Acta Chiropterologica, 24(1): 167–176, 2022
PL ISSN 1508-1109 © Museum and Institute of Zoology PAS
doi: 10.3161/15081109ACC2022.24.1.013

Finding bat roosts along cliffs: using rock climbing surveys to identify roosting habitat of bats

Robert A. Schorr[1, 2], Michael D. Matthews[1], and Bailey A. Hoover[1]

[1]*Colorado Natural Heritage Program, Climbers for Bat Conservation, Colorado State University, Fort Collins, Colorado 80523, USA*
[2]*Corresponding author: E-mail: robert.schorr@colostate.edu*

When white-nose syndrome arrived in eastern North America, bat colonies declined at an alarming rate and the large-scale mortality events were obvious at caves and mines. However, there is concern that the disease and its impacts will be more difficult to detect in western North America where there are fewer winter roosts with thousands of bats. Thus, documenting and responding to precipitous declines will be more challenging. To allow population-level monitoring, western biologists and land managers need to expand search efforts for colonies. One roosting resource that is under-sampled is cliffs, and although we know bats roost along cliffs, biologists know little about roost-site characteristics or the colonies that reside there. Two methods of identifying bat roosts along cliff systems are to collaborate with rock-climbing citizen scientists who report bat encounters, and another is to conduct rock-climbing surveys for bats. We conducted acoustic surveys, thermal videography, and climber-based surveys along the Front Range of northern Colorado, USA, to find bats and describe their roosting habitat. We climbed 48 routes and located two roosts, and received an additional citizen-science record of a third roost. Bats use cracks that were east facing and approximately 12 m above the ground. Climber-based surveys can locate bats and roosting habitat along cliffs, and identify large colonies to be monitored. Targeting climber-based surveys in areas with recreational-climbing citizen-science records may increase the likelihood of finding bat roosts and bat colonies.

Key words: cliffs, Colorado, conservation, rock climbing, recreation

Introduction

In North America, much of our understanding of bats' roosting requirements comes from natural cave and tree roosts, or roosts associated with human structures or mining activity (Furey and Racey, 2016; Voigt *et al.*, 2016). Many of the largest bat colonies are associated with caves and mines (Furey and Racey, 2016). Large subterranean bat colonies in eastern North America have experienced unprecedented declines from white-nose syndrome (WNS) (Frick *et al.*, 2010). The scale and prevalence of WNS-associated mass mortality events made the disease easy to detect in eastern North America (Frick *et al.*, 2016). The fungus that causes white-nose syndrome is spreading westward, and biologists have discovered infected individuals in western North America (Lorch *et al.*, 2016). Unfortunately, there are fewer cave and mine hibernacula with large numbers of bats compared to eastern North America, making it more challenging for biologists to monitor disease impacts and detect disease spread (Weller *et al.*, 2018). Detection of WNS spread in western North America has relied on citizen science observations and sampling bat colonies that are not associated with hibernacula (Frick *et al.*, 2016; Lorch *et al.*, 2016). Especially in western North America, biologists need to identify and monitor more winter and summer roosts to detect WNS and understand population impacts. A roosting resource for bats that is under-sampled is cliffs.

Cracks (also called crevices, flakes, and pockets) in cliffs and boulders provide roosting habitats for bats (Bogan *et al.*, 2003); however, there have been few attempts to survey cliffs to look for bat roosts (Knecht and Lyons-Gould, 2016; Bat Rock Habitat Key, 2021). Studies using radio-telemetry have identified cracks used by bats, but unless the crevice is easily accessible, the roost characteristics are difficult to assess (Neubaum *et al.*, 2006; Moosman *et al.*, 2017; Loeb and Jodice, 2018; White *et al.*, 2020). Data from rock-climbing citizen scientists and climber-biologists provide roost-specific information on cliff and crevice use by bats (Knecht and

Lyons-Gould, 2016; Davis *et al.*, 2017). These records provide biologists with new data on bat roosting locations and may direct conservation or long-term monitoring efforts. Climber citizen-science reports provide valuable bat-roosting data, but these are incidental encounters from a minority of the recreational climbers and do not address the prevalence of bat habitat along cliff systems.

Targeted climbing surveys for bats can assess the abundance of roosting habitat along cliff systems and more-thoroughly search for roosting colonies. To better understand the prevalence of bat roosting along recreational climbing routes, we conducted climbing surveys to locate bat roosts and describe roosting habitat in northern Front Range of Colorado. We conducted acoustic, thermal-imaging, and climbing surveys to understand: 1. The feasibility of using active climbing surveys to find bat roosts; 2. Refine and test survey methodology for climber-based surveys; and 3. Provide local land managers information about where bat roosts exist along climbing routes.

Materials and Methods

We surveyed climbing routes from July–November 2019 on City of Boulder Open Space and Mountain Parks (OSMP) and Jefferson County Open Space (JCOS) lands along the Front Range of Colorado, approximately 50 km west of Denver, Colorado, USA (Fig. 1). There are greater than 1,000 recreational climbing routes combined in JCOS and OSMP lands. We surveyed routes that were less than 5.12 on the Yosemite Decimal System (YDS) scale of climbing difficulty. The climbing areas of OSMP lands consist of arkosic and conglomerate sandstone of the Fountain Formation, while the climbing areas of JCOS are a complex of gneiss, with schists, garnet gneiss, and various hornblendite masses (Lovejoy, 1951; Knight, 1964). Elevations of climbing areas ranged from 1,700–2,200 m, with surrounding forests of Ponderosa pine (*Pinus ponderosa*) and Douglas fir (*Pseudotsuga menziesii*), mountain mahogany (*Cercocarpus montanus*) shrublands, and intermixed grasslands. Cliffs in the study area vary widely in vertical angles, from less-technical 50° scrambles to sheer, overhanging walls.

