SD2 detectors (Titley Electronics, Ballina, New South Wales, Australia), one approximately 1.4 m high and one approximately 6.1 m high to ensure that we recorded bats no matter what height they were flying along the cliff faces. We placed detectors approximately 5 m from the cliffs but this varied somewhat due to terrain. We placed microphones in a 45° polyvinyl chloride tube with drain holes drilled in the bottom (Britzke et al. 2010) and mounted them on a 1.4-m tripod or 6.1-m extendable pole and oriented microphones parallel with the cliff. We programmed detectors to start recording 15 min prior to sunset and stop recording 15 min after sunrise and ran them for at least two consecutive nights. At each site we recorded whether the cliff was climbed or unclimbed, whether the area was climbed or unclimbed, the number of sport routes within 20 m on either side of the detector, the presence of boulders at the base of the cliff, the presence of rubble or talus at the base of the cliff, cliff aspect, cliff height, and the presence of an obvious overhang directly above the cliff area where we had placed the detectors (Table S1, *Supplemental Material*). We measured cliff height with a TruPulse 200 laser range finder (± 1 m accuracy; Laser Technology, Centennial, CO).

We uploaded bat calls to a computer after we surveyed each point. We used a customized filter in AnalookW to remove files that contained only insects or other noise. We used the remaining files to examine overall bat activity between climbed and unclimbed areas and between climbed and unclimbed cliffs. We applied a more stringent filter to remove all files with fewer than three pulses and those with nonsearch phase calls. We visually examined these files to further remove any nonsearch phase calls. We used Kaleidoscope Pro 3.1.1 to identify these call files to species and examined each identified call to verify the program's identification. We grouped calls identified as big brown or silver-haired bats, small-footed or northern long-eared bats, and little brown or Indiana bats.

Mist-netting and radiotelemetry

We used single- or double-high 2.6–9-m-wide mist nets and a G-7 harp trap (0.9 m × 1.5 m; Bat Conservation and Management, Inc, Carlisle, PA) to capture bats along trails, forest roads, or other flyways at eight sites (Table S2, *Supplemental Material*). We checked the harp trap and mist nets every 8–10 min and identified bats to species and weighed them. We determined age (juvenile or adult) by determining the degree of fusion of the epiphyses of the third and fourth metacarpals. We classified males as scrotal or nonscrotal and females as lactating, postlactating, or nonreproductive (we captured no pregnant females). We placed numbered aluminum-lipped 2.4-mm bands (Porzana Ltd., East Sussex, UK) on small-footed, tri-colored, and northern long-eared bats, and 2.9-mm bands on big brown bats. We placed 0.29-g Lotek PicoPip (Lotek Wireless, Newmarket, Ontario, Canada) or 0.25-g Blackburn transmitters (Blackburn Transmitters, Nacogdoches, TX) between the scapulae of four adult male small-footed bats. Transmitters represented 6.1–7.1% of the body weight of small-footed bats. We tracked bats to their day roosts with a Wildlife Materials TRX2000S receiver and a three-element antenna the day after capture and every day thereafter until the transmitter battery died, the tag fell off, or we could not locate the bat for four to five consecutive days. When possible we attempted to observe the bats in their roosts. When that was not possible, we listened for the radio signal of the bat in the early evening near the roost to verify that the animal left the roost and that the transmitter was still attached to the bat. Our methods were approved by the Clemson University Institutional Animal Use and Care Committee (AUP 2015-018) and the National Park Service Institutional Animal Use and Care Committee (SER_OBWS_Jodice_Bats_2015_A2), and were conducted under Tennessee Wildlife Resources Agency Scientific Collection Permit 3806, Federal Endangered Species Permit TE-119937-3, and National Park Service Scientific Research and Collecting Permit OBRI-2015-SCI-0002.

Statistical analysis

We used a 1-way analysis of variance to test whether climbed and unclimbed cliffs and areas differed in height and the number of routes within 20 m. We used Tukey's contrasts to compare individual means. We converted cliff aspect to sine and cosine to determine mean aspect of climbed and unclimbed areas and cliffs.

