Notes

Evening Bats Captured in a Managed Wildlife Refuge Used Trees in a Human-Dominated Landscape as Maternity Roosts

Jacob A. Rogers, Matthew C. Parker, Sarah R. Fritts*

Texas State University, 601 University Avenue, Supple Science Building, San Marcos, Texas 78666

Abstract

Similar to many chiropteran species, pregnant and lactating evening bats *Nycticeius humeralis* form maternity colonies to bear and raise their pups. Although evening bat maternity roosts have been studied in other locations, knowledge gaps exist regarding maternity roost site selection on the Gulf Coast of Texas, United States; thus, our objective was to quantify maternity roost characteristics of evening bats in this region. We radiotracked 11 female and subadult evening bats to 9 roosts during June and July 2018 and 2019 captured in San Bernard National Wildlife Refuge (SBNWR). No transmittered bats roosted in SBNWR and instead all roosts were located 3.6–4.5 km from the same capture site, within an 81-ha residential area of a 5,496-ha city. Five of the nine roosts were located in tall, live, live oak trees *Quercus virginiana* and one roost was in a residential home. Colony size of bats occupying the roosts ranged from 16 to 500+ bats. All evening bats, including those on properties to which we were denied access, stayed in roosts for the full life of the transmitter (5–21 d) and no roost switching occurred. Although evening bats used SBNWR, potentially for foraging, results suggest trees in the residential area provided suitable maternity roost characteristics. A lack of roost switching may suggest a lack of available roost trees in SBNWR and residential areas or the selected roost trees were high quality. We recommend future studies increase sample sizes of evening bat roosts on the Gulf Coast of Texas, as well as assessing roost site selection of evening bats and monitoring bachelor colony and evening bat winter roost ecology.

Keywords: Chiroptera; Columbia bottomland hardwood; Gulf Coast; live oaks; *Nycticeius humeralis*; *Quercus virginiana* telemetry

Received: May 2021; Accepted: October 2022; Published Online Early: January 2023; Published: June 2023

Citation: Rogers JA, Parker MC, Fritts SR. 2023. Evening bats captured in a managed wildlife refuge used trees in a human-dominated landscape as maternity roosts. *Journal of Fish and Wildlife Management* 14(1):163–170; e1944-687X. https://doi.org/10.3996/JFWM-21-052

* Corresponding author: fritts.sarah@txstate.edu

Introduction

Bats spend more time roosting than in any other activity and do so in numerous natural and anthropogenic structures. Roosts promote energy conservation and provide protection from predators and environmental conditions and space for social interaction (Barclay and Kurta 2007). Roosting habits are influenced by the availability of suitable sites, abundance of food, and the physical environment (Scheel et al. 1996; Barclay and Kurta 2007). Many bat species are seemingly flexible in roost site selection, roosting in both natural and anthropogenic structures. Often, bats will use cavities within trees as roost sites. Selection of a cavity depends on a myriad of factors including species using the roost, reproductive status of the bat, cavity size, proximity to foraging areas and water, and surrounding forest stand composition (Campbell et al. 1996; Sedgeley and O'Donnell 1999; Boonman 2000; Kerth et al. 2001; Henry et al. 2002; Lumsden et al. 2002; Willis et al. 2006; Perry and Thill 2007). Although some species exhibit plasticity in roost selection, tree cavity roosts may be limited and local distributions, species composition, and population

abundances are affected by interspecific competition for limited roost sites (McCracken 1988; Scheel et al. 1996; Fenton 1997). Many species of bats sexually segregate while roosting during the spring and summer because of variations in requirements of food, behavior, thermal profiles of roosts, and activity budgets, with some females forming large maternity colonies (McCracken and Wilkinson 2000; Senior et al. 2005; Angell et al. 2013). A tradeoff likely exists between location on the landscape and structural characteristics of the maternity roost, because both are influential to pup development.

