

Bats Roosting in Buildings in Great Smoky Mountains National
Park: Ecology, Human Dimensions, and Management
Implications

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Kirstin Emily Fagan
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DEDICATION

To M.C. Steppins.

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ABSTRACT

During summer, bats are regularly observed in buildings of Great Smoky Mountains National Park (GRSM or the Park), the most visited National Park in the USA. As a result, natural and cultural resources managers seek to ensure public safety and protect historic structures while minimizing impacts on bats, especially in light of declines in bat populations as a result of white-nose syndrome. To inform management decisions, I examined the ecological and human dimensions of bats roosting in buildings in GRSM.

To assess roost selection by building-roosting bats, I surveyed 140 buildings in the Park for bats during May to August, 2015 and 2016, identifying 48 roost sites and detecting 5 species. I compared the microclimate conditions, building features, and habitat patch characteristics of buildings used and unused by bats using an information-theoretic approach. Averaged parameter estimates from logistic regression models developed with survey data indicated bat presence was more likely in old buildings with dark conditions surrounded by low road density. Of all roost buildings, 66% were accessed regularly by tourists and 68% were managed as historic structures.

For the human dimensions study, I surveyed 420 park visitors at three sites in the Cades Cove area of GRSM during June to August 2016. The questionnaire assessed visitor attitudes toward bats, knowledge about threats to bats, knowledge about ecosystem services provided by bats, and support for management of bats. Most respondents supported management action to protect bats in buildings in Cades Cove during summer (76%). Standardized parameter estimates from a multiple linear regression developed with survey data indicated attitudes toward bats and knowledge of threats to bats had the greatest effects on support for bat management.

I present alternative management and public communication strategies that may be implemented to meet multiple conservation objectives. The methods used in each study could be used to assess roost selection by building-roosting bats or public perceptions of building-roosting bats in other regions. Future research on building-roosting bats in both historic and modern structures may contribute to conservation efforts as the extended impacts of white-nose syndrome on North American bat populations are further observed and understood.

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CHAPTER 1: INTRODUCTION

Bats provide critical ecosystem services worldwide, including pollination, seed dispersal, and insect suppression (Kunz et al. 2011). In North America, where most species are insectivorous, bats exert top-down control of beetles (Coleoptera), moths (Lepidoptera), true bugs (Hemiptera), and true flies (Diptera), thereby reducing crop destruction and resulting needs for pesticides (Cleveland et al. 2006, Kunz et al. 2011). In the United States alone, bats provide an estimated \$22.9 billion annually in biological pest control (Boyles et al. 2011). However, this service is jeopardized by a number of threats to bat populations, including wind energy development (Cryan and Barclay 2009), habitat loss and landscape transformation (Agosta 2002, Jones et al. 2009, Weller 2009), roost and hibernacula disturbance by humans (Mann et al. 2002, López-Roig and Serra-Cobo 2014), and climate change (Jones et al. 2009, Sherwin et al. 2012). An emerging infectious disease, white-nose syndrome (WNS) poses the most severe threat to cave-hibernating species (Turner et al. 2011, Frick et al. 2015).

Since its documentation in 2006 at Howe's Cave in Albany, New York, WNS has killed at least 5.7 million bats (USFWS 2012). The disease is caused by the invasive fungal pathogen *Pseudogymnoascus destructans* (formerly *Geomyces destructans*), which colonizes the muzzle, ears, and wing membranes of hibernating bats (Meteyer et al. 2009, Lorch et al. 2011, Minnis and Lindler 2013). Bats infected with WNS suffer from respiratory acidosis, hypotonic dehydration, and increased fat metabolism (Cryan et al. 2010, Warnecke et al. 2012, Cryan et al. 2013, Warnecke et al. 2013). These physiological disruptions result in more frequent arousals from torpor, increased emergence from hibernacula, and erratic daytime flight during winter (Thomas et al. 1990, Verant et al. 2014, Carr et al. 2015). Once bats are infected, mortality normally occurs within 2–3 months (Warnecke et al. 2012).

Currently, WNS has spread to 33 states and 5 Canadian provinces, and *P. destructans* has been documented in two additional states (Figure 1; USFWS 2017). Transmission of the fungus primarily occurs from direct bat to bat contact, but the spread of WNS has been exacerbated by humans entering infected caves, subsequently neglecting to decontaminate gear, and transferring *P. destructans* to other uninfected caves (Langwig et al. 2012, Lorch et al. 2013). Nine bat species have been confirmed with diagnostic symptoms of WNS, with an additional five confirmed as carriers of *P. destructans* (Blehert et al. 2009, Bernard et al. 2015, USFWS 2017, USGS 2017). Of these, the little brown bat (*Myotis lucifugus*) and northern long-eared bat (*Myotis*

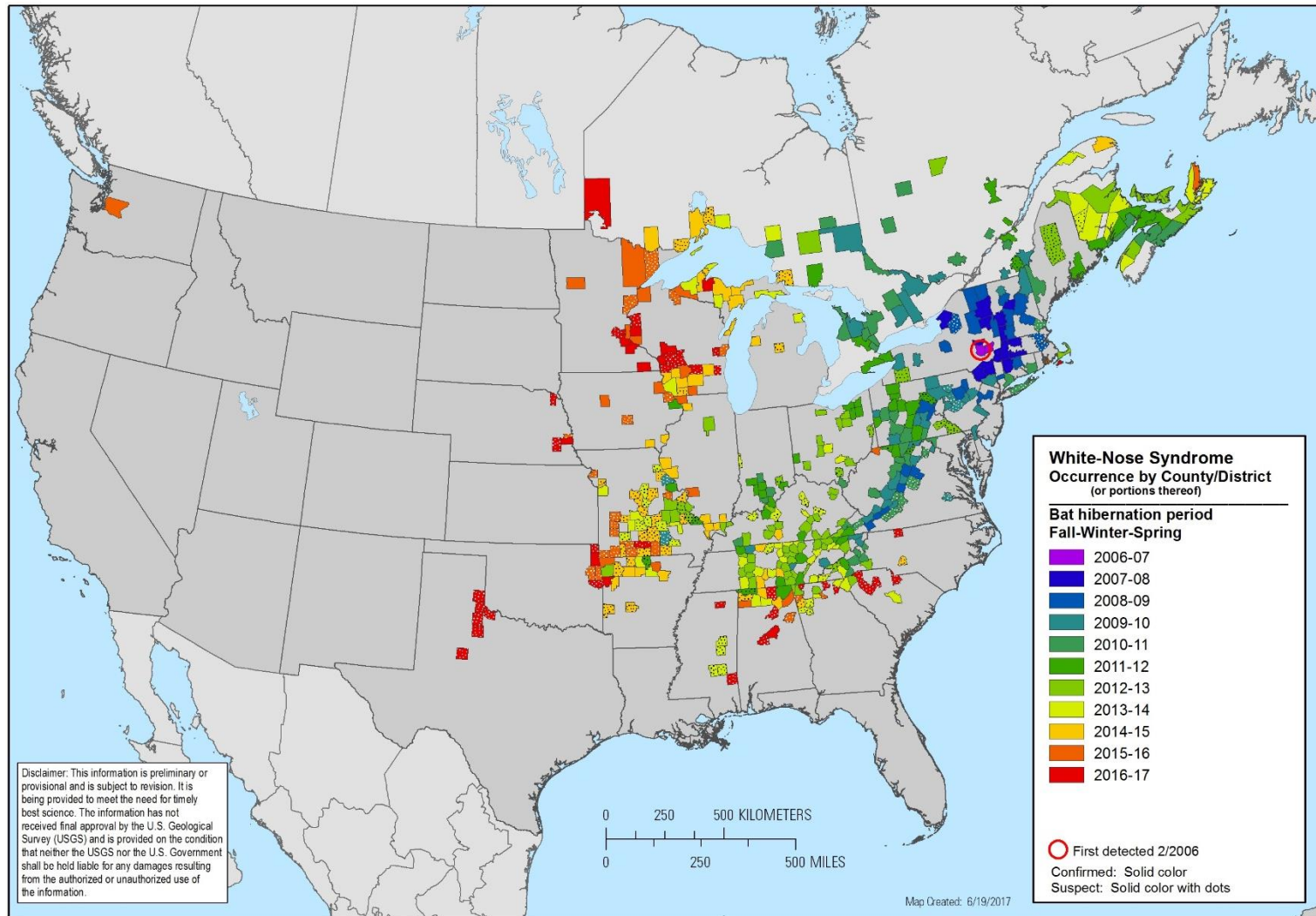


Figure 1. Map of white-nose syndrome and *Pseudogymnoascus destructans* occurrence in North America. Distributed on June 19, 2017 by the United States Fish and Wildlife Service. Available at <http://www.whitenosesyndrome.org/resources/map>.

septentrionalis) are threatened with regional extinction in eastern North America as a result of WNS (Frick et al. 2010, Ford et al. 2011, Turner et al. 2011, USFWS 2013, Frick et al. 2015). Given the importance of bats for biological control of insects, these declines emphasize the importance of maintaining population viability through individual survival and breeding success, and therefore the importance of protecting and managing critical habitat (O'Shea et al. 2003).

Together with foraging habitat and winter hibernacula, summer roosts are one of the most important habitat features for bats (Fenton 1997, Kunz and Lumsden 2003). After arousal from hibernation and spring staging, females often form maternity colonies, whereas males primarily roost solitarily or in small bachelor colonies (Davis and Hitchcock 1965, Buchler 1980, Whitaker and Hamilton 1998). Pups are born in early summer and are dependent on their mothers until they become volant, after which adults and juveniles build fat reserves in preparation for winter hibernation, when exposure to WNS may occur (Davis and Hitchcock 1965, Buchler 1980, Whitaker and Hamilton 1998).

Summer roost preferences vary by species. Rock crevices, exfoliating bark, foliage, and tree cavities are considered natural summer roost sites, but human activities, including landscape conservation and habitat fragmentation, have simultaneously destroyed natural roosts and provided anthropogenic roosts. More than half of North American bat species use anthropogenic structures, including mines, bridges, and buildings, at some point during their annual life cycle (Kunz and Reynolds 2003). Building-roosting bats are particularly challenging to manage due to their inherent association with people; managers must consider threats to people, bats, and the occupied buildings.

Bats worldwide can present threats to human health as they may carry and transmit disease to people (Anthony et al. 2017, Lilley et al. 2017). In North America, this includes rabies (Constantine 2009) and histoplasmosis (Emmons et al. 1966). Conversely, bat survival, fecundity, and body condition can be negatively impacted by building maintenance, artificial illumination, and disturbance by people (Boldogh et al. 2007, Howard 2009, López-Roig and Serra-Cobo 2014). Bat urine and guano, meanwhile, can cause unpleasant odors and act as a corrosive force to building surfaces, resulting in challenges for managers of historic buildings (Feilden 2003, Zeale et al. 2016). Vandalism and general use by people also result in cumulative structural degradation (Namba and Dustin 1992). Maintenance is required to prevent such buildings from losing historical attributes or becoming structurally compromised, which would be detrimental both to bats using

the structure and to the historical value of the building. In the United States, these efforts are supported by the National Register of Historic Places (NRHP), maintained by the National Historic Preservation Act of 1966 (NHPA), which seeks to document and protect historic buildings for the benefit of the people.

Historic building preservation, bat conservation, and human health and safety, must be incorporated into management decisions regarding building-roosting bats. Since varying stakeholder goals are the primary source of conflict with respect to resource management, cooperation among stakeholders increases the likelihood of implementing action that leads to desired, lasting conservation impacts (Moore et al. 2001, Layden et al. 2003, Riley et al. 2003, Decker and Bath 2010). Given the traditionally negative connotations associated with bats, public perceptions of bats in buildings, and efforts to protect them, are particularly valuable to management (Daniels and Stevans 1903, De Vries 1974, Brass 1994, Tuttle 2013).

Managers want to manage buildings used by bats to promote survival, reproduction, and, for relevant species, recovery from WNS. However, previous research on roosting ecology of building-roosting bats is limited to Vespertilionids in Europe (e.g., Entwistle et al. 1997, De Boer et al. 2013), and the big brown bat (*Eptesicus fuscus*) and Brazilian free-tailed bat (*Tadarida brasiliensis*) in North America (e.g., Williams and Brittingham 1997, Neubaum et al. 2007, Li and Wilkins 2015). In addition, the few existing studies related to the human dimensions of bat conservation have focused on children's and students' perceptions of bats (e.g., Knight 2008, Prokop and Tunnicliffe 2008, Prokop et al. 2009). A single study assessed residents' knowledge and perceptions of bats in an urban area of Colorado, USA (Sexton and Stewart 2007). In this context, the goal of this thesis is to better enable natural and cultural resources managers to make informed decisions that balance bat conservation and cultural resource preservation while ensuring human health and safety. Throughout the United States, buildings occupied by bats during summer are a persistent concern for National Park Service (NPS) managers (W.H. Stiver, NPS, personal communication). Great Smoky Mountains National Park (GRSM), located in the southeastern United States along the border of eastern Tennessee and western North Carolina, is the most visited park within the U.S. National Park Service and was selected as the study area for this research.