The number of bat passes recorded from the lower and upper detectors were highly correlated ($r = 0.98$, $P < 0.0001$) and examination of passes suggested that the paired detectors primarily recorded the same bat calls. Further, neither the low nor the high detector was more likely to record more passes (Wilcoxon paired signed test; $V = 222$, $P = 0.68$); a greater number of passes was recorded by the lower detector in 15 pairs and by the upper detector in 13 pairs. Thus, we used the number of passes from the detector with the highest number of passes, and we defined bat activity at each site as the average number of bat passes per night from the detector with the highest number of bat passes. We also used the data from the detector that had the earliest mean time after sunset and the latest mean time before sunset to examine first and last activity. We transformed activity data (ln) to approximate a normal distribution and we report back-transformed means and 95% confidence intervals. We conducted paired *t*-tests to compare overall bat activity between climbed and unclimbed areas within climbed cliffs and between climbed and unclimbed cliffs, and Wilcoxon paired signed rank tests to compare the number of species or species groups between climbed and unclimbed areas within climbed cliffs and between climbed and unclimbed cliffs. The time of the first and last bat passes were not normally distributed and no transformations resulted in a normal distribution. Thus, we used Wilcoxon

Table 1. Characteristics of sampling sites along climbed and unclimbed areas of climbed cliffs, and along unclimbed cliffs at Obed Wild and Scenic River, Morgan County, Tennessee, June–August 2015. Mean ± 1 SE cliff height and number of routes within 20 m of both sides of the detector, number (percentage) of sites with an overhang above the detector and with rubble or boulders at the base of the cliff are presented, and mean aspect of cliffs at the survey points. Means within a row followed by the same letter are not significantly different ($P > 0.10$).

Characteristic	Climbed area	Unclimbed area of climbed cliff	Unclimbed cliff
Cliff heights (m)	23.5 ± 2.0 a	17.7 ± 2.3 ab	11.4 ± 1.6 b
Routes within 20 m	6.8 ± 0.9 a	0.3 ± 0.2 b	0 b
Overhang	10 (76.9%)	6 (85.7%)	2 (40%)
Rubble/boulders	6 (46.2%)	4 (57.1%)	1 (20%)
Mean aspect (°)	147.0	120.0	98.8

paired signed rank tests to compare the time of first and last activity between climbed and unclimbed areas and between climbed and unclimbed cliffs. We used Pearson's correlation coefficients to examine the relationship between bat activity and species richness and cliff height. We ran all statistics in R 3.1.0. Because this was an exploratory study with limited sample sizes, we used a significance level of $P < 0.10$ but report P values throughout.

Results

Bat activity and species presence on climbed and unclimbed cliffs

Between June 3 and August 12, 2015, we surveyed 27 sites (we sampled one site, Hardwick Rd-2, twice). We recorded 30,360 bat passes (15,578 in high detectors and 14,782 in low detectors) in 151 detector nights (75 detector nights for high detectors and 76 detector nights for low detectors) resulting in 207.7 passes per night in high detectors and 194.5 passes per night in low detectors. We used eight pairs of sites for comparisons between climbed and unclimbed areas of climbed cliffs and six pairs for comparisons between climbed and unclimbed cliffs. Cliff height did not differ significantly between climbed and unclimbed areas of climbed cliffs but climbed areas were significantly taller than areas sampled along unclimbed cliffs (Table 1). Areas sampled within climbed areas had an average of 6.8 climbing routes within 20 m of either side of the detector. Areas sampled along climbed cliffs (both climbed and unclimbed areas) tended to have more overhangs and rubble or boulders at the cliff base (Table 1). Although mean aspect of climbed areas (147.0°) was higher than mean aspect of unclimbed areas (120.0°) and unclimbed cliffs (98.8°), all mean aspects were east to southeast.

We recorded bats at every site but bat activity and the number of species detected were positively related to cliff height ($r = 0.33$, $P = 0.09$ and $r = 0.40$, $P = 0.04$, respectively). Bat activity did not differ significantly between climbed and unclimbed areas of climbed cliffs ($t = 1.742$, df = 7, $P = 0.125$). The mean number of bat passes per night in climbed areas was 133.4, (95% CI =19.0, 937.4) and the mean number of bat passes per night in unclimbed areas was 62.6 (95% CI = 9.4, 417.6). The mean number of bat passes per night recorded at climbed cliffs ($\bar{X} = 198.4$, 95% CI = 132.0, 298.4) was significantly greater than the mean number of passes per night at unclimbed cliffs ($\bar{X} = 19.45$, 95% CI = 6.8, 55.6; $t = 5.968$, df = 5, $P = 0.002$). The time to the first bat pass after sunset did not differ significantly between climbed and unclimbed areas of climbed cliffs ($V = 15$, $P = 0.9326$) or between climbed and unclimbed cliffs ($V = 16$, $P = 0.3125$). Although the time of the last bat pass before sunrise also did not differ significantly between climbed and unclimbed areas of climbed cliffs ($V = 25$, $P = 0.3828$), the last bat calls recorded along climbed cliffs were significantly later than along unclimbed cliffs ($V = 20$, $P = 0.0625$; Figure 1).

