CHARACTERISTICS OF ROOSTS USED BY RAFINESQUE'S BIG-EARED BAT (*CORYNORHINUS RAFINESQUII*) ON CAMP MACKALL, NORTH CAROLINA

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Abstract—Military bases are charged with stewardship of threatened and endangered species, and data collection on species of concern is important for management of these species on military land holdings. We studied roosting behavior of Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) during a multiyear inventory on Camp Mackall and Fort Bragg, NC. From 2006 to 2009, *C. rafinesquii* were captured (n = 24), banded, and/or radio-tagged to gain information on roosting habits within and adjacent to bottomland hardwood forests. Twenty roosts were identified: 11 trees [9 tupelo (*Nyssa* spp.) and 2 bald cypress (*Taxodium distichum*)] and 9 anthropogenic structures. Bats used these roosts in similar proportions and switched roosts often (every 1.2 days). Diameter at breast height of roost trees ($\bar{x}$ = 83.0±6.7 cm) used by *C. rafinesquii* was smaller than reported elsewhere for this species. In 2008, temperature data were collected in anthropogenic structures used as roosting sites. None of these roosts housed large numbers of bats, but the range of temperatures for two different roosts, each housing one pregnant female, was 24.5 to 46.0 °C for an attic roost on May 27, 2008, and 19.0 to 27.0 °C for a cistern roost on May 30, 2008. A female that roosted in the attic while pregnant then roosted in the basement of the same building the following September when she was postlactating. The significantly warmer attic temperatures may have allowed the female to avoid torpor, thereby contributing more metabolic resources to the developing fetus. Other temperature data collected suggest that bat use of other roosts was not affected by roost temperature. Choice of trees and anthropogenic structures used as roosting sites by *C. rafinesquii* was comparable to published studies of these bats in similar habitats, demonstrating the importance of these features to the persistence of local populations.

INTRODUCTION

The Sikes Act was amended in 1997 to direct military installations to create integrated natural resources management plans (Boice 2006). These plans must be reviewed at least every 5 years to ensure that military lands are managed to conserve and rehabilitate natural resources in their charge (Legacy Resource Management Program 2005). The 12 million ha managed by the U.S. Department of Defense houses three times more federally listed or imperiled species than all other Federal lands despite comprising only 3 percent of Federal land holdings (Stein and others 2008). Military land is relatively protected from urban encroachment and is presumably less inundated with potential agricultural pollutants, such as fertilizer and pesticides, than surrounding rural areas. This permits military lands to be a safe haven for species that might otherwise be negatively affected by human interactions. In some cases, military activity may even benefit some species. For example, Jentsch and others (2009) found that some pioneer plant species thrived after ground disturbance such as tank activity on a retired military base in Germany. Alternately, managing for some species can be beneficial to the military. Maintaining open stands in pine (*Pinus* spp.) forests for the red-cockaded woodpecker (*Picoides borealis*) created optimal training areas for troops by supplying open areas for maneuvers (Beaty and others 2003).

Fort Bragg was established as Camp Bragg in September 1918 in southcentral North Carolina among a large expanse of pine forests and sandy soil and was renamed Fort Bragg upon becoming a permanent post in September 1922 (Fort Bragg 2002). As the base expanded, forests were removed for development, timber, and agriculture, resulting in the reduction of a diverse ecosystem and the Federal listing of many endemic species (Britcher 2006). Two bat species with at least two levels of State status (Legacy Resource Management Program 2005) are known from Fort Bragg and Camp Mackall, NC: Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) and southeastern myotis (*Myotis austroriparius*). These species are also designated as species of concern by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2010).

Loss of natural habitat has prompted the need for information on roosting and foraging requirements of *C. rafinesquii* so that land holdings can be managed appropriately for the species. Forests provide roost trees and foraging areas; however, anthropogenic structures could be significant roost structures, particularly where there is a lack of sufficient tree roosts, e.g., in younger aged forests. *C. rafinesquii* also exhibits frequent roost switching (Clark and others 1997, Gooding and Langford 2004, Lance and others 2001, Trousdale and others 2008); therefore, this species may benefit from greater roost diversity and

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increased availability across the landscape. Variation in roost microclimate is required by these bats when roosting (Clark 1990, Hoffmeister and Goodpaster 1963, Hurst and Lacki 1999, Lewis 1995), and evidence suggests that the environment surrounding roosts, such as roads, water, and canopy cover (Clark 1990, Lance and others 2001), can be as important as the surrounding landscape in providing foraging opportunities (Menzel and others 2001).