Charged with preserving natural and cultural features for the enjoyment and safety of current and future generations, NPS managers seek to effectively manage building-roosting bats and the structures they occupy while preserving human health and safety. In GRSM, high visitation

results in increased threats to hundreds of historic buildings and at least eight building-roosting bat species, seven of which known to be affected by WNS or carriers of *P. destructans* (Harvey 1987, Harvey et al. 2011, Blehert et al. 2009, Bernard et al. 2015, Linzey 2016). During summer, employees and visitors regularly report sightings or sign of bats in buildings. Bats are the only taxon confirmed with rabies within GRSM and in some cases, people have come into physical contact with bats, thereby increasing the risk of zoonotic disease transmission (NPS, unpublished report; W.H. Stiver, personal communication). With the exception of limited observational studies (Harvey 1987, E.R. Britzke, US Army Engineer Research and Development Center, unpublished report), informal summer reports make up the majority of bat records in buildings in GRSM. To inform natural and cultural resource management regarding bats roosting in buildings, two components will be assessed in this thesis: 1) bat presence and roost selection in GRSM buildings and 2) visitor attitudes toward the presence and management of bats in GRSM buildings.

CHAPTER 2: ROOST SELECTION BY BATS IN BUILDINGS OF GREAT SMOKY MOUNTAINS NATIONAL PARK

This chapter is modified from a paper in revision:

Fagan, K.E., E.V. Willcox, L.T. Tran, R.F. Bernard, and W.H. Stiver. *In revision*. Roost selection by bats in buildings of Great Smoky Mountains National Park, southeastern United States. *Journal of Wildlife Management*.

My consistent use of “we” throughout this chapter is in reference to my co-authors and myself. I was the primary contributor to this work, which involved the following tasks: (1) development of project design and all data collection, (2) statistical analysis, (3) gathering and interpretation of relevant literature, and (4) all writing. E.V. Willcox advised on project design and assisted with editing, L.T. Tran advised on statistical analysis, R.F. Bernard advised on project design on management implications, and W.H. Stiver advised on management implications.

ABSTRACT

Bats roosting in buildings are a challenge for wildlife managers due to their conservation needs and potential to transmit diseases to humans. An understanding of roost selection by bats in buildings is essential to effective management, but was lacking in the southeastern United States. During 2015 and 2016, we surveyed 140 buildings in eastern Tennessee and western North Carolina for bats, identifying 48 roost sites and detecting 5 species. We compared the microclimate conditions, building features, and habitat patch characteristics of buildings used and unused by bats using an information-theoretic approach. Averaged parameter estimates from logistic regression models developed with survey data indicated bat presence was more likely in old buildings with dark conditions surrounded by low road density. Of all roost buildings surveyed, 66% were accessed regularly by tourists and 68% were managed as historic structures. We present alternative management strategies that may be implemented to ensure human health and safety and preserve historic sites while protecting bats during the reproductive period.

INTRODUCTION

The availability and quality of summer roosts for bats influences individual survival and breeding success (Austad and Fischer 1991, Mickleburg et al. 2002). In North America, population declines among cave-roosting bat species as a result of white-nose syndrome (WNS) emphasize the importance of identifying and protecting summer roosting habitat (Frick et al. 2015). More than half of all bat species in North America have been documented roosting in buildings for at least part of the year (Kunz and Reynolds 2003). This includes 8 of the 9 species known to contract WNS and 3 of the 5 additional species known to carry *Pseudogymnoascus destructans*, the

pathogen that causes WNS (Blehert et al. 2009, Bernard et al. 2015, USFWS 2017, USGS 2017). Of these, the little brown bat (*Myotis lucifugus*) and northern long-eared bat (*Myotis septentrionalis*) are threatened with regional extinction in eastern North America as a result of WNS (Frick et al. 2010, Ford et al. 2011, Turner et al. 2011, USFWS 2013, Frick et al. 2015).

Building-roosting bats can to be managed to promote their persistence on the landscape and to mitigate human-wildlife conflict. This is particularly true of bats roosting in buildings used by the public, where bats may present a risk to human health through potential zoonotic disease transmission (e.g., histoplasmosis and rabies; Emmons et al. 1966, Constantine 2009). Noise and artificial illumination associated with the presence of people at roost sites can also have detrimental impacts on bat behavior and survival (Mann et al. 2002, Boldogh et al. 2007, Cardiff et al. 2012, López-Roig and Serra-Cobo 2014). Management decisions are further complicated when bats roost in historic buildings, as bat guano and urine can damage the historic integrity of structures (Hales 2014). Such buildings may receive legal protection, as with historical sites documented by the National Register of Historic Places (NRHP) in the USA, and are often used for tourism. In these cases, management decisions must account for bat conservation, building preservation, and human health and safety.

Management decisions for both bats and buildings, including timing of maintenance activities, restriction of human use, and bat deterrence or exclusion, require information on the roosting habits of building-roosting bats. Previous research suggests micro- and macro-habitat factors influence the use of buildings by Vespertilionids in Europe, and the big brown bat (*Eptesicus fuscus*) and Brazilian free-tailed bat (*Tadarida brasiliensis*) in North America. Buildings used by bats have been found to have warmer and darker roost site conditions relative to unused buildings (Entwistle et al. 1997, Williams and Brittingham 1997, Lausen and Barclay 2006, Neubaum et al. 2007). Researchers have also identified attributes of buildings selected for roosting by bats, including building age, height, construction materials, structural complexity, and accessibility due to damage or disrepair (Entwistle et al. 1997, Williams and Brittingham 1997, Neubaum et al. 2007, Mazurska and Ruczyński 2008, Li and Wilkins 2015). Anthropogenic factors, such as urbanization and disturbance by people, may decrease site suitability (Neubaum et al. 2007, De Boer et al. 2013, Li and Wilkins 2015). Similarly, the presence of roads may pose a risk to bats through collisions with vehicles or barriers to movement (Fensome et al. 2016). Landscape-scale studies of building and natural roosts have found a preference for sites close to

and with a local abundance of woodland, water, and wetland (Entwistle et al. 1997, Neubaum et al. 2007, Lookingbill et al. 2010, Dixon 2012, Li and Wilkins 2015).

To our knowledge, no research investigating the roosting habits of bats in buildings has been conducted in the southeastern USA, and no study has examined the use of buildings by other North American Vespertilionids known to roost in buildings, including the eastern small-footed bat (*Myotis leibii*) and Rafinesque's big-eared bat (*Corynorhinus rafinesquii*). Similarly, no study has examined roost selection by bats in historical buildings used for tourism in North America. In addition, recent confirmation of *P. destructans* on bats roosting in buildings and on free-flying bats during summer requires proper testing of roosting bats and building surfaces in order to reduce the risk of inadvertent spreading of *P. destructans* by people (Carpenter et al. 2016, McAlpine et al. 2016). In this context, our study is among the first to examine summer roosting ecology of building-roosting bats in the southeastern USA. Our goal was to evaluate the relative importance of site attributes influencing roost selection by bats in buildings to guide future survey efforts and provide suggestions for management options that may benefit bat species impacted by WNS. To accomplish this, we compared the site attributes of buildings used and unused by bats at the micro- and macro-habitat scale. Our main objectives were to 1) identify active roost buildings, 2) test roost surfaces and roosting bats for *P. destructans*, the causative agent of WNS, 2) assess microclimate conditions, building attributes, human activity, and habitat patch characteristics at roost buildings and unused comparison sites, 3) model site attributes as predictors of bat presence in buildings in our study area.

METHODOLOGY

Study Area

We conducted our study in Great Smoky Mountains National Park (GRSM or the Park), a 1288 km² area in the southern Appalachian Mountains (259–2026 m in elevation). Located along the border of eastern Tennessee and western North Carolina, USA, the Park was approximately 95% forested, predominantly cove hardwood forest at low elevations, northern hardwood forest at intermediate elevations, and spruce-fir forest at the highest elevations. Other common habitat types included pine-oak forest, hemlock forest, rock outcroppings, and maintained grassland, as well as abundant streams and rivers originating at high elevations. Roads and trails dissected the Park's interior leading to historic structures, visitor amenities, and maintenance and

administrative buildings clustered in districts. Average monthly recreation visitation to GRSM from 1 May–31 August 2015–2016 was 1,250,835 people (NPS 2017).

In Cade’s Cove, TN, a district of GRSM located in a valley (564 m), mean minimum temperature, mean maximum temperature, mean daily relative humidity, and mean monthly precipitation from 1 May–31 August 2015–2016 were 15.9° C, 27.6° C, 81.4%, and 23.9 cm, respectively (NPS 2016a). At Clingmans Dome, TN and NC, the highest peak in the Park (2,021 m), mean minimum temperature, mean maximum temperature, mean daily relative humidity, and mean monthly precipitation during the same period were 10.0° C, 15.6° C, 90.4%, and 34.0 cm, respectively (NPS 2016a).

Throughout the USA, buildings occupied by bats during summer were a persistent concern for National Park Service (NPS) managers (W.H. Stiver, NPS, personal communication). In GRSM, visitors and employees regularly reported sightings of bats or bat sign (e.g., guano or urine staining) roosting in anthropogenic structures during summer. Bats are the only taxon confirmed rabies-positive within GRSM; in some cases, people have come into physical contact with bats, increasing the risk of zoonotic disease transmission (NPS, unpublished report; W.H. Stiver, personal communication). Combined with limited observational notes (Harvey 1987, E.R. Britzke, US Army Engineer Research and Development Center, unpublished report), informal summer reports were the only records of bats roosting in buildings in GRSM. The Park contains at least 8 bat species known to use buildings during their annual life cycle (Kunz and Reynolds 2003, Linzey 2016), 7 of which were known to be affected by WNS or carriers of *P. destructans* (Blehert et al. 2009, Bernard et al. 2015).

Natural and cultural resource managers in GRSM identified 8 priority districts, containing buildings where bats have been reported, receive high visitor traffic, or meet both criteria (Figure 2). Our study examined all buildings in these districts exceeding 400 ft² ground floor surface area to account for time and personnel constraints without excluding buildings likely to be regularly accessed by the public and GRSM employees (140 buildings; 47.1% of buildings in priority districts; 28.5% of all buildings in GRSM). This sample included 49.5% of all maintained historic buildings in the Park, many of which are also listed on the National Register of Historic Places (NRHP).

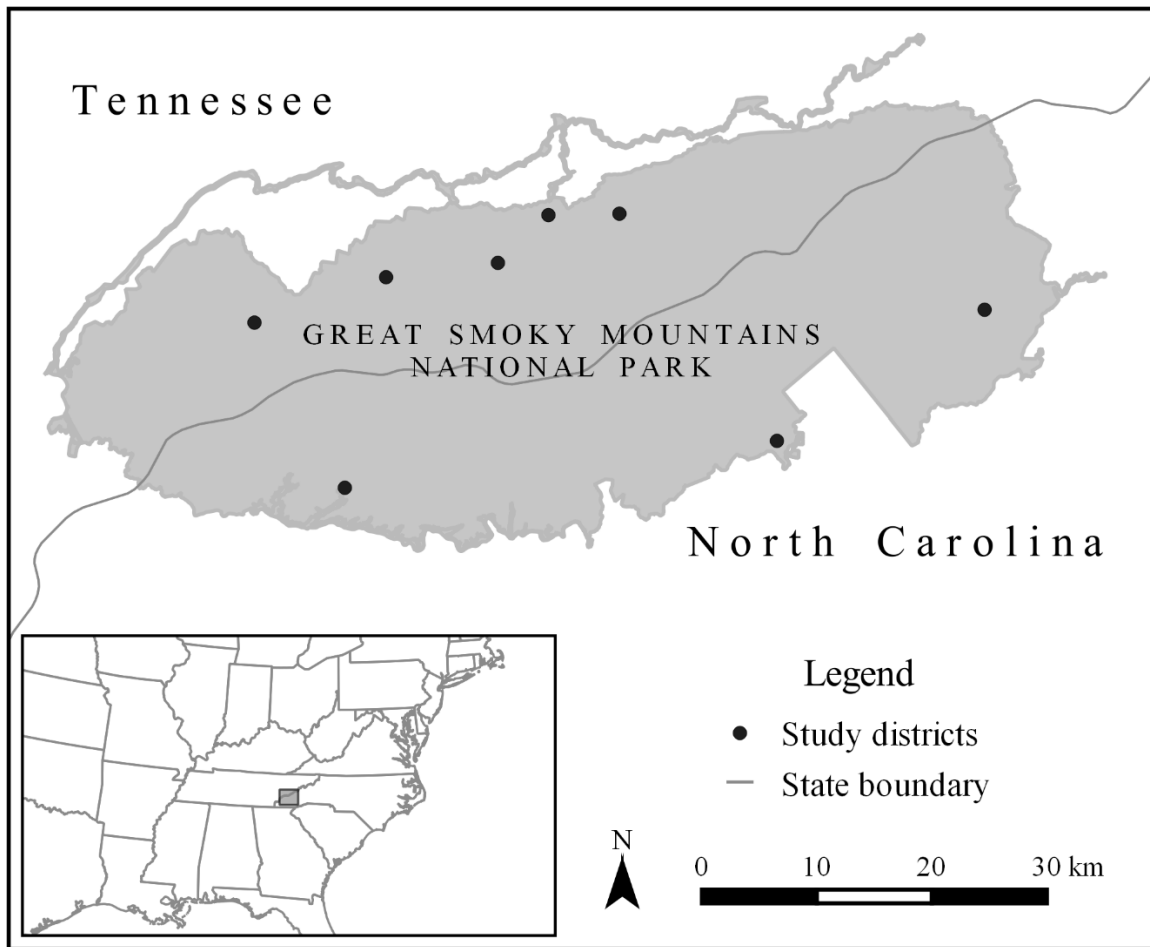


Figure 2. Study area in eastern Tennessee and western North Carolina, USA, depicting the location of study districts in Great Smoky Mountains National Park, where buildings were surveyed for roosting bats, 2015–2016.