We recorded eight species or species groups across all of the sites (Table S1, *Supplemental Material*). The median number of species recorded at climbed areas was 3.5, which was not significantly different from the median number of species recorded at unclimbed areas (3.5; $V = 8.5$, $P = 0.751$). The median number of species at climbed cliffs was 5.0 which was not significantly different ($V = 12.5$, $P = 0.223$) from the median number of species at unclimbed cliffs (4.0). We detected the big brown/silver-haired bat group at every site except for one, an unclimbed area (Figure 2). It is likely that most of the calls in the big brown/silver-haired bat group were big brown bats as these were also the most commonly captured bat species (see below). Red bats were the second most commonly recorded species and we detected them at 23 of the 27 sites. We recorded Rafinesque's big-eared bats *Corynorhinus rafinesquii*, gray bats *Myotis grisescens*, and evening bats *Nycticeius humeralis* only at climbed cliffs (both climbed and unclimbed areas) whereas we detected the other species or species groups at both climbed and unclimbed cliffs (Figure 2).

Roost use

We captured 39 bats of four species: 32 big brown bats, 4 small-footed bats, 2 northern long-eared bats, and 1 tricolored bat (Table S2, *Supplemental Material*). Although we frequently recorded red bats with acoustic detectors, we captured none in nets. All four of the captured small-footed bats were adult males and all were radio-tagged.

We followed radio-tagged small-footed bats for an average 11.5 d each (range 5–15 d) and located nine roosts. Three roosts were in large boulders in or on the

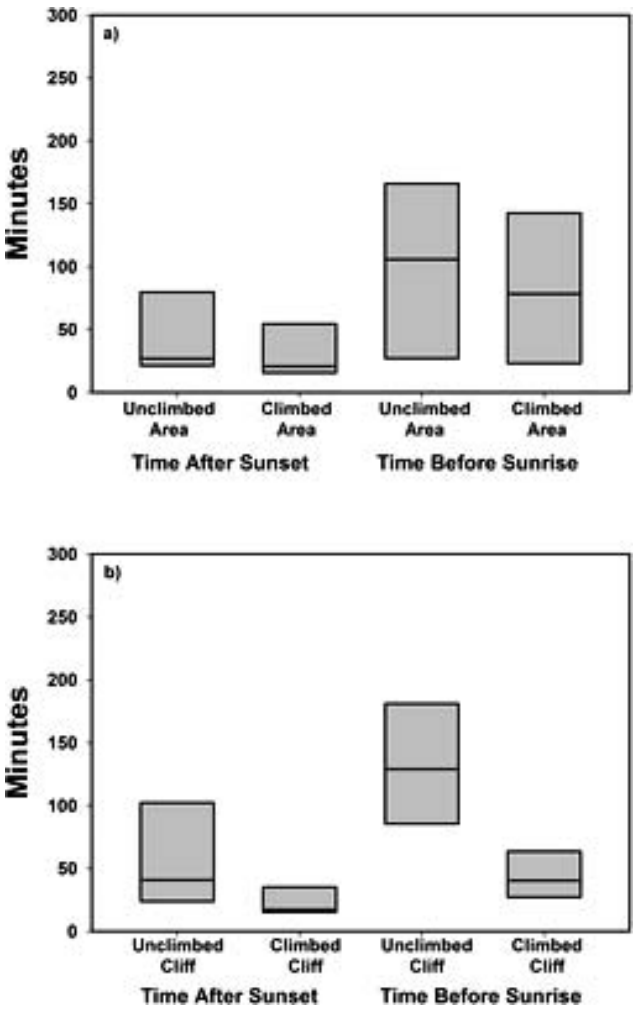

Figure 1. Median (horizontal lines) and 95% confidence limits (box outline) of earliest and latest bat passes in (**a**) climbed and unclimbed areas of climbed cliffs and (**b**) climbed and unclimbed cliffs at Obed Wild and Scenic River, Morgan County, Tennessee, June–August 2015.