Energy and hydration requirements usually are greatest for pregnant and lactating female bats (Fenton and Barclay 1980; Kurta et al. 1989a, 1989b; Kunz et al. 1995). Often during lactation, females return to the maternity roost frequently throughout the night to nurse (Barclay 1982; Henry et al. 2002). Therefore, lactating females may select foraging habitat near maternity roosting structures (Nelson and Gillam 2019). However, many species select maternity roosts based on temperature regimes as well (Tinkle and Patterson 1965; Fenton and Barclay 1980; Williams and Brittingham 1997) because warmer temperatures support growth and development of pups.

Evening bats *Nycticeius humeralis* are medium-sized (5–10 g) and widespread. Evening bats inhabit various rural and urban habitats throughout most of the eastern United States, and the geographic range of evening bats may be expanding in Texas, Nebraska, Kansas, New Mexico, Michigan, and Wisconsin (Watkins 1972; Davis and Boyles 2005; Münzer 2008; Auteri and Kurta 2015; Auteri et al. 2016; Andersen et al. 2017; Kaarakka 2018). These bats are usually abundant, except along the northern edge of their range, and occupy a great diversity of roosts in cavities of live and dead trees, beneath exfoliating bark, and within tree foliage, moss, leaf litter, and buildings sometimes shared with Brazilian free-tailed bats *Tadarida brasiliensis* (Menzel et al. 2001; Boyles et al. 2005; Münzer 2008; Hein et al. 2009). During spring and summer, male and female evening bats typically segregate. Pregnant females form maternity colonies in roosts where they will bear their pups, whereas males and nonreproductive females roost solitarily or in smaller groups (Barclay and Kurta 2007). Female bats aggregate into separate colonies, so maternity roost sites are critical to populations of evening bats.

Our broad goal was to fill knowledge gaps regarding evening bat ecology on the Gulf Coast of the United States, particularly because of recent documented range expansion of the species (Davis and Boyles 2005; Kurta et al. 2005; Auteri and Kurta 2015) and the lack of information on evening bats in this area. Our objective was to quantify maternity roost characteristics of evening bats captured in bottomland hardwood habitat within the San Bernard National Wildlife Refuge (SBNWR). We hypothesized evening bats captured in SBNWR would roost within the managed refuge because bats likely were foraging at the capture site, which provided food and water resources. We predicted tall trees with greater diameter at breast height within the managed refuge would be most often used as roosts likely because higher roosts may obtain more solar radiation and microclimate can influence growth and development of pups (Altringham 1996; Kalcounis-Rüppell et al. 2005; Neubaum et al. 2007; Fabianek et al. 2015).

Methods

We captured evening bats during June and July of 2018 and 2019 within a 130-ha tract of Columbia bottomland hardwood old-growth forest named "Dow Woods" (29.07631 N, 95.42773 W) a satellite unit within SBNWR (Figure 1). We selected Dow Woods as the capture location based on the proximity to year-round water. Based on the Texas Parks and Wildlife Department Ecological Mapping Systems, Columbia bottomland hardwood forest is characterized by live oak *Quercus virginiana*, pecan *Carya illinoinensis*, and palmettos *Sabal mexicana* (Elliott 2014). The vegetation structure causes Columbia bottomland hardwood to resemble less of a swamp than does traditional bottomland hardwood habitat, which is generally dominated by sweetgum *Liquidambar* spp., cypress *Taxodium* spp., and gum/tupelo *Nyssa* spp. trees (Clark and Benforado 1981). Dow Woods is situated adjacent to Bastrop Bayou, which provides year-round water. Since acquisition in 2006, there has been no active land management conducted on Dow Woods other than maintenance of grass and public pathways. Dow Woods is located approximately 3 km from the city of Lake Jackson, Texas, USA (population 27,220 in 2019 with 5.3 people/ha in 2010; U.S. Census Bureau 2021) and considered within the Greater Houston Metropolitan Area (population 2.3 million).