Locating Roost Sites

We employed a case-control study design, and established 3 sampling periods each year (2015 and 2016) based on estimates of maternity colony formation and dispersal: 15 May–14 June (pregnancy and parturition), 15 June–14 July (pre-volancy), and 15 July–14 August (volancy; Buchler 1980, Whitaker and Hamilton 1998). These sampling periods overlap with peak visitation at the Park, based on visitor estimates for GRSM from 2013 and 2014 (NPS 2015). We visited all buildings ($n = 140$) during each sampling period.

We followed a standard inspection protocol to identify buildings actively used by bats, evidenced by the direct observation of roosting bats or the presence of fresh guano. We conducted surveys during the day from exterior to interior, progressing from the ground floor to higher levels. We utilized a handheld acoustic monitor (Echo Meter EM3, Wildlife Acoustics, Maynard, MA, USA), while concurrently searching for bats, guano, or urine staining. We directed special attention to potential roost sites (e.g., crevices, rafters, beams) and entry points (e.g., broken windows, gaps in walls or roof). We considered roost sites within the same building to be distinct given sufficient separation (e.g., first floor and attic; front and back porch). We counted roosting bats and identified to species based on morphology. When necessary for distinguishing among species of the genus *Myotis*, we captured adults and volant juveniles by hand or with a fine mesh hand-net. For captured bats, we recorded age, sex, reproductive status, mass (g), and forearm length (mm), and banded with individually numbered 2.9-mm or 2.4-mm narrow split-ring aluminum Porzana forearm bands (Porzana Ltd., East Sussex, UK), depending on species. We collected fungal swabs from the muzzle and forearm of captured bats, as well as the substrate of roost sites, which were stored in microtubes containing RNAlater[®] tissue stabilization solution (Life Technologies, Grand Island, New York, USA) at -4° C. Samples were analyzed at the University of New Hampshire to detect the presence and load of *P. destructans* DNA (Carpenter et al. 2016).

We noted and removed pre-existing guano prior to the first sampling period each year (15 May–14 June, 2015 and 2016), so subsequent observations of guano would indicate recent use of the building by bats. We collected 1–5 pellets from each guano accumulation with forceps and sterile nitrile gloves and stored the samples in microtubes containing silica gel desiccant (4–10 mesh, Fisher Scientific, Pittsburgh, PA, USA) at -20° C. We extracted fecal DNA from individual pellets using PowerSoil DNA Isolation Kits (Mo Bio Laboratories, Carlsbad, CA, USA), which

was then amplified by polymerase chain reaction (PCR). We sequenced positive PCR results via Sanger Sequencing on an Applied Biosystems 3730 (Applied Biosystems, Foster City, CA, USA), which were compared to a reference database for bat species of the southeastern USA in Sequencher v5.0.1 (GeneCodes, Ann Arbor, MI, USA; Brown et al. in revision).

Uncertain roost fidelity within seasons, clearing of guano by NPS staff, and relatively infrequent visits per building (i.e., 3 each year) likely resulted in imperfect detection of roost buildings from one sampling period to the next. To reduce error in roost classification, we defined buildings as roosts if we observed roosting bats or fresh guano during any sampling period.

Capture, handling, and sample collection protocols were authorized under scientific collection permits from the USFWS (TE35313B-3) and NPS (GRSM-2015-SCI-1228), approved by the University of Tennessee Institutional Animal Care and Use Committee (IACUC 2026-0515) and by the American Society of Mammalogists (Sikes et al. 2016).

Surveying Building Attributes

Microclimate conditions.—

We assessed illumination, minimum temperature, and maximum temperature at roost sites and paired random unused sites (Entwistle et al. 1997, Williams and Brittingham 1997, Neubaum et al. 2007, Li and Wilkins 2015). Within each study district where we identified roost buildings, we randomly selected control sites from the pool of buildings confirmed as unused by bats. At these control buildings, we recorded microclimate measurements at potential roosting locations (i.e., where bat roosts were encountered at similarly designed structures).

We measured light levels (lux) at roost sites and randomly selected unused sites with an Enviro-Meter (Model 02-401-5, Thermo Fisher Scientific, Waltham, MA, USA) once each sampling period in 2016. We matched our measurements with hourly ambient light data from the nearest NPS weather station (mean distance = 14.5 km, mean difference in elevation = 867.0 m; NPS 2016a). To adjust for variation in ambient conditions, we calculated illumination as the median ratio of site light level to ambient light level.

We measured temperature (°C) at roost and control sites at 60 min intervals with dataloggers (Thermocron iButtons, Model DS1921, Maxim Integrated, San Jose, CA, USA) during each sampling period. We wrapped each datalogger in a layer of 2 mm polystyrene to attenuate emitted ultrasound and avoid potential impacts on bat behavior (Willis et al. 2009). We calculated

daily minimum and maximum temperature at all sites and matched our measurements at buildings with daily minimum and maximum ambient temperature data available from the nearest NPS weather station (mean distance = 6.4 km; mean difference in elevation = 101.6 m; NPS 2016a). To adjust for variation in ambient conditions, we calculated minimum temperature as the mean ratio of daily minimum site temperature to minimum ambient temperature. We calculated maximum temperature in the same manner.

Building attributes.—

We measured 10 variables at all sampled buildings where such measurements were available or possible to assess building accessibility, characteristics that may influence movement within buildings, features that may provide discrete roost sites, and anthropogenic influence (Entwistle et al. 1997, Williams and Brittingham 1997, Neubaum et al. 2007, Mazurska and Ruczyński 2008, Li and Wilkins 2015).

We assessed 4 continuous variables and 6 categorical variables: 1. Building age (years); 2. Footprint area (m²); 3. Height from base to peak (m); 4. Construction: Open – gaps in structure that increase accessibility (i.e., doors, windows, or chinking absent) or Closed – no gaps in structure (i.e., doors, windows, and chinking intact); 5. Roof material: Wooden shingles, asphalt shingles, or corrugated metal; 6. Primary structural material: Traditional wood (i.e., uneven or rough-cut logs or timber), conventional wood (i.e., modern factory-cut lumber), masonry (i.e., stone, brick, or cinder block); 7. Exterior complexity: High – presence of features resulting in potential hiding places (i.e., complex footprint, > 1 gable, dormer, belfry, or porch) or Low – absence of features resulting in potential hiding places; 8. Interior clutter: High – presence of barriers to movement (i.e., walls, floors, columns, half-walls, and lofts) or Low – absence of barriers to movement; 9. Attic: Presence or absence of compartment adjacent to roof interior separate from main building compartment; 10. Estimated human disturbance.

Previous studies have examined human disturbance with respect to roosting habits during summer (Mann et al. 2002, White 2004, Cardiff et al. 2012, Li and Wilkins 2015), hibernation (De Boer et al. 2013, Thomas 2016), and survival probabilities (López-Roig and Serra-Cobo 2014). To estimate human disturbance at buildings throughout GRSM during summer 2016, we utilized modified creel surveys, used in fisheries science to estimate angler effort and fish harvest. We used stratified, multi-stage sampling to control for spatial, temporal, and anthropogenic variability (Malvestuto 1983, Soupier et al. 2006, Steffe et al. 2008).

Using statistics on traffic, recreation visits, and campground use from May–August, 2015, we established monthly non-uniform probabilities for day type (i.e., weekday or weekend/holiday), building use type (i.e., public use or exclusive NPS use), and park district (NPS 2016b). We estimated one additional stratum, building accessibility to people, by assigning each building to one of three classes: high – directly accessible from road/lot; medium – less than 0.5 km from road or parking lot; low – more than 0.5 km from road/lot. Within each month from 15 May–14 August, 2016, we randomly selected half of all available days without replacement based on day type probabilities. For each selected date, we randomly established building use type and park district using assigned probabilities, then randomly selected two buildings meeting those criteria using building accessibility probabilities.

On selected dates, we surveyed the first building from 10:00–12:00, and the second from 13:00–15:00, counting people accessing the building (i.e., crossing over the footprint of the building). To estimate relative disturbance among building use types within each park district, we adjusted individual building counts by probability of selection for sampling and aggregated by building use type and park district. We estimated relative disturbance at each building by weighting the overall district estimate by the probability of each building being selected for sampling.

Habitat patch.—

Buildings, particularly those in historical settings, are inherently associated with various spatial features, including proximity to water, roads, and habitat edge (i.e., located within a clearing). These associations precluded analysis of proximity variables typically considered in habitat selection studies of bats, including distance to water feature, road, and habitat edge (Rainho and Palmeirim 2011, Berthinussen and Altringham 2012, Jantzen and Fenton 2013).

We calculated 5 habitat patch variables within a 500 m buffer centered on each building in ArcMap 10.3.1 (ESRI, Redlands, CA; Entwistle et al. 1997, Neubaum et al. 2007, Johnson et al. 2008, Lookingbill et al. 2010, Dixon 2012): 1. Percent cover of forest (Homer et al. 2015); 2. Percent cover of field (grassland and pasture merged; Homer et al. 2015); 3. Percent cover of developed land (Homer et al. 2015); 4. Percent cover of water feature (water feature and wetland land cover merged; USGS 2016, Homer et al. 2015); and 5. Road density (sum length [m] of road; US Census Bureau 2016).

Statistical Analyses

We used an information-theoretic approach (Burnham and Anderson 2002) to identify building characteristics important for roost selection by bats. We developed three categories of candidate models using explanatory variables as predictors of bat presence at buildings: site microclimate conditions, building structural attributes, and habitat patch characteristics.

We evaluated all explanatory variables prior to forming candidate models. We examined contingency tables of categorical explanatory variables with the response variable (i.e., bat presence) to ensure no cells contained zero cases, which would result in model instability (Hosmer and Lemeshow 2000). To eliminate redundant explanatory variables, we examined pairplots and contingency tables, conducting correlation analyses among continuous variables and chi-squared analyses among categorical variables (Burnham and Anderson 2002, Zuur et al. 2010). We selected variables to be used in global models based on the combinations that would minimize variable redundancy and be biologically meaningful based on current knowledge of bat ecology.

For the global model at each scale, we confirmed negligible overdispersion (c), the absence of influential observations, and assessed model deviance relative to the null model (Burnham and Anderson 2002). We ranked all subsets of each global model using Akaike's Information Criterion corrected for small sample sizes (ΔAIC_c ; Akaike 1973, Hurvich and Tsai 1989, Burnham and Anderson 2002).

To reduce the likelihood of eliminating informative models, we produced a confidence set of models where the difference in AIC_c between the i th and top-ranked model (Δ_i) was less than 4 (i.e., $\Delta AIC < 4$; Burnham and Anderson 2002). For models in the confidence set, we calculated model averaged parameter estimates and unconditional standard errors to assess the relative importance of each variable and account for model uncertainty (Burnham and Anderson 2002). To avoid reporting spurious effects, only parameters with 95% confidence intervals not including 0 were considered to be informative (Payton et al. 2003, Arnold 2010). We derived and examined odds ratios to quantify effects of informative parameters on the odds of bat presence in buildings, given ratio of bat presence and absence we observed in GRSM (Hosmer and Lemeshow 2000, Liberman 2005).

All modeling was performed in RStudio (RStudio: Integrated Development for R, Version 1.0.136, <http://www.rstudio.com>, accessed 27 Apr 2016) using the package MuMIN

(MuMIn: Multi-Model Inference. Version 1.15.6, <https://CRAN.R-project.org/package=MuMIn>, accessed 8 Feb 2017).

RESULTS

We identified 48 bat roost sites in 44 buildings (31.4% of buildings surveyed). Sixteen of these buildings were protected under the NRHP (53.8% of all surveyed buildings listed on the NRHP) and 30 were accessed regularly by park visitors during summer (40.3% of all surveyed public-access buildings). Roost use (or nonuse) was consistent between years for 90.3% of cases, including 4 roost sites with more than 30 reproductive female bats and their pups at season peak (i.e., mid-June to mid-July). Most roosts were located inside buildings (67.7%), and consisted of beams, corners of rooms, and attics or crawlspaces. Bats at exterior roost sites used rafters of first-floor porches, floor joists of second-floor porches, louvres at gable ends, and in 2 cases the waist-high ledges made by stone veneer. Exterior roosts were located at either buildings with inaccessible interiors or at shelter-like structures with no true interior. All swabs collected from bats and roost sites in buildings were *P. destructans* negative.

We detected 5 species. Little brown bats (*Myotis lucifugus*, 8 roost sites) and northern long-eared bats (*Myotis septentrionalis*, 2 roost sites) were only detected through genetic analysis of guano. All cases of Rafinesque's big-eared bat (*Corynorhinus rafinesquii*, 4 roost sites) were detected visually. We most frequently encountered big brown bats (*Eptesicus fuscus*, 36 roost sites of which 50.0% were detected through analysis of guano only) and eastern small-footed bats (*Myotis leibii*, 15 roost sites of which 66.7% were detected through analysis of guano only; Fagan et al. 2016). Active roost sites indicated by guano only (62.3% of species identifications) may have been used during night. Visual identification confirmed daytime use of roost sites by three species: *E. fuscus*, *M. leibii*, and *C. rafinesquii*.