Passive Evening Surveys

In the evening (> 9:00 pm), we used infrared thermal cameras (ATN THoR-HD 384, ATN Corporation, San Francisco, California) to film bats as they flew near routes. We used hand-held ultrasonic recorders (EchoMeter Touch 2, Wildlife Acoustics, Inc., Maynard, Massachusetts) and the associated species identification software (Kaleidoscope Pro Auto-ID Classifier, Wildlife Acoustics, Inc.) with smart phones (iPhone 7, iPhone operating system version 10.3.3, Cupertino, California) to identify bat species vocalizing in the area. We conducted passive evening surveys at an open area that allowed us to film as much of the wall as possible and avoid vegetation that might interfere with acoustic recording equipment. Passive surveys were conducted within 1 week prior to climbing surveys.

Active Climbing Surveys

We searched continuously for bats but mandated that searching occur at four equidistance heights along a route. For example, we would survey a 12-m (40-ft) route at 3 m, 6 m, 9 m, and near the top (12 m). We mandated surveying at these four locations to ensure thorough searching occurred along a route even if obvious cracks were not abundant. If there was no crack at a particular height, we selected the nearest crack along the vertical climbing route. We used endoscopic cameras (Milwaukee M12, Grâef Tool, Brookfield, Wisconsin, or Teslong NTS150, Teslong Technology Limited, Shenzhen, China) to search for bats or evidence of bats, such as guano or culled insect parts. We recorded the crack characteristics, including height (m), width (cm) and orientation (diagonal, horizontal, or vertical). We estimated the aspect of the wall and the route using a compass (Suunto MC-2G, Suunto, Vantaa, Finland). When we found a bat or evidence of bat use, we used an infrared thermometer (Extech IR Thermometer 42510A, Extech Instruments, Nashua, New Hampshire) to record temperatures in the roost and used an endoscopic camera to record video or pictures. We collected data on cracks without bats so that we might compare crack measurements between locations with bats and those without bats.

Results

From July–November 2019, we climbed 48 routes to look for bats and conducted passive evening acoustic and videographic surveys at 42 locations (Table 1). A majority of climbing surveys occurred between the months of July–August (90%). There are fewer passive surveys than climbing surveys because some routes were in proximity, and passive surveys overlapped multiple climbing routes. We conducted 21 climbing surveys on OSMP lands, and 27 climbing surveys on JCOS lands. We performed acoustic and thermal imaging videography at 24 JCOS and 18 OSMP climbing areas. Climbing route difficulty ranged from 5.2 to 5.11 YDS, with most routes at 5.7 YDS (n = 15) or 5.10 YDS (n = 9). Average route height was approximately 16 m (± 7 m SD) with a southern aspect (181 ± 98º SD) (Table 1). The climbing routes selected for this study were not selected randomly and were from regions that both JCOS and OSMP identified as priorities for understanding bat use.

We recorded ultrasonic call profiles of hoary bats (*Lasiurus cinereus*), eastern red bat (*Lasiurus borealis*), silver-haired bats (*Lasionycteris noctivagans*), big brown bats (*Eptesicus fuscus*), western small-footed bats (*Myotis ciliolabrum*), long-eared myotis (*Myotis evotis*), little brown bats (*Myotis lucifugus*), and Brazilian free-tailed bats (*Tadarida*

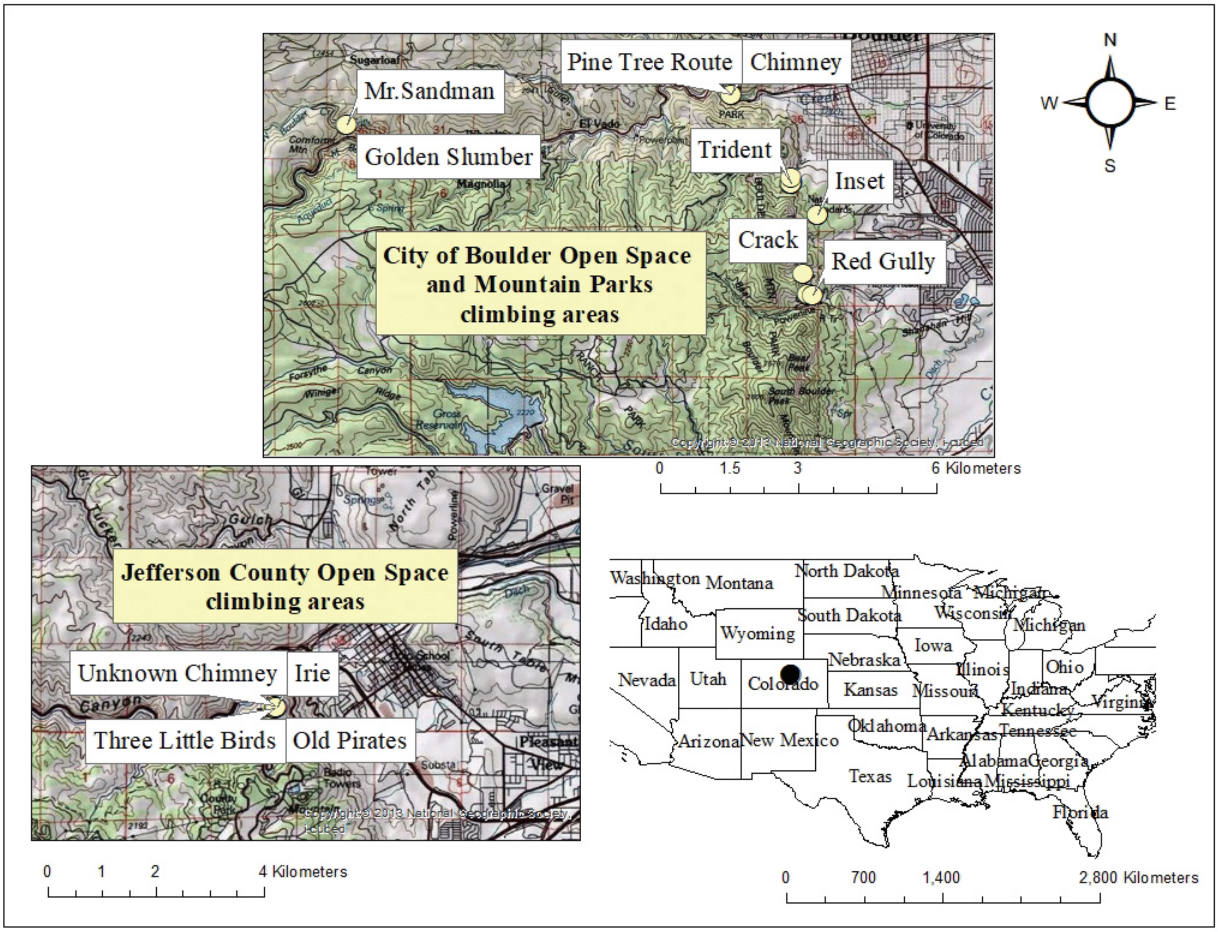

FIG. 1. Climbing areas surveyed in Jefferson County Open Space and City of Boulder Open Space and Mountain Parks, Colorado, 2019