Because no prior study of bats had been conducted on Camp Mackall and Fort Bragg, our objectives during this 6-year project were to: (1) document the presence of bat species on the base, (2) locate and characterize roosts used by *C. rafinesquii*, and (3) conduct an exploratory examination of temperature variation among roosts of this species. We expected to find a small population of *C. rafinesquii* at the site due to a limited amount of bottomland hardwood forest that contained relatively young trees with few roosting opportunities (Gooding and Langford 2004), and we predicted extensive use of anthropogenic structures by these bats.

STUDY AREA

The 65,084 ha of Camp Mackall and Fort Bragg (39°26´N, 123°48´W) are located within six counties in the sandhills ecoregion of the inner Coastal Plain physiographic region of North Carolina (Griffith and others 2002). The sandhills upland complex consists of mesic and wetland plant communities including pine/scrub oak sandhill and xeric sandhill scrub, coastal plain small stream swamp, and streamhead pocosin (Fort Bragg 2005). Woodlands on the base are composed primarily of loblolly pine (*P. taeda*) and shortleaf pine (*P. echinata*) in association with bald cypress (*Taxodium distichum*) and a mixture of hardwoods including, but not limited to, water tupelo (*Nyssa aquatica*), black tupelo (*N. sylvatica*), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), tuliptree (*Liriodendron tulipifera*), water oak (*Quercus nigra*), post oak (*Q. stellata*), blackjack oak (*Q. marilandica*), and turkey oak (*Q. laevis*).

Camp Mackall encompasses 3,211 ha of the total land holdings and lies 64.4 km west of the Fort Bragg cantonment in a rural region interspersed with small towns and villages. The area is surrounded by upland forest, agriculture, rural housing, and nonforested military training areas and airfields. Drowning Creek, a fourth-order blackwater stream, flows through Camp Mackall and is accompanied by bottomland hardwood forest in adjacent habitats. This forest type is important because although *C. rafinesquii* use several types of roosts, when the species is documented in trees, those trees are often located in bottomland hardwood forests (Carver and Ashley 2008, Gooding and Langford 2004, Lance and others 2001, Menzel and others 2003, Trousdale and Beckett 2005). Bottomland hardwood forest in the riparian zone of Drowning Creek has an open understory and is comprised primarily of tupelo trees (*Nyssa* spp.) with scattered *T. distichum* and oaks. This habitat type accounts for 8.6 percent of all vegetation types on Camp Mackall as calculated using a Geographic Information System Fort Bragg vegetation layer for ArcView ver. 9.2/3 (Esri, Redlands, CA). Temperatures in this area ranged from 13 to 33 °C with an average of 22 °C during the study period when roost temperatures were collected in 2008.

METHODS

We deployed mist nets over creeks, water-filled road ruts, wildlife ponds, open bottomland forest, and dry road corridors in varying habitat types, e.g., bottomland hardwood forest, planted pine stands, and small sandy streams, twice a year from 2004 to 2009 in two of the following three seasons: spring (April, May, and June), summer (July and August), and fall (September and October). We deployed nets at sunset and typically left them in place for at least 5 hours after sunset. In most years, we netted 10 sites twice per year, but as many as 17 sites were netted in 2009. Each year we also visited a varying number of buildings, bridges, and other anthropogenic structures to search for bats. We conducted a total of 214 searches of structures (range: 13 to 102, mean: 35.7) from 2004 to 2009. From 2006 to 2009, no structure was searched during December, January, or February. We recorded data on captured bats including age (adult or juvenile), sex, body mass (g), and forearm length (mm). After a banding program was established at Camp Mackall and Fort Bragg in 2006, forearms of all *C. rafinesquii* caught ($n = 18$) were fitted with uniquely numbered aluminum alloy lipped identification bands (bat rings; Porzana Ltd., East Sussex, UK). We also fitted 11 *C. rafinesquii* with 0.48-g radio transmitters (model LB-2; Holohil Systems Ltd., Ontario, Canada) in May, June, or July depending on the year. We clipped a small amount of hair from between the scapulae, and a transmitter was applied using Skin Bond® adhesive (Smith & Nephew, Inc., Largo, FL). We held bats for 5 to 10 minutes after transmitter placement to ensure secure attachment prior to release at or near the point of capture.