Thirteen roost sites (27.1% of roosts) were used by multiple species. We observed one case of roost sharing (*E. fuscus* and *M. leibii*; Fagan et al. 2016), but could not confirm concurrent species presence at the remaining multiple-species roosts, which were determined through genetic analysis of guano. This includes 10 roost sites used by two species (5 cases of *E. fuscus* and *M. leibii*, 3 cases of *E. fuscus* and *C. rafinesquii*, 1 case of *E. fuscus* and *M. lucifugus*, 1 case of *M. leibii* and *M. septentrionalis*) and 2 roost sites used by three species (1 case of *E. fuscus*, *C. rafinesquii*, and *M. leibii*; 1 case of *E. fuscus*, *M. leibii*, and *M. septentrionalis*). We recaptured 8

bats at maternity roosts in both 2015 and 2016, including 1 adult female *E. fuscus* which was recaptured both between and within seasons. We did not recapture individuals at different buildings from where they were originally captured.

In the microclimate category, we did not detect relationships among explanatory variables so all were included in the global model of roost selection by bats (Table 1). Theft of and tampering with dataloggers resulted in incomplete observations and subsequently a reduced sample size ($n = 61$, reduced from $n = 96$). All subsets of the global models resulted in 8 candidate models, including the intercept-only model, 5 of which were in the confidence set (Table 2).

Table 1. Min., max., $\bar{x}$, and SE of site microclimate, building attribute, and habitat patch covariates used in a study of roost selection by bats in buildings in Great Smoky Mountains National Park, USA, 2015–2016.

Variable	Description	Used by bats		Unused by bats	
		$\bar{x}$	SE	$\bar{x}$	SE
Site microclimate		$n = 32$		$n = 29$	
Illumination ^{a,b,c}	Illumination (% of ambient Lux)	39.3	7.8	77.2	7.3
Max. temp ^{a,c,d}	Maximum temp (% of ambient °C)	97.2	2.2	103.8	2.6
Min. temp ^{a,c,d}	Minimum temp (% of ambient °C)	114.7	1.3	110.3	1.2
Building attribute		$n = 39$		$n = 92$	
Age ^{a,c,d}	Age of building in 2016 (yr)	103	7	67	5
Disturbance ^{a,b,c}	Number people from 10:00–15:00	206	28	233	41
Height ^{b,c,d}	Height of building (m)	7.0	0.5	5.7	0.3
Habitat patch ^e		$n = 41$		$n = 99$	
Forest cover ^{a,c}	Area of forest (% cover)	77.6	3.5	75.6	2.0
Road density ^{b,d}	Sum length of road (km)	2.8	0.3	3.9	0.2
Water cover ^c	Area of water and wetland (% cover)	2.0	0.4	3.1	0.3

^a Entwistle et al. 1997.

^b Li and Wilkens 2015.

^c Williams and Brittingham 1997.

^d Neubaum et al. 2007.

^e Habitat patch variables calculated within 500 m buffer.

Table 2. Confidence set of logistic regression models ($\Delta AIC < 4$) of site microclimate, building attribute, and habitat patch covariates in explaining bat presence in buildings in Great Smoky Mountains National Park, USA, 2015–2016. We present the number of model parameters (K), log likelihood (LogLik), Akaike’s Information Criterion corrected for small sample sizes (AIC_c), difference in AIC_c between the i th and top-ranked model (Δ_i), and Akaike weight (w_i) for each model.

Model	K	LogLik	AIC_c	Δ_i	w_i
Site microclimate					
Illumination + Min. temp	2	−34.67	75.75	0.00	0.43
Illumination + Max. temp + Min. temp	3	−34.11	76.94	1.19	0.24
Illumination	1	−36.70	77.61	1.85	0.17
Illumination + Max. temp	2	−36.52	79.45	3.70	0.07
Max. temp + Min. temp	2	−36.54	79.50	3.75	0.07
Building attribute					
Age	1	−71.70	147.49	0.00	0.40
Age + Height	2	−70.96	148.12	0.63	0.29
Age + Disturbance	2	−71.46	149.11	1.63	0.18
Age + Disturbance + Height	3	−70.64	149.60	2.11	0.14
Habitat patch					
Forest cover + Road density + Water cover	3	−76.77	161.83	0.00	0.40
Road density + Water cover	2	−77.99	162.15	0.32	0.34
Road density	1	−79.79	163.66	1.83	0.16
Forest cover + Road density	2	−79.59	165.36	3.53	0.07

Model averaging results indicated illumination was the only informative explanatory variable (i.e., confidence interval did not overlap 0; Table 3). Relative illumination (i.e., the light level [lux] at a roost site or comparison site as a percentage of ambient light) also had the highest relative variable importance value ($w_+ = 0.93$) compared with minimum and maximum temperature (Table 4). Increased relative illumination was associated with lower odds of bat presence. An odds ratio of 0.983 (parameter estimate = -0.017 , Table 3) indicated a 1.7% decrease in the odds of bat presence given a 1 unit increase in relative illumination. The estimated odds ratio for an increase of 5 units in relative illumination was $\exp(5 \times -0.017) = 0.918$, which indicated for every 5% increase in relative illumination, the odds of bat presence changed by a factor of 0.918. Based on the observed probability of bat presence at sites within buildings ($P = 0.331$), we estimated a 1.9% decrease in the probability of bat presence given a 5% increase in illumination. Sites selected for roosting by bats were 49.1% darker on average than unused sites (Table 1).

The global model for structural attributes included building age, building height, and estimated disturbance by people (Table 1). To reduce variable redundancy, we eliminated many structural explanatory variables that were initially considered. We included building age, as this variable accounted for categorical variables describing interior and exterior building materials, features, complexity, and accessibility. We found size-related building variables were related, and chose to include building height as this variable was found to be important in other roost-selection studies in North America (Williams and Brittingham 1997, Neubaum et al. 2007, Soper and Fenton 2007, Li and Wilkins 2015). Estimated disturbance by people was unrelated to other explanatory variables. All subsets of the global model resulted in 8 candidate models, including the intercept-only model, of which 4 were in the confidence set (Table 2).

Model averaging results indicated building age was the only informative explanatory variable (Table 3). Building age also had the highest relative importance value ($w_+ = 1.00$) compared with building height and estimated disturbance by people (Table 4). Increased building age was associated with higher odds of bat presence. An odds ratio of 1.016 (parameter estimate = 0.016 , Table 3) indicated a 1.6% increase in the odds of bat presence given a 1 year increase in building age. The estimated odds ratio for an increase of 10 years in building age was $\exp(10 \times 0.016) = 1.177$, which indicated for every 10 year increase in building age, the odds of bat presence

Table 3. Model-averaged parameter estimates, unconditional SE, lower and upper confidence limits (CL) for 95% confidence intervals, and odds ratios for the confidence set of logistic regression models ($\Delta\text{AIC} < 4$) of site microclimate, building attribute, and habitat patch covariates in explaining bat presence in buildings in Great Smoky Mountains National Park, USA, 2015–2016.

Variable	Parameter estimate	SE	Lower CL	Upper CL	Odds ratio
Site microclimate					
Illumination	−0.017	0.008	−0.033	−0.001	0.983
Max. temp	−0.011	0.021	−0.053	0.031	0.989
Min. temp	0.068	0.056	−0.041	0.177	1.070
Building attribute					
Age	0.016	0.005	0.007	0.025	1.016
Disturbance	−0.0002	0.001	−0.001	0.001	1.000
Height	0.037	0.072	−0.088	0.163	1.038
Habitat patch					
Forest cover	−0.008	0.012	−0.032	0.016	0.992
Road length	−0.333	0.116	−0.563	−0.104	0.717
Water cover	−0.115	0.079	−0.299	0.070	0.892

Table 4. Relative variable importance (w_+), calculated as the sum of variable Akaike weights across the most supported logistic regression models of site microclimate, building attribute, and habitat patch covariates in explaining bat presence in buildings in Great Smoky Mountains National Park, USA, 2015–2016.

Variable	w_+
Site microclimate	
Illumination	0.93
Min. temp	0.76
Max. temp	0.38
Building attribute	
Age	1.00
Height	0.43
Disturbance	0.31
Habitat patch	
Road length	0.98
Water cover	0.75
Forest cover	0.47

increased by a factor of 1.177. Based on the observed probability of bat presence in buildings ($P = 0.314$), we estimated a 3.6% increase in the probability of bat presence given a 10-year increase in building age. Buildings selected for roosting by bats were 53.8% older on average than unused buildings (Table 2).

The global model of habitat patch characteristics included percent cover of forest, percent cover of water, and road density (Table 1). In this category, we eliminated two explanatory variables that were initially considered to reduce variable redundancy. We included percent cover of forest, as this variable was associated with percent cover of field and percent cover of developed land. Percent cover of water and road density were unrelated to other variables. All subsets of the global model resulted in 8 candidate models, including the intercept-only model, of which 4 were in the confidence set (Table 2).

Model averaging indicated road density (i.e., sum length of road [km] within 500 m buffer around building) was the only informative explanatory variable (Table 3). Road density also had the highest relative variable importance value ($w_+ = 0.98$) compared with percent area of forest and percent area of water (Table 4). Increased road density was associated with lower odds of bat presence. An odds-ratio of 0.717 (parameter estimate = -0.333 , Table 3) indicated a 28.3% decrease in the odds of bat presence given a 1 km increase in the sum length of roads within a 500

m buffer. Based on the observed probability of bat presence in buildings ($P = 0.314$), we estimated a 6.7% decrease in the probability of bat presence given a 1 km increase in the sum length of roads within a 500 m buffer. Mean road density within 500 m of buildings used by bats was 28.7% less than unused buildings (Table 2).

DISCUSSION

Active bat roosts were common in buildings throughout our study sites in GRSM. Many of these buildings were protected under the NHRP and accessed regularly by park visitors, consistent with concerns from GRSM managers for public health and safety. All species we detected at roosts sites may contract white-nose syndrome (WNS) or carry *P. destructans* (Bleher et al. 2009, Bernard et al. 2015). However, we did not detect *P. destructans* on roosting bats or on roost substrates. We detected little brown bat (*M. lucifugus*) and northern long-eared bat (*M. septentrionalis*) rarely in buildings, both of which are threatened with regional extinction in eastern North America as a result of WNS (Frick et al. 2010, Turner et al. 2011). While *M. septentrionalis* was not documented in buildings of GRSM prior to our study, maternity colonies of *M. lucifugus* were common in buildings throughout the Park before WNS was documented in the region (Harvey et al. 1987). Identification and protection of roosting habitat for these vulnerable species, as well as common bat species, requires knowledge of roost selection in buildings. We found that site illumination, building age, and road density were important site attributes influencing roost selection.

Darker conditions increased the likelihood of bat presence in buildings of GRSM, which has been examined in previous studies of bats roosting in buildings in Europe and the USA. In the United Kingdom, a study of roost use by brown long-eared bats (*Plecotus auritus*), which relied on a qualitative assessment of illumination in conjunction with validation with a photometer, found 89% of roosts sites were “completely dark,” but did not find a significant difference between roost buildings and adjacent unused buildings (Entwistle et al. 1997). A recent study of Brazilian free-tailed bats (*Tadarida brasiliensis*) in Texas, USA did not find illumination to be an important factor for roost selection in buildings, and while researchers measured light levels at roost sites with a photometer (lux, $\bar{x} = 117.31$, 95% CI = 96.63–137.99), they did not account for ambient light (Li and Wilkins 2015). In Pennsylvania, USA, researchers accounted for ambient light levels using different methods than our study (i.e., difference between roost and ambient illumination, rather than ratio) and reported roost sites in attics used by big brown bat (*Eptesicus fuscus*)

maternity colonies were slightly darker than non-roosts, although these differences were not significant (Williams and Brittingham 1997).

Low-light conditions may increase habitat suitability for bats because darker roost sites may provide concealment from predators or, in the case of buildings, people that might disturb them. While our analyses did not detect disturbance by people as important, this may be the result of small sample size or confounding variables. We documented multiple cases of direct human interference with roosting bats during the course of our study, including 4 cases of mortality of lactating female bats. Negative impacts of disturbance by people on roosting bats has been documented previously in Europe, Africa, and the USA. In a study of a maternity colony of pipistrelle bat (*Pipistrellus pipistrellus*) located inside a school in Spain, the survival probability of adult females declined as a result of human disturbance, although researchers could not definitively discern between mortality and permanent emigration (López-Roig and Serra-Cobo 2014). Other studies have examined the effect of tourism on bat colonies in caves. At a maternity colony of cave myotis (*Myotis velifer*) in Arizona, USA, light intensity and noise from tour groups caused increased takeoffs (Mann et al. 2002). Similarly, in a colony of Madagascar rousette (*Rousettus madagascariensis*) located in a cave in Madagascar, the proximity of humans, and resulting illumination, caused an increase in bat alertness and flights (Cardiff et al. 2012). Considering these prior studies and our observations in GRSM, building managers should consider human disturbance to be a risk to roosting bats, and, given the risk of zoonotic disease transmission to people, manage structures to limit interactions between people and bats.