We used mist nets to capture evening bats, and recorded forearm length (mm), body mass (g), age (subadult or adult), sex, and reproductive condition. We attached radiotransmitters (Holohil BD-2X, 0.35 g: Holohil Systems Ltd., Carp, ON, Canada) to reproductive females and subadults (Figure 2). We selected only adult females and subadults for telemetry because locating the day roost of an adult female or subadult is likely to be a maternity roost. Transmitters did not exceed 5% of body mass (mean = 3.68 $\pm$ 0.85%). We glued transmitters to the skin in the middle of the back, between the shoulder blades, with Perma-Type surgical cement (Perma-Type Company Inc., Plainville, CT, USA). We carefully removed fur from this area with scissors before attachment. After attachment, we held bats for up to 10 min while the glue dried, then released evening bats near the capture site. We tracked bats for at least 1 h, once per day, between sunrise and sunset using three- or five-element Yagi antenna and a telemetry receiver (ATS R-4000; Advanced Telemetry Systems, Isanti, MN, USA) for the life of the transmitter ($\sim$21 d).

After a tree roost was located, we recorded tree species and condition (dead or alive), height (m) with a clinometer (SUUNTO PM-5, Vantaa, Finland), understory vegetation density using a Robel pole (Robel et al. 1970), canopy cover using the mean of four densiometer readings estimated from each cardinal direction from the tree approximately 0.5 m from the trunk, and DBH (cm). We also measured distance to capture site (km) in