brasiliensis). We collected thermal image videography of bats flying along cliff walls but did not identifiy any roosts. During climbing surveys, we observed a single bat at each of two climbing routes and found guano at a third route (6% of routes climbed). Bats had facial and body-size characteristics of *Myotis* species, roosted at 12.8 m and 10.7 m from the base of routes, were in narrow crevices of 0.7 cm and 1.0 cm at eastward (70°) aspects, and were in cracks with temperatures of 34°C and 28°C (Table 2 and Fig. 2). Both bat roosts had rock overhangs above, and both routes were visited later in the summer to see if bats still roosted in these cracks (Table 1). While conducting climbing surveys, we regularly interacted with climbers, and one climber shared an observation of guano along a route that we climbed and confirmed.

DISCUSSION

Understanding where North American bats roost and how they survive when threats, such as WNS arrive, is critical for conserving bat colonies (O'Shea *et al.*, 2003). An inability to monitor bat colonies and accurately assess consequences of threats can leave land managers ill-equipped to develop appropriate management actions. Thus, creative methods, such as surveying under-sampled roost habitat and collaborating with citizen scientists, may be solutions to acquiring bat roosting data (Davis *et al.*, 2017). Cliff systems are important roosting habitat for bats, but there have been few attempts to identify the specific locations of colonies in cracks or monitor the bat colonies using those cracks (Bogan *et al.*, 2003; O'Shea *et al.*; 2003, Snider *et al.*, 2013; Lemen *et al.*, 2016). Incorporating citizen science knowledge can increase data for informing conservation action and increases public awareness and engagement in conservation (Barlow *et al.*, 2015; McKinley *et al.*, 2017; Frick *et al.*, 2020). Except for cavers, few recreational citizen-science groups encounter roosting bat as frequently as rock climbers (Zagmajster, 2019; personal communication). Observations from recreational

TABLE 1. Climbing routes surveyed for bats in Jefferson County Open Space (JCOS) and City of Boulder Open Space and Mountain Parks (OSMP) lands, July–November 2019. 'NA' designates data that was not collected either because there was no appropriate feature for bat roosting or because it was unsafe to collect data while climbing. Flakes are thin sections of rock that run along the face of the cliff, while cracks are openings that run into the cliff. Climbing: Traditional = Trad, Top Rope = TR, and Sport. SD = standard deviation. 'Pinetree Route' was surveyed using acoustic/thermal equipment, but was not climbed

Routes where no bats were found	Land Management Agency	Climbing	Dates surveyed	Height (m)	Aspect of wall (°)	Aspect of route (°)	1st height Height (m)	1st height Crack width (cm)	2nd height Height (m)	2nd height Crack width (cm)	3rd height Height (m)	3rd height Crack width (cm)	4th height Height (m)	4th height Crack width (cm)
Beauty for Ashes	JCOS	Sport	11 July	9.2	300	300	1.2	NA	3.7	10.2	5.5	NA	7.3	1.3
Big Dihedral	JCOS	Trad. TR	2 August	12.2	200	300	3.1	1.9	6.1	1.3	9.2	3.8	12.2	10.2
Buffalo Soldier	JCOS	Sport	11 July	22.9	80	20	3.1	5.1	7.6	5.1	10.7	7.6	13.7	10.2
Christmas Night	JCOS	Trad. TR	13 August	9.2	180	40	3.1	20.3	4.6	12.7	6.1	1.0	7.6	0.5
Cornmeal Porridge	JCOS	Sport	18 July	15.3	300	300	6.1	2.5	10.7	7.6	12.2	5.1	13.7	17.8
Crack	JCOS	Trad. TR	13 July	10.7	180	120	NA	1.3	NA	1.9	7.6	7.6	9.2	1.3
Crack (2 left of Interface)	JCOS	Trad	13 August	9.2	180	180	1.5	1.3	4.6	7.6	7.6	1.0	9.2	1.3
Crack/Chimney	JCOS	Trad. TR	29 July	10.7	180	120	NA	5.1	NA	8.9	NA	1.0	10.7	1.3
Don't Rock My Boat Pitch 1	JCOS	Sport	6 August	30.5	325	325	NA	NA	15.3	0.8	25.9	4.4	30.5	0.8
Don't Rock My Boat Pitch 2	JCOS	Sport	6 August	33.6	325	325	10.7	7.6	13.7	10.2	16.8	5.1	19.8	2.5
In Between The Lines	JCOS	Sport. TR	14 August	10.7	200	300	NA	11.4	NA	10.2	NA	2.5	NA	5.1
Irie	JCOS	Sport	11 July	9.2	330	330	2.4	5.1	6.1	3.8	7.6	3.8	9.2	6.4
John Adam's Adams Apple	JCOS	Trad. TR	2 August	10.7	168	168	4.6	1.3	6.1	5.1	7.6	10.2	10.7	20.3
Killians Dead	JCOS	Trad. TR	2 August	12.2	168	168	1.5	10.2	3.1	7.6	6.1	1.9	9.2	10.2
Lyin' like a Lion	JCOS	Sport	11 July	19.8	20	20	NA	NA	7.6	5.1	12.2	NA	18.3	NA
Old Pirates	JCOS	Sport	18 July	19.8	270	350	4.6	5.1	9.2	1.3	18.3	NA	19.8	NA
Shadow of a Hangdog (Fat Fingers)	JCOS	Trad. TR	6 July	15.3	180	100	3.1	1.0	7.6	1.0	10.7	1.9	13.7	0.8
The Ark	JCOS	Trad	2 August	10.7	168	168	1.5	10.2	4.6	20.3	7.6	20.3	10.7	25.4
Thick Crust	JCOS	Trad	2 August	12.2	200	200	3.1	2.5	4.6	50.8	9.2	50.8	9.2	50.8
Three Little Birds	JCOS	Sport	18 July	16.8	350	350	4.6	1.9	7.6	2.5	12.2	1.3	15.9	15.2
Unknown Chimney to Crack	JCOS	Trad. TR	18 July	18.3	340	300	4.6	8.9	6.1	5.1	13.7	2.5	15.3	3.8
Unknown Crack	JCOS	Trad. TR	13 August	10.7	180	140	NA	1.3	NA	10.2	NA	2.5	7.6	1.9
Unknown Crack (Right of the Virus)	JCOS	Trad	2 August	12.2	210	210	4.6	10.2	6.1	1.3	10.7	3.8	12.2	NA
Unknown left of Left Slab	JCOS	Trad	13 August	9.2	180	180	NA	1.0	NA	2.5	NA	5.1	9.2	7.6
Variation to the Virus	JCOS	Trad. Sport	2 August	10.7	200	300	3.1	1.9	6.1	15.2	7.6	1.9	10.7	2.5
Wide Crack	JCOS	Trad. TR	23 August	12.2	210	210	3.1	15.2	7.6	12.7	9.2	10.2	12.2	12.7
Ypsilon	JCOS	Trad. TR	2 August	12.2	210	210	0.9	7.6	4.6	1.0	9.2	5.1	12.2	3.8
Chimney	OSMP	Trad. TR	29 July	27.5	270	320	13.7	2.5	18.3	5.1	24.4	50.8	30.5	10.2
Crack	OSMP	Trad. TR	12 July	7.6	90	90	NA	2.5	NA	1.9	NA	2.5	NA	NA
Dinosaur Rock	OSMP	Trad	6 August	35.1	340	340	12.2	20.3	18.3	20.3	24.4	20.3	30.5	15.2
Direct West Bench	OSMP	Trad	6 August	16.8	20	20	NA	25.4	NA	10.2	NA	12.7	13.7	3.8
East Bench Dihedral	OSMP	Trad	23 August	9.2	192	228	4.6	1.9	6.1	1.3	7.6	3.8	9.2	2.5
Feeling Lucky	OSMP	Sport	21 September	15.3	237	210	4.6	0.8	7.6	10.2	10.7	0.8	13.7	5.1
Final Address	OSMP	Trad	21 September	13.7	237	237	4.6	1.3	7.6	1.9	10.7	1.9	12.2	1.0