Minimum temperature (% of ambient) had a moderate importance value ($w_+ = 0.76$), but was considered uninformative because the confidence interval overlapped zero. However, warmer roost site temperatures are associated with the use of buildings as roosts, as energy savings are crucial for reproductive female bats and their pups during summer (Williams and Brittingham 1997, Lausen and Barclay 2006, Neubaum et al. 2007), and our small sample size may have precluded the detection of truly important variables.

Likelihood of bat presence in buildings of GRSM increased with building age. The age of buildings used by bats in our study ($\bar{x} = 102.9$ years, CI = 88.2–117.6) was similar to buildings used by *E. fuscus* in Pennsylvania, USA (Williams and Brittingham 1997; $\bar{x} = 100$ years, SE = 9, CI = 82.4–117.6) and *E. fuscus* in Ontario, Canada (Soper and Fenton 2007; buildings aged 81–160 years selected more frequently than expected randomly), but older than buildings used by *E.*

fuscus in Colorado, USA (Neubaum et al. 2007; $\bar{x}$ = 70 years, CI = 53.5–86.5). While old structures are more abundant in Europe than in North America, the age of roost buildings in GRSM was similar to those documented in the United Kingdom, where the median age of buildings used by *P. auritus* was 110 years (Entwistle et al. 1997). Similarly, the upper range of the age of European structures is inherently greater than those found in North America, and may result in a wider range of available buildings for roosting. Buildings used by bats in our study ranged from 9–200 years, whereas the reported age of buildings used by *P. auritus* in the United Kingdom ranged from 53–440 years (Entwistle et al. 1997) and 13–750 years (Jenkins et al. 1998).

We found qualitative variables describing building materials and construction were related to building age. Older buildings tended to be wooden rather than masonry or metal, and tended to be accessible due to damage, disrepair, or inherent construction (i.e., log cabins with structural gaps, open door frames, etc.). Wooden buildings with structural gaps may not only provide access to the interior, but also create specific thermal conditions beneficial to roosting bats. Our study emphasizes the importance of variables acting as proxies for others, which is important for both analytical purposes and for management. A small number of easily measured characteristics are invaluable for management purposes, where feasibility often dictates conservation action.

Older buildings in our study tended to be managed as historic buildings and therefore received specific building maintenance to preserve the historical integrity of the structure. For roosting bats, this meant the preservation of building access. In comparison, maintenance of modern buildings used frequently by people would result in reduction of accessibility. Attics used by maternity colonies of *E. fuscus* in Pennsylvania, USA were more easily accessed than unoccupied sites (Williams and Brittingham 1997). Abandoned buildings in Texas, USA, which were more likely to be accessible due to structural damage, were preferred by *T. brasiliensis* over buildings frequently used by people (Li and Wilkins 2015). Since building interiors provide inherent shelter from predators and the elements, accessibility may be one of the most influential factors for roost selection among buildings. The potential detrimental impacts of human presence associated with building use may be outweighed by such fitness advantages.

Buildings with a lower road density within 500 m were more likely to be used by bats in GRSM. Our findings are contrary to a study in urban Colorado, USA that found known *E. fuscus* maternity roosts in buildings had a greater number of roads within 1 km than unused buildings, but with overlapping confidence intervals (Neubaum et al. 2007). The density of street

intersections (number within 100 m) did not impact probability of building occupancy by *T. brasiliensis* (Li and Wilkins 2015). These studies, however, examined the use of buildings by bats in urban areas in Colorado and Texas, USA, whereas our study was conducted in a rural, mountainous National Park in the southeastern USA. Most roads within 500 m of buildings in our study were unlit by traffic lights and used infrequently at night, thereby limiting potential impacts from vehicles, including collisions, noise pollution, or artificial light pollution. Still, roads can present a risk to bats through collisions with vehicles and through barriers to movement between habitats (Fensome et al. 2016).

Road density may be a proxy for variables we did not measure in this study, or variables we examined in other model categories. Human disturbance may be related to road density, whereby fewer roads could limit human access to structures, resulting in reduced potential disturbance relative to buildings surrounded by high road density. Similarly, low road density may be indicative of a greater percent cover of forest surrounding roosts, which was preferred by *P. auritus* roosting in buildings in the United Kingdom (Entwistle et al. 1997). The influence of roads on habitat use by bats requires further investigation not only at small and large spatial scales but also among urban and rural landscapes.

Our study emphasizes the importance of guano collection when conducting roost surveys. The presence of guano at study buildings was often the only indication of bat occurrence since the previous visit, and was essential for roost identification at buildings where we never observed bats directly. Discerning between day, night, and alternate roosts, however, is not possible at roosts indicated only by guano. Genetic analysis of DNA extracted from guano, in buildings or natural roost sites, is useful for detecting bat species that are cryptic or exhibit frequent roost switching, and is an important tool for researchers and managers in light of declines in populations of North America bats as a result of WNS (Turner et al. 2011, Frick et al. 2015, Brown et al. in revision).

CHAPTER 3: VISITOR ATTITUDES TOWARD BATS IN BUILDINGS OF GREAT SMOKY MOUNTAINS NATIONAL PARK

This chapter is modified from a paper in preparation:

Fagan, K.E., E.W. Willcox, and A.S. Willcox. *In prep.* Public attitudes toward the presence and management of bats roosting in buildings in Great Smoky Mountains National Park, southeastern United States. Planned submission to Biological Conservation.

My consistent use of “we” throughout this chapter is in reference to my co-authors and myself. I was the primary contributor to this work, which involved the following tasks: (1) development of project design and all data collection, (2) statistical analysis, (3) gathering and interpretation of relevant literature, and (4) all writing. E.V. Willcox advised on study design and management implications, and assisted with editing. A.S. Willcox advised on study design, data analysis, and management implications, and assisted with editing.

ABSTRACT

During summer, bats are regularly observed in buildings of Great Smoky Mountains National Park (GRSM), the most visited National Park in the USA. As a result, natural and cultural resources managers seek to ensure public safety and protect historic structures while minimizing impacts on bats, especially in light of declines in bat populations as a result of white-nose syndrome (WNS). However, managers lacked information on visitor perceptions of bats and support for potential management action regarding the taxon. From June to August 2016, we surveyed 420 park visitors at three sites in the Cades Cove area of GRSM on their attitudes toward bats, knowledge about threats to bats and ecosystem services provided by bats, and support for management of bats. Most respondents supported management action to protect bats in buildings in Cades Cove during summer (76%). Standardized parameter estimates from a multiple linear regression developed with survey data indicated that attitudes toward bats and knowledge of threats to bats had the greatest effects on support for bat management. Wildlife management and conservation agencies seeking to further cultivate support for management of bats, in buildings or other locations, may apply these results in the design of tailored programming and outreach materials.

INTRODUCTION

Interactions between wildlife and humans are a persistent concern for wildlife management and conservation. In the USA, where wildlife are owned by the public, agencies such as the National Parks Service and US Fish and Wildlife Service are charged with balancing wildlife resource conservation with human needs. As a result, successful implementation of policy and

action to manage wildlife requires an understanding of public opinions and concerns about target species (Teel et al. 2010). When target species have appealing physical features and life histories, they tend to be adored and more familiar to people and subsequently benefit from stronger support for conservation efforts (Kellert 1985, Knight et al. 2003). Conversely, less charismatic species, including bats, may be controversial or vulnerable to misunderstanding, especially if they are associated with human activities or dwellings.

In North America, bats are a conservation and management priority due to their biological importance in the control of agricultural insect pests (Boyles et al. 2011) and unprecedented population declines due to white-nose syndrome (WNS; USFWS 2012). For bats that roost in buildings, more than half of all bat species in North America (Kunz and Reynolds 2003), conservation efforts are complicated by concerns for zoonotic disease transmission to people (i.e., rabies and histoplasmosis; Emmons et al. 1966, Constantine 2009). When buildings used by bats are also historic, concerns for cultural resource preservation arise (Howard 2009, Hales 2014). Currently, the perceived risks associated with human-bat interaction can result in disproportionate and unnecessary retaliatory action, including eradication and exclusion during the summer maternity season, a critical period for recovery from WNS (Barclay et al. 1980, Bexell and Feng 2013).

To benefit conservation efforts and mitigate human-bat conflict, agencies such as Bat Conservation International, the National Wildlife Federation, and the US Fish and Wildlife Service have utilized public outreach and education. These efforts often focus on dispensing information on threats to bats and ecosystem services provided by bats while dispelling traditionally negative connotations rooted in mythology and folklore (i.e., vampirism, knotting in women's hair; Daniels and Stevans 1903, De Vries 1974). To our knowledge, however, the impacts of bat-focused education efforts on public perceptions of bats are unknown. Our personal observations suggest a shift from historically negative characterizations. The positive social media presence of bats is abundant and persistent, including videos and pictures of bats that incite emotional responses, such as sympathy and adoration.

An understanding of current public perceptions of bats, including the factors that influence support for management, is required to enact effective conservation strategies. The general values and value orientations people hold lead to specific attitudes and norms, not only about wildlife, but also the way by which wildlife is managed; and such attitudes are well-studied as predictors

of behavior (Homer and Kahle 1988, Vaske and Donnelly 1999, Vaske and Donnelly 2007, Manfredo 2008, Vaske and Manfredo 2012). Support for or opposition to management actions are among the most important behaviors for wildlife conservation. Through the study of the stakeholder perceptions of wildlife and wildlife management, communication and outreach programming can be tailored to promote support for management action (Ajzen 1988, Ajzen and Fishbein 2005, Fishbein and Ajzen 2010).

Efforts to quantitatively assess perceptions about bats are limited. To our knowledge, one study has sampled the general public. Sexton and Stewart (2007) found that despite low knowledge of bats, urban residents in Colorado, USA, did not perceive bats as a threat, held positive attitudes towards bats, and supported bat protection. Other studies found that undergraduate and primary school students in Slovakia who had accurate knowledge about bats, rather than belief in fear-related myths, were more likely to have positive attitudes towards them (Prokop and Tunnicliffe 2008, Prokop et al. 2009). In the mid-western USA, children held conflicting emotional perceptions of fruit bats, yet were concerned about their welfare in a zoo exhibit (Kahn et al. 2008). Other studies found that bats, relative to other species, were categorized as unlikeable (i.e., greater mouse-eared bat; Schlegel and Rupf 2010) and ranked more negatively on scales of aesthetic value, fearful qualities, and support for protection (i.e., Ozark big-eared bat; Knight 2008).

Informed management decisions regarding bat exclusion, restriction of human use, and timing of maintenance activities require an understanding not only of the biology of building-roosting bats, but also human perceptions of bats and bat management. To our knowledge, no study has examined perceptions of building-roosting bats or North American bats with respect to WNS. Similarly, no such research has focused on bats associated with historic buildings. Our goal was to assess visitor perceptions of building-roosting bats and related management action in Great Smoky Mountains National Park (GRSM or the Park) to provide suggestions for management decisions and outreach strategies that may benefit bat conservation. Our first objective was to survey visitors in GRSM on their 1) attitudes toward resource management, 2) attitudes toward bats, 3) knowledge of ecosystem services provided by bats, 4) knowledge of threats to bats, 5) support for management action to protect bats. Our second objective was to model attitudes and beliefs/knowledge as predictors of visitor support for bat management and conservation.

METHODOLOGY

Study Area

We conducted our study in the Cades Cove district of GRSM. Cades Cove is 18 kilometers from the nearest town, and consists of a campground area and an 18-kilometer one-way paved road, Cades Cove Loop Road (CCLR). This road enables visitors and park employees to navigate the area, providing scenic views, vehicle pull-offs at four trailheads, and direct access to 25 historic buildings, most of which are less than 0.15 kilometers from the road. We selected this area of the Park after reviewing the summer 2015 results of a concurrent study of bat roosting ecology in buildings of GRSM (Fagan et al. in revision). While we observed overt bat sign in visited historical buildings throughout the park, Cades Cove contained the most bat roosts in buildings, the most historic buildings, and the highest, most consistent visitation by tourists. A study conducted during 22–28 June 2008 found that 55% of 700 visitor groups to the Park visited CCLR, of which 47% spent 4 or more hours at the site (Papadogiannaki et al. 2009). An average of 1,257,649 people visited GRSM each month during the study period, 1 May –31 August 2016 (National Park Service [NPS] 2017). Based on estimated CCLR visitation rates from Papadogiannaki et al. 2009, we estimate an average of 691,707 people visited CCLR each month during our study period.

Sampling Design

Three sites within Cades Cove were selected for sampling: the Methodist Church, the Cable Visitor Center, and the Campground Store (Figure 3). These sites were chosen purposively not only to maximize the likelihood of encountering a representative sample, but to also capture visitors at three stages of their experience in Cades Cove. We assume that visitors to Cades Cove visit at least one of these sites during their visit.

The Methodist Church is located 1.6 kilometers into the one-way loop, and is the first historic structure directly accessible from the road. This structure is large ($>90\text{ m}^2$ footprint), well-maintained, and abutted by a large cemetery and parking lot, attracting many visitors early in their drive along CCLR. Based on personal observation prior to this study, this prominent structure invites high visitation. Our survey station was located outside the entrance to the Methodist Church to encounter visitors entering and exiting the structure.