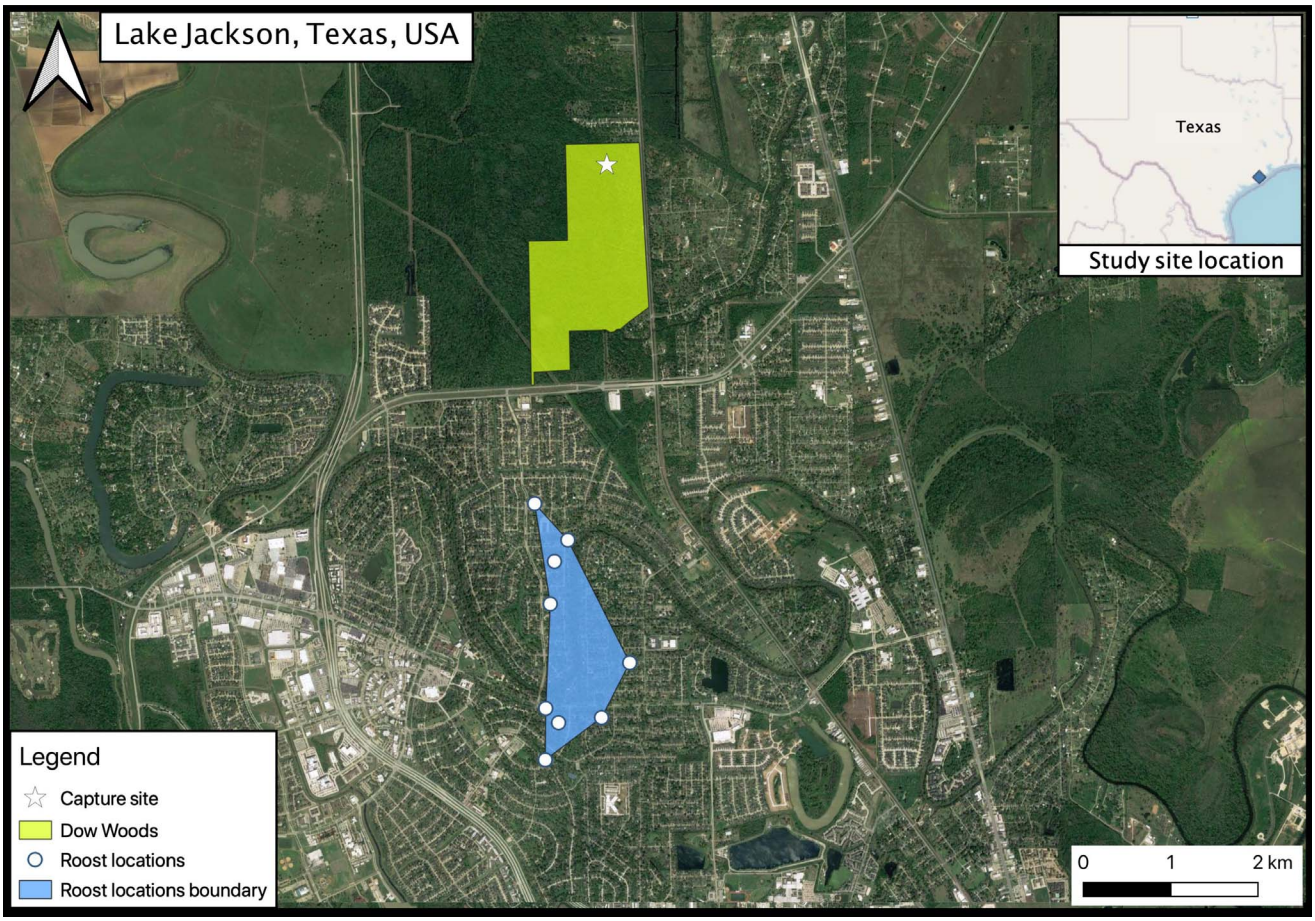

Figure 1. Roost trees occupied by evening bats *Nycticeius humeralis* ($n = 11$) during summers of 2018 and 2019 in Lake Jackson, Texas, USA. White dots represent roost locations. Blue polygon represents 0.81-km^2 boundary in which all roosts were located within a 5,496-ha city. The green polygon represents the area within San Bernard National Wildlife Refuge where all transmittered evening bats were captured (named "Dow Woods"). White star denotes capture location of all bats tracked to roosts. Inset in top-right corner shows study site location.

ArcMap Pro (Esri Geographic Information Systems, Redlands, CA, USA). At each roost, we conducted emergence counts to estimate colony size and identify exit points.

Results

We captured 120 evening bats and attached radio-transmitters to 14 bats. We were unsuccessful at locating 1 transmittered evening bat in Year 1 and 2 bats in Year 2; thus, we tracked 11 bats from Dow Woods to 9 unique roost locations. Overall, we tracked seven bats to cavities of five separate tree roosts, all of which were live, tall, large, live oak trees; height: 27–31 m; DBH: 108–201 cm, with moderate canopy cover (33–70%) and low understory vegetation; 0.5–1.9 dm on private property in the city of Lake Jackson, Texas, USA (Figure 1; Table 1). We were denied access to three evening bat locations on three different parcels, but we visually identified large live oaks as the probable roost for each. An adult female evening bat was tracked to an attic of a two-story residential home. We tracked three bats to the same tree in both 2018 and 2019, with similar colony sizes both years. Lake Jackson was dominated by large live oak trees, which all tree-roosting individuals used as roost sites (Table 1).

All roosts were located 3.6–4.5 km from the same capture site, within an 81-ha residential area of a 5,496-ha city (Figure 1). Characteristics of roost trees are listed in Table 1. Colony size of bats occupying the roosts ranged from 16 to 500+ bats (Table 1). All evening bats,

Table 1. Characteristics of maternity roost trees occupied by evening bats *Nycticeius humeralis* during summers 2018 and 2019 in Lake Jackson, Texas, USA. No. of bats = number of bats using roost; Ht = height; DBH = diameter at breast height; CC = canopy cover; UV = understory vegetation. All trees were live oaks *Quercus virginiana*.

No. of bats	Ht (m)	DBH (cm)	CC (%)	UV (dm)	Dist. (km)	Road dist. (m)
500	31	201	67.3	1.94	4.6	38.6
16	27	120	33.3	0.53	4.0	16.4
295	28	168	50.2	0.88	4.2	7.5
180	29	169	48.6	0.41	3.6	10.1
170	27	108	69.7	0.61	4.5	14.1

Figure 2. A photo of an attached transmitter (Holohil BD-2X, 0.35 g) on a female evening bat *Nycticeius humeralis* to locate the maternity roost site in the San Bernard National Wildlife Refuge, Texas, USA, in 2018.

including those on properties to which we were denied access, stayed in roosts for the full life of the transmitter (5–21 d) and no roost switching occurred.