TABLE 1. Continued

Routes where no bats were found	Land Management Agency	Climbing	Dates surveyed	Height (m)	Aspect of wall (°)	Aspect of route (°)	1st height		2nd height		3rd height		4th height	
							Height (m)	Crack width (cm)	Height (m)	Crack width (cm)	Height (m)	Crack width (cm)	Height (m)	Crack width (cm)
Golden Slumber	OSMP	Trad. Sport	5 October	22.9	130	162	4.6	1.3	12.2	2.5	18.3	5.1	21.4	2.5
Halls Of Ivy	OSMP	Trad	22 August	19.8	70	150	9.2	17.8	12.2	0.8	15.3	1.9	18.3	1.3
Mr.Sandman	OSMP	Sport	5 October	19.8	130	145	7.6	1.3	9.2	5.1	13.7	2.5	13.7	1.9
Pine Tree Route	OSMP	Trad. TR	29 July	30.5	50	270	NA	NA	NA	NA	NA	NA	NA	NA
Red Wall (Raptors in Cellophane)	OSMP	Sport. TR	6 August	15.3	300	300	3.1	1.9	6.1	2.5	10.7	15.2	12.2	1.3
The Inset	OSMP	Trad	6 August	18.3	20	20	4.6	5.1	6.1	2.5	9.2	2.5	10.7	10.2
The Red Gully	OSMP	Trad. TR	8 August	39.7	20	20	10.7	3.8	18.3	3.8	24.4	5.1	30.5	2.5
West Bench Dihedral	OSMP	Trad. TR	6 August	16.8	20	20	2.1	1.0	4.6	10.2	6.1	1.0	7.6	1.0
What if You're Not?	OSMP	Trad. Sport	21 September	15.3	237	210	6.1	0.8	7.6	0.8	9.2	0.8	10.7	12.7
Wide Crack	OSMP	Trad. TR	23 August	16.8	70	70	3.1	0.8	7.6	2.5	12.2	1.0	15.3	2.5
Yellow Christ	OSMP	Trad. TR	13 July	7.6	90	90	3.1	1.3	NA	1.3	NA	1.3	NA	NA
Mean				16.3	186	192	4.7	5.6	8.2	6.9	11.9	7.1	14.1	7.4
SD				7.8	97	107	3.1	6.3	4.1	8.5	5.6	11.1	6.5	9.5
Routes with evidence of bats														
Standard Inside East Face	OSMP	Trad. TR	6 August, 6 October	16.8	70	70	2.4	5.1	6.1	1.0	10.7	1.3	12.2	1.0
Thin Crack (guano)	OSMP	Trad. TR	23 August	16.8	70	70	6.1	0.8	10.7	5.1	12.2	0.8	15.3	1.3
Trident (bat)	OSMP	Trad. TR	23 August, 6 October	16.8	70	70	6.1	2.5	7.6	5.1	9.2	5.1	10.7	0.8
Mean							4.9	2.8	8.1	3.7	10.7	2.4	12.7	1.0
SD							2.1	2.2	2.3	2.3	1.5	2.4	2.3	0.3

TABLE 2. Bat observations along climbing routes and night survey data at those climbing routes in city of Boulder Open Space and Mountain Parks lands, 2019. Note: no bats were found along climbing routes in Jefferson County; only one bat was found at each location

Route name	Height of bat (m)	Width of crack at bat (cm)	Depth of bat in crack (cm)	Depth of crack at roost (cm)	Distance to top of climb (m)	Temperature of roost (°C)	Overhang present?
Standard Inside East Face	12.8	0.8	10	38	4	34	Yes
Trident	10.7	1.0	41	41	6	28	Yes

climbers are helping biologists identify bat colonies and cliff-roosting habitats, but climbing surveys will provide better information on roost-site characteristics and increase bat observations because biologists have more familiarity with bat ecology (Bat Rock Habitat Key, 2021).