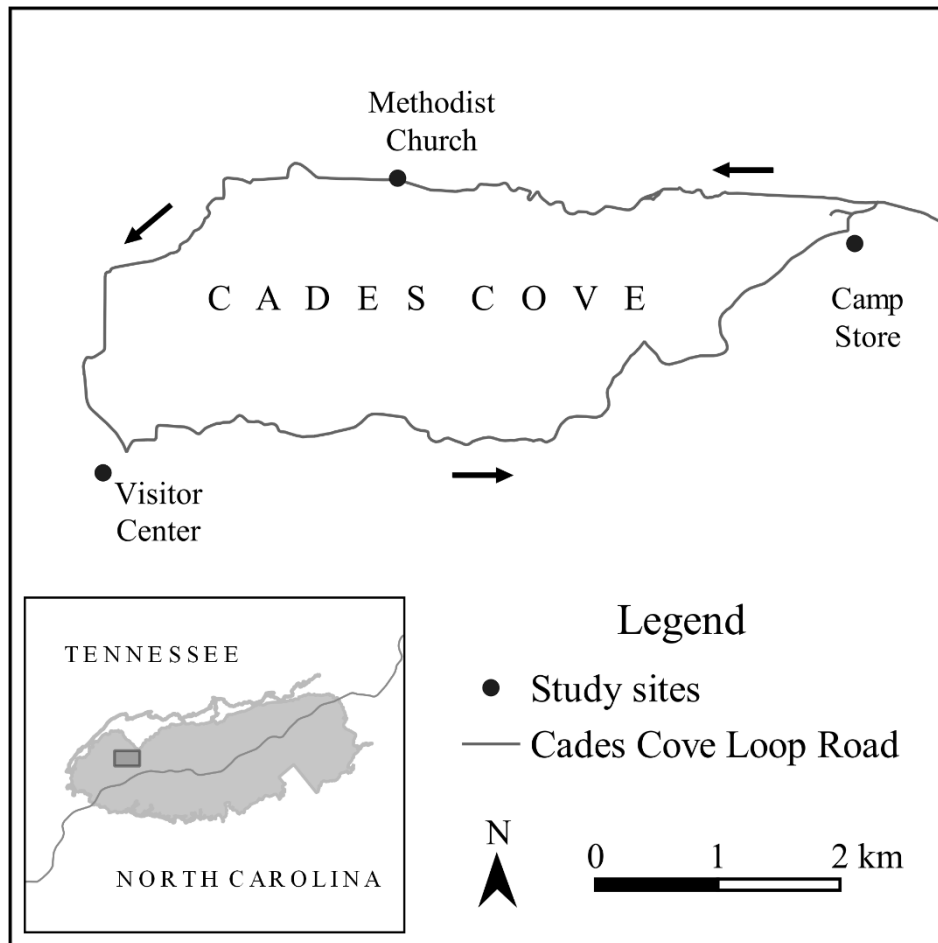


Figure 3. Study area in eastern Tennessee, USA depicting the location of study sites in Cades Cove, Great Smoky Mountains National Park, where visitors were surveyed during June to August, 2016 on their perceptions of bats roosting in buildings. Cades Cove Loop Road is a one-way road, and arrows indicate the direction of traffic.

The Cable Visitor Center is located in the Cable District, 10.6 kilometers from the beginning of CCLR. The area is accessed through a large parking lot (>50 parking spots) and contains 10 well-maintained historic buildings and the first available restroom with running water on the loop. The Visitor Center (>175 m² footprint) mainly functions as a gift shop, and has a front porch with a few benches overlooking the area. Based on personal observations, many tourists choose to stop here to use the facilities, explore the cluster of historic buildings, or participate in activities led by NPS interpretive rangers and volunteers. Our survey station was located outside the entrance to the Visitor Center to encounter visitors entering and exiting the Cable District.

The campground area of Cades Cove is located just beyond the exit of CCLR, although it is accessible to visitors before entering the loop. The area contains a large parking lot (>50 parking spots), ranger's station and campground check-in, restroom, picnic shelter, gift shop, and other amenities. All buildings in this area are modern. Based on our observations of visitor use and traffic flow during the summer 2015 field season, visitors tend to pursue the one-way loop first, and conclude their visit at the campground area. Our survey station was located in front of the large structure (>370 m² footprint) containing the stores, restrooms, and picnic shelter to encounter visitors entering and exiting any one of these facilities or vendors.

Our sample site selection is limited by our assumptions about the order in which visitors explore Cades Cove. The Cable District can only be accessed after first passing the Methodist Church on the one-way loop, but there is no barrier preventing visitors from accessing the campground area before entering the loop. In addition, some visitors do not enter historic buildings in Cades Cove, choosing to enjoy the scenic landscape and opportunities for large wildlife viewing (e.g., American black bear, white-tailed deer, and wild turkey); such visitors would not have the opportunity to encounter bats or bat sign. Indeed, some visitors do not leave their vehicles during their drive through Cades Cove. We believe these instances are rare, and have selected our study sites with the assumption that most visitors will stop at one or more of our sites during a given visit.

We chose sampling periods to maximize both public visitation to the Park and the possibility of bat presence in buildings in Cades Cove. Based on a concurrent study on the roosting ecology of bats in buildings of GRSM (Fagan et al. in revision), bats were most frequently encountered in buildings during June–August. We initially selected three sample periods for each month from June through August. Each period, we intended to sample one site per day for three

consecutive days with fair weather, which we defined as partly cloudy to sunny, with temperatures, humidity, and wind speed within historic norms identified by the Cades Cove weather station. We intended to have an equal chance of sampling park visitors, removing weather variables that may deter a visit to the park. The historic church was sampled first, followed by the visitor's center on the second day, and the campground store on the final day (Table 5). After the first sampling period, however, we chose to conduct surveys more frequently in order to obtain a sufficient sample size (Table 6).

Table 5. Mean ($\bar{x}$) daily visitor encounters, participants, and response rates for the five sample periods used to administer a survey of visitor perceptions of bats roosting in buildings in the Cades Cove district of Great Smoky Mountains National Park, Tennessee, USA, during June to August, 2016.

Sampling site	Daily encounters ($\bar{x}$)	Daily participants ($\bar{x}$)	Daily acceptance rate ($\bar{x}$)
Methodist Church	64	32	47.9%
Cable Visitor Center	91	31	33.9%
Campground Store	48	21	45.3%

On-Site Surveys

On sample days, the research team used on-site intercept sampling from 0900–1600 to recruit voluntary participants for an iPad-based, self-administered survey at the sample site for that day. When an iPad was available, visitors were approached, provided with a description of the study, and asked if they would like to participate. In this way, all visitors had an equal chance of being approached and subsequently recruited for participation in the study. We used the iSurvey iPad application (iSurvey, Version 2.12.14, <https://www.harvestyourdata.com>, accessed 12 Feb 2016) to administer the questionnaire. The survey consisted three sections. All survey materials and procedures met the approval of the University of Tennessee's Office of Research and Engagement Institutional Review Board (UTK IRB-16-03040-XM).

The first and third sections of the survey assessed participants' general experience in the park and demographic qualities (Appendix. Survey Items Used to Assess Visitor Perceptions of Bats in Buildings in Great Smoky Mountains National Park). Questions were modified from those found in surveys from the National Park Service (Taylor et al. 2011) and the Sustainable Tourism Cooperative Research Centre (Moore et al. 2009). Questions assessed attributes of the participants

and their group, including where they were from, how often they visited the park, the size of the travel group, the number of adults and children in the group, the main purpose for visiting the park, and if they had or intended to explore historic buildings in Cades Cove.

Table 6. Mean ($\bar{x}$) daily visitor encounters, participants, and response rates for the five sample periods used to administer a survey of visitor perceptions of bats roosting in buildings in the Cades Cove district of Great Smoky Mountains National Park, Tennessee, USA, during June to August, 2016.

Sampling period	Daily encounters ($\bar{x}$)	Daily participants ($\bar{x}$)	Daily response rate ($\bar{x}$)
June 8 – 10	82	34	43.2%
July 11 – 13	70	30	48.8%
July 18 – 20	71	29	41.3%
July 25 – 27	82	34	41.8%
August 2 – 4	35	12	36.7%

The second section contained a suite of attitude questions about bats and potential management actions related to bats (Appendix. Survey Items Used to Assess Visitor Perceptions of Bats in Buildings in Great Smoky Mountains National Park). All questions consisted of statements presented in batteries with a 5-point scale of ordered response options (i.e., 1 = strongly disagree to 5 = strongly agree; Dillman et al. 2009). After assessing risk perceptions about bats and bat encounters, we asked general knowledge questions about the economic benefits provided by bats and the impacts of WNS. We provided brief statements informing participants of the impacts of WNS on North American bats and the importance of bats for the control of agricultural insect pests. After providing this awareness, we proceeded to questions on support for potential management action related to bats, including partial or full building closures in GRSM to protect bats that roost in buildings during the maternity season.

Statistical Analysis

In order to utilize statistical techniques that require complete observations, we performed missing data imputation with a random forest algorithm, a non-parametric method for both continuous and categorical data, using the R package missForest (missForest: Nonparametric Missing Value Imputation using Random Forest. Version 1.4, <https://CRAN.R-project.org/package=missForest>, accessed 24 May 2017; Stekhoven and Bühlmann 2012, Shah et al. 2014). To assess non-response error, we used likelihood ratio analysis to compare

sociodemographic data from our survey with frequencies available from Visitor Services Report for the Great Smoky Mountains National Park Visitor Survey, conducted 22–28 June, 2008 (Papadogiannaki et al. 2009).

We conducted exploratory factor analysis using principal components analysis with a Varimax rotation to categorize attitudes toward resource management in Cades Cove, risk perception regarding bat encounters, knowledge of threats to and ecosystem services provided by bats, and support for management of bats. We used Cronbach's α to assess extracted factor reliability (Agresti and Finlay 1997). Factor scores from the support for management of bats factor were used as the response variable in regression models. For explanatory variables, we used the mean value of measurement items that factored together into the following categories: attitudes toward resource protection, attitudes toward bats, knowledge about ecosystem services provided by bats, and threats to bat populations.

We used multiple linear regression to examine relationships between support for bat management (response variable) and the standardized explanatory variables. We assessed normality and homoscedasticity of residuals, and checked multicollinearity with Pearson correlations and variance inflation factor (Agresti and Finlay 1997; Vaske 2008). We evaluated standardized coefficients and 95% confidence intervals to estimate the relative importance of explanatory variables and to determine if a parameter's effect differed significantly from zero. We concluded statistical significance at $P = 0.05$. All analyses were conducted in RStudio (RStudio: Integrated Development for R, Version 1.0.136, <http://www.rstudio.com>, accessed 27 Apr 2016) and SPSS (IBM SPSS Statistics for Windows, Version 23.0, Armonk, NY: IBM Corp.).

RESULTS

We encountered 1,017 visitors, of which 420 agreed to participate in the survey, resulting in an overall response rate of 41.3%. Among sample sites, mean daily response rate was the greatest at the Methodist Church (Table 5). While mean daily encounters were the greatest at the Cable District Visitor's Center, mean daily response rate was the lowest at this location (Table 5). Among sample periods, mean daily response rate was the greatest during late June to early July (Table 6). Before random forest imputation, mean item-nonresponse rate was 1.7%. We compared sociodemographics (e.g., age, ethnicity, maximum education, approximate annual income) and visitation information (e.g., visitor group composition, size, origin) with data available from a

Visitor Services Report for GRSM conducted during summer 2008. Gender data were not available from the 2008 Visitor Services Report, and thus were not considered in this preliminary analysis. We found no evidence of non-response error from available data, suggesting that our data collected in Cades Cove may accurately reflect visitors to GRSM in general.

Respondents were 55% female, 96% white, and averaged 47.9 ± 0.7 years old ($\bar{x} \pm SE$). Thirty-three percent had obtained more than a bachelor's degree, 36% had obtained a bachelor's or associate's degree, 21% had completed some college courses, 9% had obtained a high school diploma or equivalent, and 1% had less than a high school diploma. Forty-one percent of respondents reported annual household income $> \$100,000$, 41% reported $\$50,000$ – $99,999$, 16% reported $\$20,000$ – $49,999$, and 2% reported less than $\$20,000$.

Forty-eight percent of visitor groups consisted of families with children. On average, traveling groups consisted of 4 ± 0.2 adults and 2 ± 0.1 children. Forty-five percent of respondents reported traveling from outside the southeastern USA, 43% reported traveling from within the southeastern USA, 12% were able to make a day-trip to Cades Cove, and 1% were visiting from another country. Forty-four percent of respondents described their home community as suburban, 41% as rural, and 14% urban. Thirty percent of respondents were visiting GRSM for the first time, 37% visited once every few years, 14% visited annually, 10% visited 2–5 times annually, 8% visited >5 times annually, and 1% visited weekly.

Respondents reported completed or planned activities during their visit to Cades Cove, which most frequently included sightseeing (96%), wildlife viewing (70%), and spending time with family and friends (63%). Other activities included photography, recreation and exercise, visiting specific historic or natural areas, and picnicking (36–49%). Less frequent activities included spiritual or restorative experiences and interpretive historic or nature tours ($<15\%$). Eighty-nine percent of respondents had visited or planned to visit historic buildings in Cades Cove during their visit.