Discussion

Female and subadult evening bats that were captured in SBNWR managed by the U.S. Fish and Wildlife Service roosted in large, live, live oak trees in suburban residential landscapes and did not switch roosts during the study. Broadly, activity and species richness of bats typically decreases along a gradient as habitats become more urban; however, older residential areas with existing vegetation sustain some species (Kurta and Teramino 1992; Walsh and Harris 1996; Gaisler et al. 1998; Lesiński et al. 2000; Jung and Threlfall 2015). Tall, large-diameter trees are critical roost sites for many species of bats with various roosting strategies (Kalcounis-Rüppell et al. 2005; Carter et al. 2007; Fabianek et al. 2015). Similar to this study, adult female evening bats in South Carolina roosted in live longleaf pines *Pinus palustris* and not in more densely canopied hardwood bottomland areas (Menzel et al. 2001), although evening bats in Georgia have been documented roosting in tall, live trees and dead snags surrounded by open, mature forested habitats and open water (Miles et al. 2006). Likewise, Yuma myotis *Myotis yumanensis* in California that were captured in a preserve were located roosting in suburban areas in large live trees surrounding the preserve (Evelyn et al. 2004).

Results suggest that the capture site of Dow Woods, which is within SBNWR, may not have trees suitable to, or preferred by, evening bats for maternity colonies. However, evening bats were captured in the Dow Woods tract, indicating that the SBNWR is regularly used, potentially as foraging habitat. The combination of large trees with no understory clutter in the residential area and the preserved Columbia Bottomland Hardwood habitat at Dow Woods may provide beneficial resources for adult female and subadult evening bats on the Gulf Coast of Texas. Trees with less clutter may be beneficial for juvenile and subadult bats when learning to fly and preferred for maternity colonies as has been documented in *Myotis* and *Lasiurus* species (Constantine 1966; Campbell et al. 1996; Adams 1997). Thus, preserving large trees with limited understory as roosts or acquiring small tracts of land near residential areas may benefit bats in various regions by providing a mixture of roosting and foraging habitats (Russo and Ancillotto 2015).

Evening bats used SBNWR at night, presumably for foraging, possibly because the residential areas did not provide the resources needed or because of the foraging ecology and morphology of evening bats. Most North American bats rely on an abundant source of nocturnal invertebrates as prey items (Avila-Flores and Fenton 2005) and prey availability and size may decrease in urban areas (Coleman and Barclay 2012). Bats often forage around streetlights in human-dominated landscapes (Jung and Kalko 2010); but bats' use of lights depends on the species' morphology and flight performance. For example, although evening bats typically forage for flying insects in uncluttered areas (Norberg et al. 1987; Jones and Rydell 1994), as a species with a low wing aspect ratio, they may be more light-averse (Rowse et al. 2015).

Bats with alternative roosts are more likely to survive predation, microclimate changes, and destruction of roosts, compared with species that rely on a single tree or building (Willis et al. 2006); however, roost switching may decrease reproductive success if bats are forced to move to an alternate roost prior to parturition, as documented in big brown bats *Eptesicus fuscus* (Lewis 1995). We did not observe roost switching by pregnant or lactating evening bats in our study. Our results contradict some previous literature that documented regular roost switching in evening bats every 1–4 d, and the greatest rates of roost switching for maternity colonies (Menzel et al. 2001; Boyles and Robbins 2006;

Münzer 2008); however, earlier studies had similar results to ours and rarely documented any roost switching (Humphrey and Cope 1970; Bain and Humphrey 1986). Although understanding the exact causes of roost switching in pregnant and lactating evening bats was beyond the scope of this study, roost switching in cavity-roosting bats is facilitated by greater densities of appropriate trees and leads to less-dense bat colonies (Kunz 1982; Johnson and Hale 2002; Willis and Brigham 2004); thus, a lack of roost switching in our study may suggest a lack of available roost trees in SBNWR and residential areas and/or evening bat colonies that have not maximized their population density within a roost. Many trees in the study area, particularly the residential area, have been damaged in hurricanes, including Hurricane Harvey in 2017, which broke branches and created cavity openings that are used as roosts; thus, the lack of roost switching may instead be because the selected roosts are high quality. We recommend additional research to understand how roost switching affects evening bat reproductive success and if the lack of roost switching increases risk such as mortality from predators or destruction from a homeowner.