During climbing surveys we observed bats or evidence of bats at 6% of routes surveyed at JCOS and BCOS lands. If bats are using climbing routes in Colorado (> 27,000, Mountain Project, https://www.mountainproject.com) at the same rate, bats may be using > 1,500 routes. Elevated rock roosts can be advantageous for bat flight and predator avoidance, as many cliffs exceed the height of surrounding features (Vonhof and Barclay, 1996; Barclay and Kurta, 2007). Also, rock roosts may provide thermoregulation habitat, as the eastern aspects of the roosts in this study allow morning solar exposure. Bats roost in rock crevices that can be warmer than ambient temperatures (Schorr and Siemers, 2013), and climbers have observed bats basking at the opening of cracks and on rock faces (unpublished CBC data, November 2021), which may save energy as torpid bats become euthermic (Geiser *et al.*, 2004). The cliffs of the Front Range of Colorado have much south- and east-facing surfaces, where solar exposure for basking and rewarming is abundant (Slough, 2009).

FIG. 2. Possible *M. evotis* found within a crack in City of Boulder Open Space and Mountain Parks, Colorado, 2019

The roosts found during this study appear to be temporary roosts as we did not detect bats during subsequent climbing surveys. Bats may choose rock roosts for temporary protection from the environmental elements, such as rain and wind. The two roosts we found had a rock overhang above, and many citizen-science climbing records have documented similar roof-like rocks above roosts (unpublished CBC data, November 2021). These rock overhangs may prevent exposure to the rain that frequently occurs along the Front Range during summer thunderstorms. As more cliff roosts are discovered, biologists likely will identify different species, sexes, and ages using cliff roosts for a variety of life history needs, including cooling for torpor (Neubaum *et al.*, 2006), hibernacula (Klüg-Baerwald *et al.*, 2017), breeding habitat (Lausen and Barclay, 2003; O'Shea *et al.*, 2011), basking, and as temporary roosts.

Biologists have known bats use cliff systems, but much of what biologists have learned has come from telemetry studies (Snider *et al.*, 2013, Klüg-Baerwald *et al.*, 2017; White *et al.*, 2020). Because of the height of many cliff systems, most telemetry studies fail to observe where bats roost. As a surrogate, biologists have used evening visual surveys or acoustic recordings below cliff walls to assess bat use (Ancillotto *et al.*, 2014; Lemen *et al.*, 2016; Wieser *et al.*, 2020). As with telemetry studies, biologists rarely observe bats using specific cracks because evening visual surveys have low detection probability and inaccuracy issues (Azmy *et al.*, 2012), and acoustic surveys do not identify roosts, but rather activity of vocalizing individuals. Our acoustic surveys documented most of the likely species found in this area, with several unexpected records of *T. brasiliensis* (Genoways *et al.*, 2000), and without confirmation of several known residents of the Boulder area, including *Myotis volans*, *Myotis thysanodes*, and *Corynorhinus townsendii* (Armstrong *et al.*, 2011). Inferring roosting habitat use from acoustic studies is problematic because some bats have short vocal ranges and have to be in close proximity to be detected (O'Farrell and Gannon, 1999), and recorders at the base of cliffs may not depict activity above the surrounding vegetation (Britzke *et al.*, 2013). Also, detected bats may not be roosting along cliffs, but simply hunting insects along the cliff walls. The value of climbing surveys is that they can locate specific roosts, which increases understanding of bat ecology and can identify bat colonies for long-term monitoring.

Our pre-climbing surveys provided data on bat activity and assemblages, but failed to identify specific roosting resources. The acoustic surveys recorded various bats in the area and the thermal videography showed bats flying along cliffs, yet these techniques did not locate any roosts. Acoustic surveys are helpful for understanding the community of bats using the areas near cliffs but cannot identify roost locations. Thermal videography had some limitations, as well, because rock faces retain heat, and viewing small heat signatures (bats) on similar thermal backgrounds can be difficult. Thermal videography may be more useful when large numbers of bats are emerging along cliff walls.

Direct observations of bats from recreational climbers have increased biologists' understanding of where bats roost and where large roosts exist. In Colorado, climbers have reported bats 60 times at 58 routes (unpublished CBC data, April 2022), and these accounts can be used to target future survey effort and understand bat roost fidelity. Surveys by trained climbers and biologists will be more informative because these individuals are familiar with bat ecology, have specialized equipment like endoscopic cameras for looking in cracks, and will recognize the high-pitched vocalizations of bats (Knecht and Lyons-Gould, 2016). However, climbing surveys can fail to identify roosts because endoscopic cameras may not reach bats that are too deep, narrow, or complex, and bats may not vocalize when climbers are nearby.