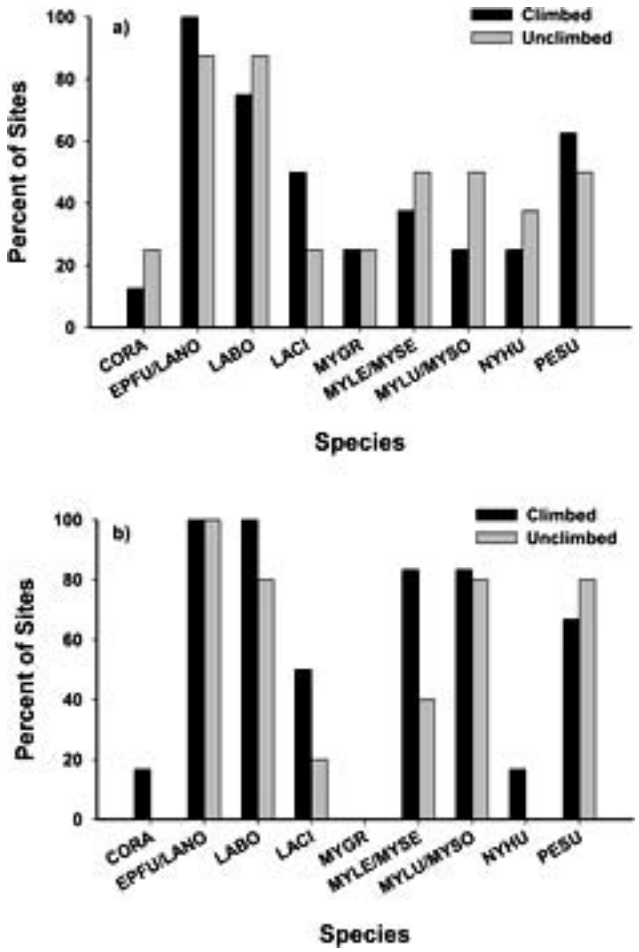

Figure 2. Percentage of sites where each species or species groups was detected in (**a**) climbed and unclimbed areas of climbed cliffs and (**b**) climbed and unclimbed cliffs at Obed Wild and Scenic River, Morgan County, Tennessee, June–August 2015. CORA = *Corynorhinus rafinesquii*, EPFU/LANO = *Eptesicus fuscus/Lasionycteris noctivagans*, LABO = *Lasiurus borealis*, LACI = *Lasiurus cinereus*, MYGR = *Myotis grisescens*, MYLE/MYSE = *Myotis leibii/Myotis septentrionalis*, MYLU/MYSO = *Myotis lucifugus/Myotis sodalis*, NYHU = *Nycticeius humeralis*, PESU = *Perimyotis subflavus*.

shore of Clear Creek, one roost was in a barn, and five roosts were in cliff faces (three on climbed and two on unclimbed faces; Table 2). All roosts were in crevices of various types. For example, the roosts in the boulders in the river were in crevices in the boulders (Figures 3a and 3b) and the bat in the barn roosted between two upright planks that formed a crevice (Figures 3c and 3d). For bats that we were able to observe in their roosts or during evening emergence, all bats roosted alone.

The number of roosts per bat ranged from one to three. Bats remained in a roost for an average of 3.3 ± 0.9 d (range 1–14 d). We were not able to locate one of the bats until 2 d after it was tagged. By the time we located the bat, it was 1,176 m from its capture site. We located the other three bats on the day after their capture and the average distance between their capture site and their first roost was 355.3 m (range 309–401 m). The average distance between consecutive roosts was 948.6 m (range 40–1,412 m).

Discussion

We found that bat activity did not differ between climbed and unclimbed areas within cliff bands that supported climbing routes. Bat activity was, however, higher along cliff bands that supported climbing routes compared to bands that did not have climbing routes. Further, small-footed bats readily used crevices in climbed cliffs and were active later in the night along climbed cliffs than unclimbed cliffs suggesting that they were approaching roosts along these cliffs. Thus, our results suggest that in OBRI, roosting, foraging, or commuting activity of bats during summer readily occurred near climbing and bouldering routes.