Among respondents who had visited Cades Cove previously, 11% had seen bats and 16% had seen guano in buildings of Cades Cove prior to the survey. However, 69% of all respondents thought that bats commonly roost in these buildings. Prior to taking the survey, 39% of respondents had heard of white-nose syndrome, of which 88% thought that WNS was a moderate to extreme threat to bats in Tennessee. Seventy-six percent of respondents supported management action to benefit bats roosting in buildings in Cades Cove during summer. Taking no action to protect these

bats was opposed (or strongly opposed) by 50% of respondents, with 38% of respondents indicating a neutral stance (neither supported nor opposed). Specifically, partial closure of roost buildings to public access during summer, which was supported (or strongly supported) by 67% of respondents, received moderate support (3.7 ± 0.0). Only 8% of respondents opposed partial building closure, and none were in strong opposition. Conversely, complete closure of such buildings during summer was slightly opposed (2.9 ± 0.1), with 37% of respondents opposing (or strongly opposing), 32% indicating neutrality (neither supported nor opposed), and 31% supporting (or strongly supporting) such action. Most respondents (63%) were interested in education materials at buildings used by bats.

Data reduction with factor analysis

Support for management of bats was measured with a series of four statements regarding efforts to protect and restore bats, threatened bats, bats in buildings, and threatened bats in buildings. Respondents indicated that they supported or strongly supported efforts to protect and restore bats, regardless of threatened status or whether bats were inhabiting buildings (79.3–88.8% of respondents). However, management of non-threatened bats in buildings (4.2 ± 0.0) and threatened bats in buildings (4.3 ± 0.0) received slightly less support on average than threatened (4.5 ± 0.0) and non-threatened bats (4.5 ± 0.0) in general (Table 7). These items factored together explaining 77.8% of the total variance with a Cronbach's $\alpha = 0.902$, suggesting that the items are unidimensional and have high internal consistency (Table 7).

Attitudes about the importance of resource protection were measured with four statements regarding the importance of protecting scenic views, historic buildings, and two categories of wildlife in Cades Cove. Respondents thought all resource categories were important to be protected in Cades Cove (73.1–74.5% of respondents). The importance of protecting large, charismatic wildlife (e.g., black bears, white-tailed deer, wild turkey) versus small, lesser-known wildlife (e.g., birds, bats, and salamanders) were equivalent (3.9 ± 0.1 ; Table 7). All four items factored together, explaining 96.6% of the total variance with a Cronbach's $\alpha = 0.988$, suggesting that the items are unidimensional and have high internal consistency (Table 7).

Attitudes toward bats were measured with four statements regarding hypothetical bat encounters in buildings in Cades Cove. If they were to encounter bats roosting on the wall in a building in Cades Cove, respondents indicated that they would be more fascinated than afraid (81.4%). Fewer respondents indicated the same if they were to encounter a flying bat (71.4%).

Respondents thought that the likelihood of being bitten by a bat was unlikely to very unlikely (87.4–92.1%). This perceived likelihood was similar for a hypothetical encounter with roosting bats (4.4 ± 0.0) and a flying bat (4.4 ± 0.0 ; Table 7). All four items factored together explaining 68.8% of the total variance with a Cronbach's $\alpha = .842$, suggesting that the items are unidimensional and have high internal consistency (Table 7).

Beliefs about the importance of ecosystem services provided by bats were measured with two statements regarding insect control by bats in the USA. Respondents thought that bats were important to very important for controlling both biting insects (92.9%) and agricultural insect pests (90.5%). However, respondents thought that bats were slightly more important for controlling biting insects than agricultural insect pests (4.6 ± 0.0 compared with 4.5 ± 0.0 ; Table 7). These items factored together explaining 89.2% of the total variance with a Cronbach's $\alpha = .879$, suggesting that the items are unidimensional and have high internal consistency (Table 7).

Beliefs about the severity of threats to bats were measured with three statements regarding the threats to bat populations in Tennessee. More respondents thought that habitat loss (4.1 ± 0.0) and human disturbance (4.0 ± 0.0) were moderate to severe threats to bats in Tennessee (76–77%), compared with disease (53%, 3.5 ± 0.1). These items factored together explaining 66.0% of the total variance with a Cronbach's $\alpha = .737$, suggesting that the items are unidimensional and have high internal consistency (Table 7).

Multiple regression

When we regressed support for bat management on all explanatory variables on visitor attitudes and knowledge, the resulting model explained 26% of the variance (Table 8). Attitudes toward bats ($\beta = 0.258$, $P < 0.001$), perceived severity of threats to bats ($\beta = 0.189$, $P < 0.001$), and perceived importance of services from bats ($\beta = 0.079$, $P = 0.024$) were significant in explaining how likely visitors to Cades Cove were to support management of bats. These variables had confidence intervals that did not overlap 0 (Table 8).

Table 7. Factors and associated measurement items assessed in an analysis of visitor perceptions of bats roosting in buildings in the Cades Cove district of Great Smoky Mountains National Park, Tennessee, USA, during June to August, 2016. We present factor loadings, item means, standard errors, Cronbach's α , and percent variance explained for each factor.

Factor and associated measurement items	Factor loadings	$\bar{x}$	SE
Support for bat management/conservation			
Cronbach's $\alpha = 0.90$, variance explained (%) = 77.8			
Bats ^a	0.834	4.5	0.0
Bats roosting in buildings ^a	0.844	4.2	0.0
Threatened bats ^a	0.827	4.5	0.0
Threatened bats roosting in buildings ^a	0.882	4.3	0.0
Importance of resource protection (Cades Cove)			
Cronbach's $\alpha = 0.97$, variance explained (%) = 98.8			
Scenic views ^b	0.975	3.9	0.1
Historic buildings ^b	0.973	3.8	0.1
Large, charismatic wildlife ^b	0.986	3.9	0.1
Small, lesser-known wildlife ^b	0.979	3.9	0.1
Attitudes toward bats (scenarios in Cades Cove)			
Cronbach's $\alpha = 0.84$, variance explained (%) = 68.8			
Bats on wall in building: fear/fascination ^c	0.807	4.0	0.0
Bats on wall in building: bite likelihood ^d	0.815	4.4	0.0
Bat flying in building: fear/fascination ^c	0.793	3.8	0.1
Bat flying in building: bite likelihood ^d	0.806	4.3	0.0
Importance of ecosystem services from bats (USA)			
Cronbach's $\alpha = 0.88$, variance explained (%) = 89.2			
Control of biting insects ^a	0.894	4.6	0.0
Control of agricultural insect pests ^a	0.910	4.5	0.0
Severity of threats to bats (Tennessee)			
Cronbach's $\alpha = 0.74$, variance explained (%) = 66.0			
Disease ^e	0.695	3.5	0.1
Habitat loss ^e	0.818	4.1	0.0
Disturbance from people ^e	0.844	4.0	0.0

^aOrdered responses: 1 = strongly oppose, 2 = oppose, 3 = neither oppose nor support, 4 = support, 5 = strongly support

^bOrdered responses: 1 = very unimportant, 2 = unimportant, 3 = neither unimportant nor important, 4 = important, 5 = very important

^cOrdered responses: 1 = primarily afraid, 2 = afraid, 3 = neither afraid nor fascinated, 4 = fascinated, 5 = primarily fascinated

^dOrdered responses: 1 = very likely, 2 = likely, 3 = neither likely nor unlikely, 4 = unlikely, 5 = very unlikely

^eOrdered responses: 1 = not at all a threat, 2 = low threat, 3 = somewhat of a threat, 4 = moderate threat, 5 = extreme threat

Table 8. Multiple regression model of support for bat management by visitors to the Cades Cove district of Great Smoky Mountains National Park, Tennessee, USA, during June to August, 2016. We present standardized parameter estimates (β), standard errors (SE), lower and upper limits of the 95% confidence interval, and statistical significance [$P(\beta)$]. Adjusted $R^2 = 0.256$, $F = 37.087$, $P < 0.001$.

Variable	β	SE	Lower CL	Upper CL	$P(\beta)$
Attitudes toward bats	0.258	0.033	0.193	0.323	<0.001
Severity of threats to bats	0.189	0.034	0.123	0.256	<0.001
Importance of ecosystem services from bats	0.079	0.035	0.010	0.148	0.024
Importance of resource protection	-0.010	0.033	-0.075	0.055	0.761

DISCUSSION

Public support for wildlife management action is essential for successfully implementing management policy and achieving conservation goals. Such support is critical for the conservation of North American bat populations, which currently face impacts not only from novel threats like white-nose syndrome (Turner et al. 2011, Frick et al. 2015) and wind energy development (Cryan and Barclay 2009), but also roost and hibernacula disturbance by humans (Mann et al. 2002, López-Roig and Serra-Cobo 2014), landscape transformation and urbanization (Agosta 2002, Jones et al. 2009, Weller 2009), and climate change (Jones et al. 2009, Sherwin et al. 2012). As a result, wildlife conservation and management agencies, including the National Park Service in Great Smoky Mountains National Park, may seek to design outreach and programming materials to promote support for bat management. We found that attitudes toward bats, perceived severity of threats to bats, and perceived importance of ecosystem services were important factors influencing support for bat management. The adjusted R^2 value for our model (0.26), while not high, is consistent with similar studies in the human dimensions of wildlife science (Armitage and Conner 2001, Gotch and Hall 2001, Morzillo et al. 2007, Jhamvar-Shingote and Schuett 2013).

Visitors to Cades Cove had positive attitudes toward bats, similar to a previous study of residents in an urban area in Colorado, USA (Sexton and Stewart 2007). These results are contrary to a study of undergraduate students' perceptions of a suite of endangered species, conducted at a university in the southeastern USA. Researchers found negative perceptions and mild support for the protection of the Ozark big-eared bat, which was conceptualized similarly to other species associated with animal phobias (i.e., Dolloff cave spider and two-striped garter snake; Knight 2008).

Attitudes regarding hypothetical bat encounters in buildings in Cades Cove had the greatest effect on support for bat management. Respondents who did not hold negativistic attitudes of fear during an encounter with a flying or roosting bat and who perceived a low risk associated with such an encounter were more likely to support efforts to conserve bats. These results appear to be consistent with previous studies on perceptions of wolves in the USA, which found that objective knowledge had a lesser influence on support for wolf reintroduction than affective factors, like emotions (Bright and Manfredi 2008, Slagle et al. 2012).

Factors related to knowledge about bats, including the severity of threats to bats and ecosystem services provided by bats, had positive effects on support for bat management. Our results are consistent with a previous study of public perceptions of desert tortoise which found that support for recovery efforts increased with knowledge of this species (Vaske and Donnelly 2007). Other studies concerning knowledge of bats did not assess support for management. However, researchers studying residents in Colorado, USA and students in Slovakia found that greater knowledge of bats was associated with more positive attitudes toward bats (Sexton and Stewart 2007, Prokop and Tunnicliffe 2008, Prokop et al. 2009).

Respondents who thought that disease, habitat loss, and human disturbance posed severe threats to bats in Tennessee were more likely to support efforts to conserve bats. These results appear consistent with undergraduate student ratings of support for wildlife protection, where animals were rated as more attractive and received more support for protection if they were framed as endangered (Gunnthorsdottir 2001). Disease was ranked lower than habitat loss or disturbance by people in terms of threat severity to bats in Tennessee (3.5 ± 0.1). While this aligns with our finding that most visitors were unaware of WNS prior to the survey, we also found that among visitors with prior awareness of WNS, most thought the disease was a severe threat to bat populations. This may indicate that when outreach efforts and media concerning North American bats reach an audience, they effectively convey the severity of WNS with respect to bat populations.

Perceptions about the importance of bats for controlling biting insects (e.g., mosquitos) and agricultural insect pests (e.g., beetles) had a positive effect on support for bat management, although not to the degree of attitudes toward bats or perceptions threats to bats. Visitor's beliefs about specific kinds of insect control by bats highlight the existence of public misconceptions about the nature these ecosystem services. In North America, where most bat species are

insectivorous, bats exert top-down control of beetles (Coleoptera), moths (Lepidoptera), true bugs (Hemiptera), and true flies (Diptera), thereby reducing crop destruction and resulting needs for pesticides (Cleveland et al. 2006, Kunz et al. 2011). Results of dietary studies indicate that relative to moths and beetles, mosquitos represent a small proportion of bat diets (Jones et al. 2009, Gonsalves et al. 2013). Despite this, visitors to Cades Cove believed that bats were important for controlling mosquitos. These results confirm personal observations and are consistent with a previous study in an urban area in Colorado, USA, where residents had low knowledge of bat ecology (Sexton and Stewart 2007). While these misconceptions appeared to benefit bat conservation in this study, we emphasize the importance of dispensing accurate information regarding the crucial ecosystem services bats provide through biological pest control (Boyles et al. 2011).

For bats roosting in modern and historic buildings in National Parks throughout the United States, public opinion on the protection of roost sites, which could impact visitor access to historically significant buildings, should be gauged before such actions are pursued. In the Cades Cove district of GRSM, the most visited National Park in the United States, we found that visitors supported management efforts to protect bats roosting in buildings during the summer maternity period (76%). Specifically, 67% of respondents supported partial closure of buildings to the public if they were used by bats during summer. Where appropriate, this management option may sufficiently reduce the likelihood of human-bat interaction while allowing for both bat use of the structure and public access to historic sites.