Cliff systems provide outdoor recreation opportunity and support local economies (Maples *et al.*, 2019). Additionally, these areas are rich in faunal and floral diversity where species flourish on inaccessible vertical terrain (Larson *et al.*, 1999). As the sport of rock climbing rapidly increases (Cordell, 2012) there is growing concern that outdoor recreational climbing jeopardizes the abundance and biodiversity of plants and animals (Camp and Knight, 1998; Kuntz and Larson, 2006; Lorite *et al.*, 2017). Recreational climbing can affect immobile biodiversity, such as plants and lichens, and wildlife that have key cliff-specific habitat requirements, such as breeding raptors (Richardson and Miller, 1997; Müeller *et al.*, 2004; Adams and Zaniewski, 2012). However, the impacts of climbing on the abundance and diversity of more-mobile or less habitat-restricted organisms is unclear (Holzschuh, 2016; Covy *et al.*, 2019). There is little evidence that recreational climbing deters bats from using cliffs (Loeb and Jodice, 2018), and accounts, photographs, and videography from climbers, suggest bats infrequently flee when climbers are in close proximity (unpublished CBC data, April 2022). Many times, bats stay in the crack, warn the climber with high-pitched chittering, or recede deeper in the crack. These behaviors suggest bats have a behavioral response to climbers, but these responses may not induce high levels of stress, as seen in other wildlife species (Camp and Knight, 1998). Additionally, recreational climbers purposely avoid cracks where bats roost to avoid being bitten. This tendency to give bat roosts a wide berth has allowed some roosts to persist along climbing routes for years. For example, not far from our study area, climbers have submitted multiple reports of a flake (thin crack along the face of a cliff) with > 100 bats, and climbers have warned other climbers to avoid this area. There is concern that climbers may spread the fungus that causes WNS, especially when climbers use their gear for underground climbing (Schorr *et al.*, 2021). Thus, it is important climbers that use their gear in subterranean environments follow established decontamination protocols (White-nose Syndrome Disease Management Working Group, 2020). Much outdoor climbing is done when ambient temperatures may limit the growth and spread of the fungus, but there is evidence the fungus can persist on bats' fur at elevated temperatures (Campbell *et al.*, 2020). Additional research is need to understand how the fungus may persist on climbing equipment at various temperatures.

The desire to balance conservation of cliff biodiversity and recreational opportunity creates new challenges for resource management professionals (Keough and Blahna, 2006). Yet, these challenges also create opportunity for biologists and land managers to collaborate with the recreation community and develop mutually-beneficial management solutions (Keough and Blahna, 2006; Hanauska-Brown *et al*., 2013; Whittle *et al*., 2017). As biologists and climbers collaborate to assess impacts or understand the ecology of cliff-dwelling organisms (McMillan *et al.*, 2003; Vogler and Reisch, 2011), climbers become an integral part of management and conservation solutions (Davis *et al*., 2017). Additionally, inclusion of climbers as valued stakeholders will increase engagement in management and compliance via social rules and norms (Carter, 2019), and involving recreational users in development of management plans increases investment in collaborative conservation (Keogh and Blahna, 2006; McKinley *et al.*, 2017).

This study is a pilot project to evaluate safe and effective surveying techniques for bat-specific climbing surveys. We designed surveys for two people, a climber and a belayer, with the climber collecting data while ascending the route. However, if there is access to the anchors, surveying while descending from a top-rope anchor is easier and less time consuming. When surveying can be done in this fashion, each climber can survey independently, belaying themselves using a device, such as a Petzl Grigri or Microtraxion (Petzl Company, Crolles, France). Our original strategy of segmenting routes into four equal lengths was unnecessary. Instead, we suggest surveying all cracks within a 2–3 m swath on either side of the climbing line. Most models of endoscopic cameras we tested made viewing in cracks challenging because sun glare made the screen difficult to view and the camera lens eventually was damaged by scraping against rock. Using protective tape around the rim of the lens prolonged camera life.

Climber-based bat surveys can be a valuable resource for identifying roosting colonies for long-term monitoring. With limited number of known densely-populated roosts in western North America, detection and monitoring bat population declines is more challenging (Weller *et al.*, 2018). Large colonies of bats may exist in western North America, but may be residing in inaccessible areas, like cliffs. Collaborating with recreational climbers or employing climber-based survey techniques can identify roosts ideal for long-term monitoring, but more importantly will provide a more-complete understanding of bats, habitat, and population dynamics.

Acknowledgements

We thank Will Keeley of OSMP and Chelsea Beebe of JCOS for their guidance and collaboration. We also thank JCOS Park Ranger Eric Krause, climber Josh Pollock, and the JCOS Fixed Hardware Review Committee for their hospitality, interest, and input. Lastly, we thank Phil Knecht of Devil's Tower National Monument for his advice and guidance. This project was funded by small grants from JCOS and OSMP. We thank the Editor-in-Chief, Associate Editor, Journal Reviewers, and Andrea Schuhmann because their candor improved this manuscript.

Literature Cited

Adams, M., and K. Zaniewski. 2012. Effects of recreation rock climbing and environmental variation on a sandstone cliff-face lichen community. Canadian Journal of Botany, 90: 253–259.

Ancillotto, L., J. Rydell, V. Nardone, and D. Russo. 2014. Coastal cliffs on islands as foraging habitat for bats. Acta Chiropterologica, 16: 103–108.

Armstrong, D. M., J. P. Fitzgerald, and C. Meaney. 2011. Mammals of Colorado, 2nd edition. Denver Museum of Nature and Science and University Press of Colorado, Boulder, Colorado, xiii + 620 pp.

Azmy, S. N., S. A. M. Sah, N. J. Shafie, A. Ariffin, Z. Majid, M. N. A. Ismail, and M. S. Shamsir. 2012. Counting in the dark: non-intrusive laser scanning for population counting and identifying roosting bats. Scientific Reports, 2: 524.

Barclay, R. M. R., and A. Kurta. 2007. Ecology and behavior of bats roosting in tree cavities and under bark. Pp. 16–59, *in* Bats in forests: conservation and management (M. J. Lacki, J. P. Hayes, and A. Kurta, eds.). Johns Hopkins University Press, Baltimore, Maryland, 329 pp.

Barlow, K. E., P. A. Briggs, K. A. Haysom, A. M. Hutson, N. L. Lechiara, P. A. Racey, A. L. Walsh, and S. D. Langton. 2015. Citizen science reveals trends in bat colonies: the National Bat Monitoring Programme in Great Britain. Biological Conservation, 182: 14–26.

Bat Rock Habitat Key. 2021. Bat roosts in rock: a guide to identification and assessment for climbers, cavers, and ecology professionals. Pelagic Publishing, Exeter, UK, x + 321 pp.