The high use of cliffs and bouldering areas by bats in OBRI for foraging and roosting habitat suggests that these landscape features may represent important

Table 2. Description of roosts used by small-footed bats *Myotis leibii* in Obed Wild and Scenic River, Morgan County, Tennessee, June–August 2015.

Bat	Roost no.	Roost type	Description
SR0001	MYLE1	Boulder	Horizontal crevice in large boulder in Clear Creek
SR0001	MYLE2	Boulder	Horizontal crevice in large boulder in Clear Creek
SR0001	MYLE3	Barn	Space between upright boards in barn
SR0003	MYLE4	Cliff face	North Clear, Rasputin climbing area. Aspect = 318°, height approximately 27.1 m
SR0002	MYLE5	Boulder	Crevice in large boulder on edge of Clear Creek
SR0002	MYLE6	Cliff face	On unclimbed cliff just off the Point Trail. Aspect = 351°, height = 13 m
SR0002	MYLE7	Cliff face	Crack on top of Lilly Bluff Overlook
SR0005	MYLE8	Cliff face	North Clear, Rasputin climbing area. Aspect = 260°, height = 23.6 m
SR0005	MYLE9	Cliff face/rock shelter	North Clear, Rasputin climbing area. Roost in long deep crack near ground level

habitat for many bat species where they exist. For example, bat activity along cliff faces was higher than activity recorded in forested areas in the eastern United States that do not contain cliffs (Owen et al. 2004; Loeb and Waldrop 2008; Armitage and Ober 2012; Cox et al. 2016). We recorded an average of 198.4 passes per night along climbed cliffs with many sites having well over 300 passes in a night (Table S1, *Supplemental Material*). In contrast, the number of bat passes per night was 11.9 in longleaf *Pinus palustris* forests in Florida (Armitage and Ober 2012); 12.6–36.2 in loblolly pine *Pinus taeda* forests of South Carolina (Loeb and Waldrop 2008), 30.1 in managed forests of West Virginia (Owen et al. 2004), and 42.6 in hardwood stands of Tennessee (Cox et al. 2016).

Ancillotto et al. (2014) suggested that cliffs are an important foraging habitat for bats on small islands, but little is known about use of cliff faces as foraging habitat for bats on mainlands. Adam et al. (1994) and Burford and Lacki (1995) found that Virginia big-eared bats commonly use unclimbed cliff habitats for foraging in Kentucky. Noctuid moths, an important food item for Virginia big-eared bats (Lacki and Dodd 2011), are abundant at the top of cliffs (Burford et al. 1999), which may explain the high use of these areas by these bats. Noctuid moths are also part of the diets of Rafinesque's big-eared bats (Lacki and Dodd 2011), red bats (Clare et al. 2009), northern long-eared bats (Dodd et al. 2012), and hoary bats (Valdez and Cryan 2013). Thus, the high use of cliffs that we observed in this study may have been due to the regular presence of a preferred prey item in these areas. The area along the cliff faces may also serve as natural flyways for bats. Many bats typically commute and forage along habitat edges such as tree lines and hedgerows (Verboom and Huitema 1997; Verboom and Spolestra 1999). In addition to having higher insect abundances, tree lines and hedgerows also provide protection from wind and predators and may serve as navigational aids. Cliff faces may function similarly, providing protection from predators and wind as well as serving as navigational aids and thus may be a preferred commuting and foraging habitat in areas where they exist.

Bat activity did not differ significantly between climbed and unclimbed areas within climbed cliffs but was significantly higher along climbed cliffs than unclimbed cliffs. Higher activity along climbed cliffs may have been due, in part, to our inability to survey climbed and unclimbed cliffs that were comparable in size and configuration. Although we tried to find comparable sites, we could not access many unclimbed cliffs due to a lack of trails to the base or restricted access due to private ownership. Unclimbed cliffs in our sample were shorter than climbed cliffs and bat activity and species richness were positively correlated with cliff height. The positive relationships we found between cliff height and bat activity and species richness may have been due to a greater number of roost sites in taller cliffs as well as more foraging and commuting space above vegetation (i.e., clutter).