CHAPTER 4: CONSERVATION AND MANAGEMENT IMPLICATIONS

ROOST SELECTION BY BATS IN BUILDINGS OF GREAT SMOKY MOUNTAINS NATIONAL PARK

When bat roosts are located in historic structures, managers must fulfill multiple objectives, including ensuring the health and safety of personnel and visitors, maintaining the condition and availability of cultural sites, and conserving wildlife. Within Great Smoky Mountains National Park, priority structures for management action could be chosen based on the location of maternity colonies, species of conservation concern (e.g., species of the genus *Myotis*), or high incidence of human-bat interaction. Priority structures for future bat surveys could be chosen based on our findings, potentially focusing on old buildings with dark conditions surrounded by low road density (Fagan et al. in revision). In other regions, roost structures could be identified through survey techniques similar to those described in this study. As bat populations decline as a result of white-nose syndrome and wind energy development (Cryan and Barclay 2009; Frick et al. 2015), guano may be an increasingly valuable indicator of bat presence. Therefore, determining species occurrence through guano collection and analysis may be an increasingly valuable research and management tool (Brown et al. in revision). After roost sites have been identified, selecting management action will depend on site-specific characteristics, predicted outcomes of actions, and relative importance of different objectives.

During summer, limiting public access to buildings used by bats would likely minimize human-wildlife conflict, as well as protect reproductive female bats and juveniles. Partial building closures may be sufficient to prevent public access to roost sites, which would simultaneously ensure partial public access to cultural sites. Maintenance of historic structures used by bats should occur during late autumn to winter once bats have dispersed to winter sites. To minimize damage to buildings and reduce human health risks, cleaning of guano accumulations could be performed depending on the rate of deposition, and should include the use of personal protective equipment and dust-suppression techniques to reduce the risk of exposure to disease, like histoplasmosis. When suitable, regular use of disposable tarps placed below roost sites could assist guano cleaning efforts. Bat deterrence and exclusion could be pursued if other options have been exhausted, and where appropriate, occur in conjunction with the provision of bat boxes near the original roost building.

VISITOR PERCEPTIONS OF BATS IN BUILDINGS OF GREAT SMOKY MOUNTAINS NATIONAL PARK

The likelihood of interactions between bats and people is inherently greater for building-roosting bats than for bats that use other roost locations, like trees and rock crevices. This is particularly true of public settings with structures used by bats during summer, like National Parks in the USA. In these locations, public support for wildlife management is crucial for lasting conservation impacts. Natural and cultural resource managers of Great Smoky Mountains National Park could use our results to cultivate further support for bat management. Public communication efforts could focus on promoting positive attitudes towards bats and clearing misconceptions about ecosystem services provided by bats. Wildlife management and conservation agencies in other regions could apply the methods we used to gauge public attitudes towards bat conservation.

Building-roosting bats could act as education tools for bat conservation. Management options to protect people and bats, for example the partial closure of roost buildings to the public during the maternity season, could be enacted in conjunction with education efforts based on our findings. If such closures were enacted, information and positive messaging regarding ecosystem services from bats and threats from white-nose syndrome could promote further support for bat management and conservation. Outreach and public communication to foster positive attitudes toward bats could address perceptions of risk concerning bats, including what people should do if they were to encounter a bat. Such efforts are essential to preventing human-bat conflict and promoting bat conservation. Popular historic structures with bat colonies could also provide citizen science opportunities. Where appropriate, and with precautions for safety and well-being of bats and people, volunteers and visitors could participate in self-reporting of bat and guano sightings, thereby assisting with bat colony monitoring in buildings. Managers could pursue infrared cameras at roost sites or building emergence sites to promote public interest and engagement during the maternity season, although such action would require precautions to preserve bat safety during the maternity period.

DIRECTIONS FOR FUTURE RESEARCH

Existing bat colonies in both historic and modern buildings provide opportunities for long-term monitoring and future research. Such colonies are invaluable to conservation efforts as the extended impacts of white-nose syndrome (WNS) on North American bat populations are further observed and understood. Long-term surveys could assess species presence and colony sizes over

time, including repeated testing of captured bats and roost surfaces for *Pseudogymnoascus destructans*, which would help managers and researchers monitor the impacts of WNS. Roost fidelity within and between years could be assessed concurrently with long-term monitoring. Such research would be assisted by radio telemetry applications to investigate the presence of alternate roosts and maternity colony networks, as well as distance to foraging sites and hibernacula. These landscape-level data would help wildlife managers select appropriate action to benefit bats, and would assist in the identification of new roost sites. To better understand region and species-specific roosting habits by bats, comparison studies of roost selection in buildings could be applied to other National Parks in the southeast region as well as other regions in North America. Similarly, to gauge support for bat conservation and inform education programming, comparison studies on perceptions of bats could be applied to visitors to other National Parks, personnel in wildlife management agencies, and to the general public. Comparing perceptions of bat conservation among stakeholder groups would inform communication both between agencies and the public and among different personnel groups within natural resource agencies.

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APPENDIX

SURVEY ITEMS USED TO ASSESS VISITOR PERCEPTIONS OF BATS IN GREAT SMOKY MOUNTAINS NATIONAL PARK

1. Please indicate which of the following activities you have (or plan to) participate in during your visit at Cades Cove today:

- | | |
|---|--|
| a. Sightseeing | g. Spiritual or restorative experience |
| b. Visit a specific natural area | h. Spending time with family, friends, or guests |
| c. Visit a specific cultural area | i. Picnic |
| d. Attend an interpretive nature tour | j. Nature photography |
| e. Attend an interpretive historic tour | k. Wildlife viewing |
| f. Recreation or exercise | l. Other |

<i>Yes</i>	<i>No</i>
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2. Have you (or do you plan to) explore historic buildings during your visit?

<i>Yes</i>	<i>No</i>
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3. Please indicate how important you think it is for the following resources to be protected in Cades Cove:

- a. Scenic views
- b. Historic buildings
- c. Wildlife like black bears, wild turkey, and white-tailed deer
- d. Wildlife like birds, bats, and salamanders

<i>Very unimportant</i>	<i>Unimportant</i>	<i>Neither unimportant nor important</i>	<i>Important</i>	<i>Very important</i>
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4. Have you ever seen a bat in a building in Cades Cove?

<i>Yes</i>	<i>No</i>
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5. Have you ever seen bat droppings (guano) in a building in Cades Cove?

<i>Yes</i>	<i>No</i>
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6. How common do you think it is for bats to be in buildings in Cades Cove?

<i>Very uncommon</i>	<i>Uncommon</i>	<i>Neither uncommon nor common</i>	<i>Common</i>	<i>Very Common</i>
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7. Imagine you are in an historic building in Cades Cove and you see a group of bats hanging on the wall. (Show picture of big brown bats in torpor on a wall). To what degree are you afraid or fascinated?

<i>Primarily afraid</i>	<i>More afraid than fascinated</i>	<i>Neither afraid nor fascinated</i>	<i>More fascinated than afraid</i>	<i>Primarily fascinated</i>
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8. Imagine you are in an historic building in Cades Cove and you see a group of bats hanging on the wall. (Show picture of big brown bats in torpor on a wall). How likely do you think it is for you to be bitten?

<i>Very unlikely</i>	<i>Unlikely</i>	<i>Neither unlikely nor likely</i>	<i>Likely</i>	<i>Very likely</i>
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9. Imagine you are in an historic building in Cades Cove and you see a bat flying around the room. (Show picture of big brown bat flying in an attic). To what degree are you afraid or fascinated?

<i>Primarily afraid</i>	<i>More afraid than fascinated</i>	<i>Neither afraid nor fascinated</i>	<i>More fascinated than afraid</i>	<i>Primarily fascinated</i>
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10. Imagine you are in an historic building in Cades Cove and you see a bat flying around the room. (Show picture of big brown bat flying in an attic). How likely do you think it is for you to be bitten?

<i>Very unlikely</i>	<i>Unlikely</i>	<i>Neither unlikely nor likely</i>	<i>Likely</i>	<i>Very likely</i>
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11. How important do you think bats are for controlling biting insect pests (like mosquitos) in the United States?

<i>Very unimportant</i>	<i>Unimportant</i>	<i>Neither unimportant nor important</i>	<i>Important</i>	<i>Very important</i>
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12. How important do you think bats are for controlling insect pests that destroy agricultural crops (like beetles) in the United States?

<i>Very unimportant</i>	<i>Unimportant</i>	<i>Neither unimportant nor important</i>	<i>Important</i>	<i>Very important</i>
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13. How much of a threat do you think each of the following are to bats in Tennessee?

- a. Disease
- b. Habitat loss
- c. Disturbance from people

<i>Not at all a threat</i>	<i>Low threat</i>	<i>Somewhat of a threat</i>	<i>Moderate threat</i>	<i>Extreme threat</i>
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14. Have you heard of white-nose syndrome?

<i>Yes</i>	<i>No</i>
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If yes to 14:

15. Is white-nose syndrome a threat to bats in Tennessee?

<i>Not at all a threat</i>	<i>Low threat</i>	<i>Somewhat of a threat</i>	<i>Moderate threat</i>	<i>Extreme threat</i>
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The following statements were provided on a separate page to provide awareness of the ecosystem services provided by bats and threats to bats:

“Bats provide natural pest control by eating insects that damage crops, saving the United States an estimated \$22.9 billion every year. They eat mosquitos too, but they are not a major component of their diet.

White-nose syndrome has killed over 6 million bats in North America. Some species are more vulnerable to the disease than others, and are now threatened with regional extinction.

In the summer, some bats roost together in maternity colonies where they give birth and raise their pups. Some species roost in trees and rocks, but many prefer buildings. Starting in the spring, bats can be found roosting in historic buildings throughout Cades Cove.”

16. Please indicate the degree to which you oppose or support efforts to protect each of the following types of wildlife.

- a. Bats
- b. Bats that live in buildings

<i>Strongly oppose</i>	<i>Oppose</i>	<i>Neutral</i>	<i>Support</i>	<i>Strongly support</i>
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17. Please indicate the degree to which you oppose or support efforts to protect each of the following types of wildlife.

- a. Threatened bats
- b. Threatened bats that live in buildings

<i>Strongly oppose</i>	<i>Oppose</i>	<i>Neutral</i>	<i>Support</i>	<i>Strongly support</i>
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18. Should park managers in Cades Cove manage historic buildings to help bats when they are raising their young (during the summer)?

<i>Yes</i>	<i>No</i>	<i>I don't know</i>
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19. Following are a number of actions that park managers of Great Smoky Mountains National Park could take to help bats that roost in historic buildings during the summer. Please indicate the degree to which you would oppose or support each of the following management actions.

- a. Partially close areas of historic buildings in Cades Cove used by bats in summer
- b. Completely close historic buildings in Cades Cove used by bats in summer
- c. Take no action

<i>Strongly oppose</i>	<i>Oppose</i>	<i>Neutral</i>	<i>Support</i>	<i>Strongly support</i>
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20. Would you be interested in education materials, like signs, brochures, or ranger talks at buildings used as summer roosts by bats?

<i>Very uninterested</i>	<i>Uninterested</i>	<i>Neither uninterested nor interested</i>	<i>Interested</i>	<i>Very interested</i>
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21. How often do you visit Great Smoky Mountains National Park? (Pick one)

- a. First visit
- b. Every few years
- c. Once a year
- d. 2-5 times a year
- e. More than 5 times a year
- f. Weekly
- g. Other

22. Which best describes you and your travel group? (Pick one)

- a. Travelling alone
- b. Adult couple, 18 years and older, no children
- c. Young family, children under 6 years old
- d. Mid-life family, children 7-17 years old
- e. Mature couple, no children at home
- f. With friends or relatives
- g. Business associates travelling together
- h. School, university, or sporting group
- i. Tour group
- j. Other

23. Including yourself, how many people are in your travel group? (Enter numbers)

___ Adults ___ Children (under 18 years old)

24. How far did you travel from your home to get to Cades Cove? (Pick one)

- a. Not far at all, I can make day trips to Cades Cove
- b. Not too far, I live in the Southeastern USA
- c. Very far, I came from outside Southeastern USA
- d. I'm visiting from another country

25. How would you describe your home community? (Pick one)

- a. Urban b. Suburban c. Rural

26. What is the highest level of education you have attained? (Pick one)

- a. Less than a high school diploma or equivalent
b. A high school diploma or equivalent
c. Some college
d. Associate degree
e. Bachelor's degree
f. More than a Bachelor's degree

27. Which of the following best describes you? (Pick one)

- a. Asian
b. Black/African American
c. Hispanic or Latino
d. Native American/American Indian
e. White
f. Other

28. Which one of the following income groups best describes your total household income in 2015 before taxes? (Pick one)

- a. Less than \$20,000 c. \$50,000 to \$99,999
b. \$20,000 to \$49,999 d. \$100,000+

29. What year were you born in? (Enter year as YYYY)

30. Are you?

- a. Female b. Male

VITA

Kirstin E. Fagan was born in Wakefield, Rhode Island on May 9, 1991. She graduated from South Kingstown High School in 2009, and completed her Bachelor of Science degree in Wildlife Biology at the University of Vermont in Burlington in 2013. For the next two years, she worked for West Virginia University, the Wildlife Rehabilitator's Association of Rhode Island, and the Division of Wildlife and Fisheries at the Rhode Island Department of Environmental Management. In 2015, Kirstin entered the Master of Science program in the Department of Forestry, Wildlife and Fisheries at the University of Tennessee to pursue research on bats roosting in buildings in Great Smoky Mountains National Park.