Bogan, M. A., P. M. Cryan, E. W. Valdez, L. E. Ellison, and T. J. O'Shea. 2003. Western crevice and cavity-roosting bats. Pp. 69–77, *in* Monitoring trends in bat colonies of the United States and territories: problems and prospects (T. J. O'Shea and M. A. Bogan, eds.). United States Geological Survey, Biological Resources Discipline, Information and Technical Report USGS-BRD-ITR-2003-0003, Fort Collins, Colorado, 274 pp.

Britzke, E. R., E. H. Gillam, and K. L. Murray. 2013. Current state of understanding of ultrasonic detectors for the study of bat ecology. Acta Theriologica, 58: 109–117.

Camp, R. J., and R. L. Knight. 1998. Rock climbing and cliff bird communities at Joshua Tree National Park, California. Wildlife Society Bulletin, 26: 892–898.

Campbell, L. J., D. P. Walsh, D. S. Blehert, and J. M. Lorch.

2020. Long-term survival of *Pseudogymnoascus destructans* at elevated temperatures. Journal of Wildlife Diseases, 56: 278–287.

Carter, D. P. 2019. Institutional enforcement, signaling, and deliberation: rock climbers attempting to maintain rules and norms through social sanctioning. International Journal of the Commons, 13: 353–377.

Cordell, H. K. 2012. Outdoor recreational trends and futures: a technical document supporting the forest service 2010 Resources Planning Act assessment. U.S. Forest Service General Technical Report SRS-150, 167 pp. Available at https://www.fs.usda.gov/treesearch/pubs/40453.

Covy, N, L. Benedict, and W. Keeley. 2019. Rock climbing activity and physical habitat attributes impact avian community diversity in cliff environments. PLoS NE, 14: e0209557.

Davis, S. K., R. Schorr, and B. Kuhn. 2017. Climbers for bat conservation: methods in forming a novel partnership. Pp. 81–94, *in* Wildlife: perceptions, threats, and conservation. (C. Ward, ed.). Nova Science Publishers, Hauppauge, New York, 96 pp.

Frick, W. F., J. F. Pollock, A. C. Hicks, K. E. Langwig, D. S. Reynolds, G. G. Turner, C. M. Butchkoski, and T. H. Kunz. 2010. An emerging disease causes regional population collapse of a common North American bat species. Science, 329: 679–682.

Frick, W. F., S. J. Puechmaille, and C. K. R. Willis. 2016. White-nose syndrome in bats. Pp. 245–262, *in* Bats in the Anthropocene: conservation of bats in a changing world (C. C. Voigt and T. Kingston, eds.). Springer, Cham, Switzerland, ix + 606 pp.

Frick, W. F., T. Kingston, and J. Flanders. 2020. A review of the major threats and challenges to global bat conservation. Annals of the New York Academy of Sciences, 1469: 5–25.

Furey, N. M., and P. A. Racey. 2016. Conservation ecology of cave bats. Pp. 463–502, *in* Bats in the Anthropocene: conservation of bats in a changing world (C. C. Voigt and T. Kingston, eds.). Springer, Cham, Switzerland, ix + 606 pp.

Geiser, F., R. L. Drury, G. Körtner, C. Turbill, C. R. Pavey, and R. M. Brigham. 2004. Passive rewarming from torpor in mammals and birds: energetic, ecological and evolutionary implications. Pp. 51–62, *in* Life in the cold: evolution, mechanisms, adaptation, and application (B. M. Barnes and C. H. Carey, eds.). Biological Paper of the University of Alaska, University of Alaska, Fairbanks, Alaska, 27: xiv + 593 pp.

Genoways, H. H., P. W. Freeman, and C. Grell. 2000. Extralimital records of the Mexican free-tailed bat (*Tadarida brasiliensis mexicana*) in central United States and their biological significance. Transactions of the Nebraska Academy of Science, 26: 85–96.

Hanauska-Brown, L., B. Maxell, and H. Bodenhamer. 2013. Montana's collaborative approach to the looming threat of white nose syndrome — an unlikely partnership. National Speleological Society News, 71(9): 22–23.

Holzschuh, A. 2016. Does rock climbing threaten cliff biodiversity? — A critical review. Biological Conservation, 204: 153–162.

Keough, H. L., and D. J. Blahna. 2006. Achieving integrative, collaborative ecosystem management. Conservation Biology, 20: 1373–1382.

Klüg-Baerwald, B. J., C. L. Lausen, C. K. R. Willis, and R. M. Brigham. 2017. Home is where you hang your bat: winter roost selection by prairie-living big brown bats. Journal of Mammalogy, 98: 752–760.

Knecht, P., and A. Lyons-Gould. 2016. Bat roost monitoring at Devils Tower National Monument. U.S. Department of the Interior, National Park Service. Devils Tower National Monument, Wyoming, 14 pp.

Knight, S. 1964. The geologic background of the Boulder area. University of Colorado Museum Leaflet, 13: 1–9.

Kuntz, K. L., and D. W. Larson. 2006. Influences of microhabitat constraints and rock-climbing disturbance on cliff-face vegetation communities. Conservation Biology, 20: 821–832.

Larson, D. W., U. Matthes, and P. E. Kelly. 1999. Cliffs as natural refuges. American Scientist, 87: 410–417.

Lausen, C. L., and R. M. R. Barclay. 2003. Thermoregulation and roost selection by reproductive female big brown bats (*Eptesicus fuscus*) roosting in rock crevices. Journal of Zoology, 260: 235–244.

Lemen, C. A., P. W. Freeman, and J. A. White. 2016. Acoustic evidence of bats using rock crevices in winter: a call for more research on winter roosts in North America. Transactions of the Nebraska Academy of Sciences, 36: 9–13.

Loeb, S. C., and P. G. R. Jodice. 2018. Activity of southeastern bats along sandstone cliffs used for rock climbing. Journal of Fish and Wildlife Management, 9: 255–265.

Lorch, J. M., J. M. Palmer, D. L. Linder, A. E. Ballmann, K. G. George, K. Griffin, S. Knowles, J. R. Huckabee, K. H. Haman, C. D. Anderson, *et al*. 2016. First detection of bat white-nose syndrome in western North America. mSphere, 1(4): e00148-16.