We found no evidence that the presence of any particular species of bat in OBRI was related to the presence or absence of climbing routes. Species richness did not differ between climbed and unclimbed cliffs and all species were detected commuting along climbed cliffs, including endangered, threatened, and sensitive species such as Rafinesque's big-eared bats, gray bats, northern long-eared bats/small-footed bats, and little brown bats/Indiana bats. We also found no evidence that roost use was affected by the presence of climbing routes. Of the five small-footed bat roosts we found on cliff faces, three were on climbed cliffs and two were on unclimbed cliffs. The three roosts on climbed cliffs were in a popular climbing area that has approximately 30 climbing routes of moderate to high quality (Sims and Hodges 2004; Brown 2011). Unfortunately, because we could not determine the exact location of roosts in the cliff face, it was not possible to determine how close the roosts were to climbing routes. Further, one of the roosts on an unclimbed cliff (Roost MYLE7) was a crevice on top of the Lilly Bluff Overlook near the visitor boardwalk. The bat stayed in this roost for five consecutive days despite moderate foot traffic and noise from visitors throughout the day.

Further evidence that bats regularly roost along climbed cliffs at OBRI comes from the activity data. We recorded the last bat passes of the night a median of 129.0 min before sunrise on unclimbed cliffs whereas we recorded the last bat passes on climbed cliffs a median of 40.3 min before sunrise. Bats may have been active later along climbed cliffs because they were approaching their roosts along these cliffs (Murray and Kurta 2004). Although the difference was not statistically significant, our data suggest that activity may have started earlier on climbed cliffs.

Although other studies have provided anecdotal evidence that small-footed bats roost in cliff faces