The International Union for Conservation of Nature recognizes land-use change, including urbanization, as a major threat to bats on a global scale (Frick et al. 2020). Bats have various life-history traits that increase susceptibility to urbanization, such as low reproductive rates, longevity, and high metabolic rates leading to high food requirements. Although Lake Jackson, Texas, can still be considered "suburban" with a population density of 5.3 people/ha, the city is within the Greater Houston Metropolitan area, one of the top five largest and fastest-growing cities in the United States with a population density of ~14 people/ha (U.S. Census Bureau 2021). Thus, suburban areas surrounding Houston likely have a high probability of increasing in population density and becoming a highly urbanized landscape. If Lake Jackson expands as much as the surrounding area, the increase in urbanization could affect all resources available to the bats of Lake Jackson. The population of Lake Jackson has been relatively stable over the past decade; however, the surrounding area continues to expand rapidly (U.S. Census Bureau 2019). Retaining large live oak trees within and around the area likely will benefit bats and other urban wildlife.

One potential limitation of our study is that we did not measure random trees in the city of Lake Jackson, where the evening bats were roosting; thus, we could not quantify habitat selection. Lactating bats often return to the maternity colony often each night to nurse (Barclay 1982; Henry et al. 2002) and energy and hydration requirements are high for pregnant and lactating bats (Fenton and Barclay 1980; Kurta et al. 1989a, 1989b; Kunz et al. 1995); therefore, we assumed the evening bats in this study would roost near the foraging habitat. However, the fact that evening bats roosted at a different location than captured suggests that a possible tradeoff occurs in regard to the energy and hydration required to commute to and from the roost site and the microhabitat properties, likely sun exposure and thermal environment, provided by the roost tree. Roosts are important components of bat ecology (Kunz 1982) and a lack of suitable roost sites may limit bat populations (Humphrey 1975); thus, we recommend continuing to explore the mechanisms responsible for roost site selection of evening bats and other species on the Gulf Coast of the United States as well as the influence of roosting in urban habitats on reproductive success. Roosting habits of most bat species tend to change seasonally (Boyles and Robbins 2006); thus, monitoring roost habits during the winter will aid in conservation efforts. Moreover, locating additional roosts in Lake Jackson will aid in developing a better understanding of potential roost density in this area. Benefits of forming maternity colonies include decreased predation risk, increased thermoregulation, and transfer of information (Wilkinson 1992). Bachelor colonies or individual males may therefore roost in different types of structures altogether; thus, investigating roost use and site selection for bachelor colonies will add to our knowledge regarding evening bat life history and contribute to management and conservation actions for the species. As urban areas continue to expand, the integration of wildlife utilizing human-dominated landscapes simultaneously increases. Future studies of this nature will continue to broaden our understanding of habitat selection criteria, barriers to movement, and conservation strategies within human-dominated landscapes.

Supplemental Material

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

Reference S1. Elliott L. 2014. Descriptions of systems, mapping subsystems, and vegetation types for Texas. Texas Parks and Wildlife Department.

Available: https://doi.org/10.3996/JFWM-21-052.S1 (1.241 MB PDF) and https://tpwd.texas.gov/landwater/land/programs/landscape-ecology/ems/emst/texasecologicalsystemsdescriptions_2016.pdf (December 2021)

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Available: https://doi.org/10.3996/JFWM-21-052.S4 (686 KB PDF) and https://www.census.gov/quickfacts/fact/table/lakejacksoncitytexas/IPE120219 (July 22, 2021)

Acknowledgments

We thank the U.S. Fish and Wildlife Service (Grant Agreement F18AP00392) and Texas State University for funding this project. A. Kurta and L. McGuire provided expertise, mentorship, and editing. A special thanks to J. Wilson, W. Woodrow, R. Davis, and C. Jones for assistance and access to the study site. We also thank K. Dyer, D. Molnar, and M. Moreno for assistance with fieldwork. We thank the journal reviewers and Associate Editor as well.

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