Lorite, J, F. Serrano, A. Lorenzo, E. M. Cañadas, M. Ballesteros, and J. Peñas. 2017. Rock climbing alters plant species composition, cover, and richness in Mediterranean limestone cliffs. PLoS ONE, 12: e0182414.

Lovejoy, E. M. P. 1951. The geology of the lower Clear Creek — Mt. Zion area, Jefferson County, Colorado. M.Sci. Thesis, Colorado School of Mines, Golden, Colorado, 92 pp. Available at https://mountainscholar.org/bitstream/handle/11124/175553/Lovejoy_10781444.pdf.

Maples, J. N., M. J. Bradley, S. Giles, R. Leebrick, and B. Clark. 2019. Climbing out of Coal Country: the economic impact of rock climbing in West Virginia's New River Gorge. Journal of Appalachian Studies, 25: 184–201.

McKinley, D. C., A. J. Miller-Rushing, H. L. Ballard, R. Bonney, H. Brown, S. C. Cook-Patton, D. M. Evans, R. A. French, J. K. Parrish, T. B. Phillips, *et al.* 2017. Citizen science can improve conservation science, natural resource management, and environmental protection. Biological Conservation, 208: 15–28.

McMillan, M. A., J. C. Nekola, and D. W. Larson. 2003. Effects of rock climbing on the land snail community of the Niagara Escarpment in southern Ontario, Canada. Conservation Biology, 17: 616–621.

Moosman, P. R., Jr., P. R. Anderson, and M. G. Frasier. 2017. Use of rock-crevices in winter by big brownbats and eastern small-footed bats in the Appalachian Ridge and Valley of Virginia. Banisteria, 48: 9–13.

Műeller, S. W., H. Rusterholz, and B. Baur. 2004. Rock climbing alters the vegetation of limestone cliffs in the northern Swiss Jura Mountains. Canadian Journal of Botany, 82: 862–870.

Neubaum, D. J., T. J. O'Shea, and K. R. Wilson. 2006. Autumn migration and selection of rock crevices as hibernacula by

big brown bats (*Eptesicus fuscus*) in Colorado. Journal of Mammalogy, 87: 470–479.
O'Farrell, M. J., and W. L. Gannon. 1999. A comparison of acoustic versus capture techniques for the inventory of bats. Journal of Mammalogy, 80: 24–30.
O'Shea, T. J., M. A. Bogan, and L. E. Ellison. 2003. Monitoring trends in bat colonies of the United States and territories: status of the science and recommendations for the future. Wildlife Society Bulletin, 31: 16–29.
O'Shea, T. J., P. M. Cryan, E. A. Snider, E. W. Valdez, L. E. Ellison, and D. J. Neubaum. 2011. Bats of Mesa Verde National Park, Colorado: composition, reproduction, and roosting habits. Monographs of the Western North American Naturalist, 5: 1–19.
Richardson, C. T., and K. C. Miller. 1997. Recommendations for protecting raptors from human disturbance: a review. Wildlife Society Bulletin, 25: 634–638.
Schorr, R. A., and J. L. Siemers. 2013. Characteristics of roosts of male pallid bats (*Antrozous pallidus*) in southeastern Colorado. Southwestern Naturalist, 58: 470–474.
Schorr, R., K. Goodwin, E. Murdock, D. Neubaum, and Z. Warren. 2021. Best practices for the development of climbing worldwide: climbers and bat conservation. The Climbing Initiative, 7 pp.
Slough, B. G. 2009. Behavioral thermoregulation by a maternity colony of little brown bats in the Yukon. Northwestern Naturalist, 90: 47–51.
Snider, E. A., P. M. Cryan and K. R. Wilson. 2013. Roost selection by western long-eared myotis (*Myotis evotis*) in burned and unburned piñon-juniper woodlands of southwestern Colorado. Journal of Mammalogy, 94: 640–649.
Vogler, F., and C. Reisch. 2011. Genetic variation on the rocks — the impact of climbing on the population ecology of a typical cliff plant. Journal of Applied Ecology, 48: 899–905.
Voigt, C. C., K. L. Phelps, L. F. Aguirre, M. C. Schoeman, J. Vanitharani, and A. Zubaid. 2016. Bats and buildings: the conservation of synanthropic bats. Pp. 427–462, *in* Bats in the Anthropocene: conservation of bats in a changing world (C. C. Voigt and T. Kingston, eds.). Springer, Cham, Switzerland, ix + 606 pp.
Vonhof, M. J., and R. M. R. Barclay. 1996. Roost-site selection and roosting ecology of forest-dwelling bats in southern British Columbia. Canadian Journal of Zoology, 74: 1797–1805.
Weller, T. J., T. J. Roadhouse, D. J. Neubaum, P. C. Ormsbee, R. D. Dixon, D. L. Popp, J. A. Williams, S. D. Osborn, B. W. Rogers, L. O. Beard, *et al*. 2018. A review of bat hibernacula across the western United States: implications for white-nose syndrome surveillance and management. PLoS ONE, 13: e0205647.
White, J. A., P. W. Freeman, H. W. Otto, and C. A. Lemen. 2020. Winter use of a rock crevice by northern long-eared myotis (*Myotis septentrionalis*) in Nebraska. Western North American Naturalist, 80: 114–119.
White-nose Syndrome Disease Management Working Group. 2020. National white-nose syndrome decontamination protocol — October 2020. Available at www.WhiteNoseSyndrome.org.
Whittle, E., I. Chechet, and T. Woods. 2017. Beer bottles, bats, and building cooperative programs: update on Montana's Lick Creek Cave. National Speleological Society News, 75(4): 26–28.
Wieser, D., H. Mixanig, K. Krainer, A. Buckner, and G. Reiter. 2020. The importance of inland cliffs and quarries for bats. Acta Chiropterologica, 22: 391–402.
Zagmajster, M. 2019. Bats. Pp. 94–100, *in* Encyclopedia of caves, 3rd edition (W. B. White, D. C. Culver, and T. Pipan, eds.). Academic Press, London, xxxii + 1225 pp.

Received 19 January 2022, accepted 26 April 2022

Associate Editor: Thomas Lilley