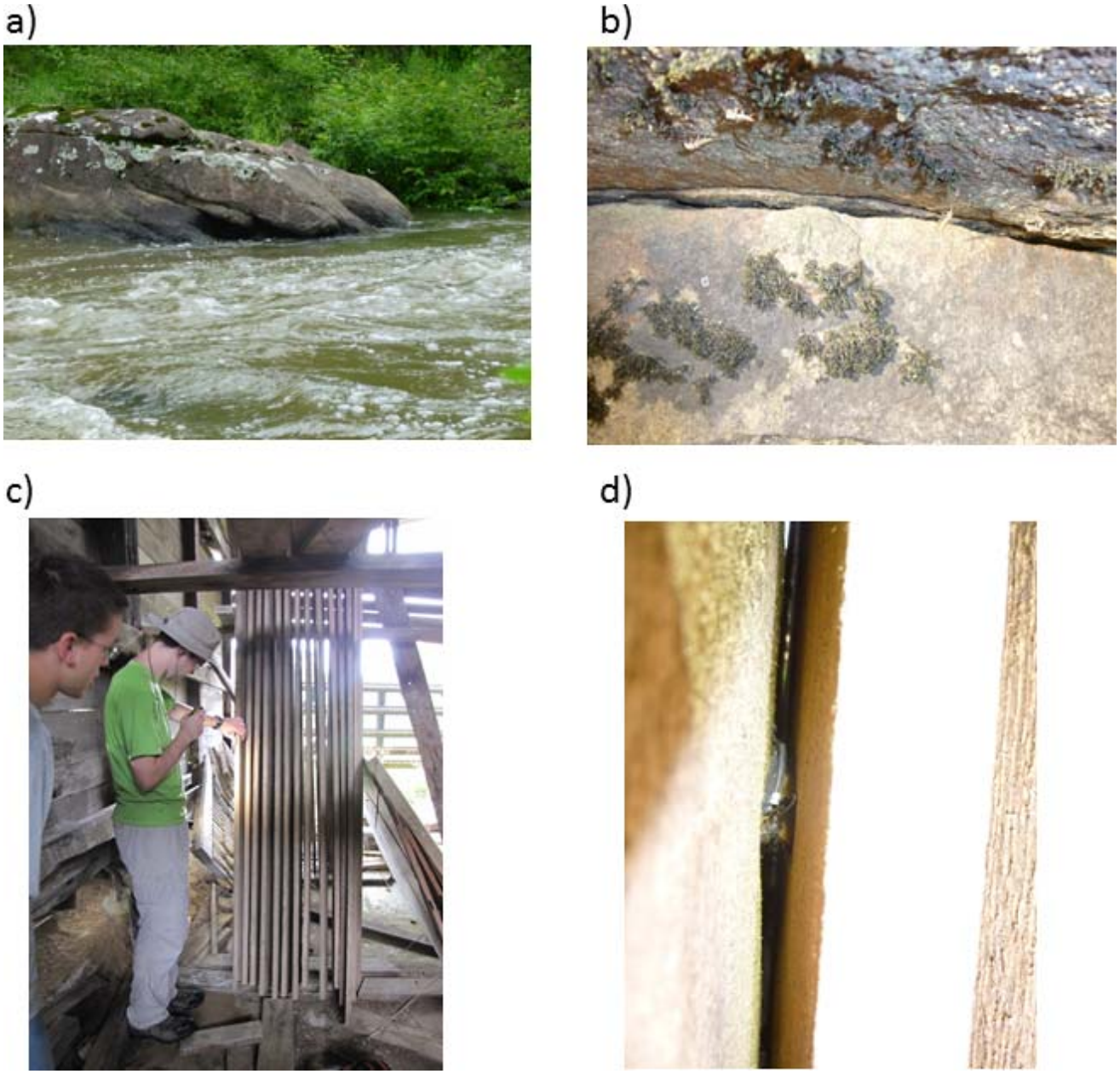

Figure 3. Crevice roosts of small-footed bat *Myotis leibii* in Obed Wild and Scenic River, Morgan County, Tennessee, June–August 2015. (**a**) Boulder roost in Clear Creek, (**b**) crevice in boulder where bat roosted, (**c**) upright boards where bat roosted, (**d**) bat between upright boards.

(McDaniel et al. 1982; Johnson et al. 2011), over half of the roosts used by this species in OBRI during our study were in cliff faces. Other roost types were crevices in boulders in a stream and an anthropogenic structure. No matter the roost type, small-footed bats consistently used a small vertical or horizontal crevice. Previous studies of small-footed bat roosting behavior have also found that they use a variety of crevice types for roosting. For example, small-footed bats have been found roosting in crevices in rock outcrops in Maryland (Johnson and Gates 2008) and Illinois (Whitby et al. 2013); in ground-level crevices in talus slopes, rock fields, and in cliff faces in West Virginia (Johnson et al. 2011); and in crevices in road cuts, bridges, natural rock walls/outcrops, a quarry, a boulder in a forest, and white pine snags in eastern Tennessee and western North Carolina (Thomson 2013). Use of anthropogenic structures has also been documented, including a maternity colony of small-footed bats roosting in a historic building in western North Carolina (O'Keefe and LaVoie 2011).

While small-footed bats in Maryland and West Virginia switch roosts approximately every day and move $<$ 50 m between roosts (Johnson and Gates 2008; Johnson et al. 2011), small-footed bats in OBRI switched roosts approximately every 3 d and moved an average of 948 m between consecutive roosts. Small-footed bats in the

Unicoi Mountains of eastern Tennessee and western North Carolina remain in roosts for an average of 2.6 d and move an average of 721 m between roosts (Thomson 2013). Thomson (2013) suggested that the longer residency times and greater distances moved by small-footed bats in the Unicoi Mountains compared to bats in Maryland and West Virginia may have been due to a limited availability of suitable roosts in the Unicoi Mountains. Given the large number of boulders and the large extent of cliff face with abundant crevices in OBRI, it is unlikely that suitable roosts were limited. Our study included only males, whereas the study by Johnson and Gates (2008) included only females and that of Johnson et al. (2011) included equal numbers of males and females. Males tend to move farther between roosts than females (Johnson et al. 2011; Thomson 2013) which may explain why the distance between roosts in our study was greater than in other studies. Longer residency may have been due to the stability of roosts, particularly in cliff faces (Lewis 1995). However, roosts in the river may become unsuitable after heavy rains. For example, bat SR0002 moved from roost MYLE5, a boulder in Clear Creek to an unknown roost on June 30 when Clear Creek rose from 1.2 to 1.9 m overnight. Although it returned to MYLE5 on July 1 and July 2, it moved to MYLE6, a roost in a cliff face on July 3 when the creek rose to 3.0 m. We also visited MYLE1, another boulder roost in Clear Creek on June 30, and observed that the crevice that had been used by SR0001 was underwater. Thus, roosts in boulders along the river may vary in suitability from day to day and be more ephemeral than roosts in cliff faces.

In summary, we found that cliff faces within climbing areas were regularly used for foraging and commuting by a number of bat species in OBRI, and that small-footed bats regularly used cliff faces for roosting. While this may suggest that the presence of climbing activities have little influence on bat activity, our data should be interpreted cautiously. Our study was restricted in time (one sampling event during summer) and space (only accessible cliff faces within a relatively small geographic area) and therefore, our results are specific to these frames of reference. Further, climbing routes in OBRI are spread across six extensive cliff faces resulting in climbing activity that may be spatially widespread, whereas other climbing areas may have a higher number of routes in a smaller area, resulting in climbing activity that is more spatially concentrated. In areas where climbing routes are more concentrated, impacts may be greater. In addition, although climbing in OBRI is restricted to a few readily accessible cliff systems, the majority of cliff within the park remains unclimbed. Where climbing does occur within OBRI, climber activity occurs primarily during spring and fall (Sims and Hodges 2004) and the impact during two crucial periods in the bat life cycle, the maternity and hibernation periods (summer and winter), may also be minimized. Thus, the spatial and temporal resolution of climbing activity could alter the relationship between climbing and bat activity and warrants additional study. Finally, climbing routes at OBRI do not extend to the top rim of the cliff face (i.e., they do not "top out") and as such, climbing activity does not impact sensitive vegetation at the top of the cliff or, perhaps, bats that roost there.

Research and Management Implications

Where they exist, cliffs appear to be an important habitat feature for bats (Ancillotto et al. 2014; this study) and greater understanding of how bats use cliffs and the factors that affect their use may reduce impacts from recreational users. Factors that may affect bats' use of cliffs include cliff structure (height, texture, presence of large features such as roofs, corners, or chimneys); the type, height, and density of surrounding vegetation; proximity, density, and quality (e.g., a star rating system is often used) of climbing routes; distance from climbing routes to access trails; style (fixed or removable anchors, bouldering) of route; number of pitches; amount of time climbers are present under or on a given route; and the extent of cliff face available in the area where climbing does and does not occur. We encourage the inclusion of these and other factors in future studies of bats' use of cliffs and the interactions between sport climbing and bats.

If future studies find that climbing activities have negative effects on bats and if protection of bats and their habitats are a priority for management, managers may consider such actions as restricting climbing to certain times of the year, placing a moratorium on the creation of new routes, or limiting the number of climbers in particularly sensitive areas as is currently done for raptor nesting (Richardson and Miller 1997). However, the interface between the climbing community and bats at cliff faces also provides an excellent opportunity for collaboration to further bat conservation. For example, climbers can be an important source of information about the seasonal presence of bats along cliff faces and their roosting habits. Further, informed climbers can be an excellent source for conducting outreach and education to other climbers and the public about the importance of bats and conserving them in cliffs and other habitats.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Table S1. Sampling locations, dates of sampling, cliff and area status (climbed or unclimbed), cliff height (m), cliff aspect, the presence or absence of an overhang and rubble, the number of sport-climbing routes within 20 m on both sides of the detector, the mean number of bat passes recorded per night, and the species detected at each site along climbed and unclimbed cliffs in Obed Wild and Scenic River, Morgan County, Tennessee, June–August 2015.

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Table S2. Locations, dates, and species, sex, age, reproductive condition, body weight (g), forearm length (mm), band numbers, and recapture status for bats captured at Obed Wild and Scenic River, Morgan County, Tennessee, June–August 2015.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-020.S2 (11 KB XLSX).

Reference S1. Attarian A, Keith J. 2008. Climbing management: a guide to climbing issues and the development of a climbing management plan. The Access Fund.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-020.S3; also available at https://www.accessfund.org/uploads/ClimbingManagementGuide_AccessFund.pdf (3430 KB PDF).

Reference S2. Britzke ER. 2006. Mammal inventory of Obed Wild and Scenic River, Tennessee. Final Report to National Park Service, Appalachians Highlands Inventory & Monitoring Network.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-020.S4 (269 KB PDF).

Reference S3. Lacki MJ, Dodd LE. 2011. Diet and foraging behavior of *Corynorhinus* in eastern North America. Pages 39–52 in Loeb SC, Lacki MJ, Miller DA, editors. Conservation and management of eastern big-eared bats: a symposium. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, North Carolina.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-020.S5; also available at http://www.srs.fs.usda.gov/pubs/gtr/gtr_srs145.pdf (123 KB PDF).

Reference S4. Outdoor Foundation. 2017. Outdoor recreation participation topline report 2017. Outdoor Foundation, Washington, D.C.

Found at DOI: http://dx.doi.org/10.3996/032017-JFWM-020.S6; also available at https://outdoorindustry.org/wp-content/uploads/2017/04/2017-Topline-Report_FINAL.pdf (692 KB PDF).

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