Tracking commenced the day after bats were radiotagged to locate day roosts. We drove roads, on and off the base, while listening for signals using a receiver (model TRX-1000S) and a 3- or 5-element Yagi antenna (receiver and antenna; Wildlife Materials, Inc., Carbondale, IL). Once a roosting site was located, we attempted visual confirmation in roost trees with a basal opening and in anthropogenic structures used as roosts. When feasible, we estimated the height (m) at which the bats were roosting and the number of bats using the roost either visually or by conducting exit counts in the evening. We obtained locations of roosting sites using a handheld global positioning system (GPS) and recorded a description of the roost location. We took photographs and made graphical representations of roosting sites to aid in future identification. We attached uniquely numbered aluminum tree tags and high visibility flagging to tree roosts to aid in relocation. We recorded the species of tree, measured diameter at breast height (d.b.h.), estimated height of tree (m), noted condition of the tree (live, live-damaged, or snag), and the presence of vegetation layers surrounding the roost tree (canopy, subcanopy, and understory). These data were also taken on all trees within a plot surrounding the roost tree that were identified using a 10 basal area factor prism. Because this method is considered point sampling and not fixed-area sampling, the plots were not uniform in size. Rather, the "probability of a given tree being sampled is proportional to its size" (Avery and Burkhart 2002). Additionally, the plot radius factor is 2.75 feet, meaning "for each inch of dbh, a tree can be 2.75 feet from the point to still be included in the point's tally" (Avery and Burkhart 2002).

In 2008, we selected 4 anthropogenic structures (cistern, building 764, house, building 104) used as roosting sites by *C. rafinesquii* for collection of temperature data. For the cistern, building 764, and the house, we placed one iButton® (Maxim Integrated Products, Sunnyvale, CA) where bats had been observed roosting and another on the north side of a neighboring tree to collect ambient temperatures. The cistern was approximately 5.2 by 1.5 by 1.8 m in size and contained water 0.5 m deep year round. Building 764 was an aboveground concrete outbuilding approximately 4.5 by 4.5 by 3.0 m in size. The abandoned single-level, eight-room house overrun with vegetation, mostly wisteria (*Wisteria* sp.), was located off the military base. Because we discovered this roost on the last day of surveys in 2008, we placed the temperature data logger in a room adjacent to the one where bats were roosting to avoid disturbance. We placed temperature data loggers in three portions of building 104. This building roost was a large, old, three-story storage barn used for military training. Because bats had been observed roosting in all three portions of the building, we placed temperature data loggers in the attic, on the ground floor, and in the cinder block basement. We deployed iButtons® (programmed to record temperature every 2 hours) at the end of May, and we retrieved them on October 2, 2008. We checked structures periodically for bat use throughout the time that iButtons® were operating.

Landscape features such as distance to streams have been shown to be good predictors of roost selection by bats (Clark 1990, Kurta and others 2002, Watrous and others 2006). Therefore, we used Mann-Whitney U tests to examine differences between roost types in distance to significant landscape features, e.g., water, roads, firebreaks. Mann-Whitney U tests were also used to compare differences in number of roosts used between sexes and in tree size by genus. We used a Kruskal-Wallis test to compare temperature differences among three levels of roosts in building 104 and used Student's t-tests to examine differences between two different anthropogenic structure roosts and their associated ambient temperatures when bats were and were not present in the roosts. We chose to use nonparametric tests for most analyses due to low and unequal sample sizes. We conducted statistical analyses using XLSTAT (Addinsoft USA, New York, NY) and SYSTAT (Systat Software, Inc., Chicago, IL). ArcView ver. 9.3 (Esri, Redlands, CA) was used to measure distances from roosts to landscape features.

RESULTS

From 2004 to 2009 we made 840 bat observations, i.e., captures, recaptures, and visual observations, on Camp Mackall and Fort Bragg representing 10 species: 317 evening bats (*Nycticeius humeralis*, 37.7 percent); 234 red bats (*Lasiurus borealis*, 27.9 percent); 77 big brown bats (*Eptesicus fuscus*, 9.2 percent); 76 *C. rafinesquii* (first capture in 2006, 9.0 percent); 64 tri-color bats (*Perimyotis subflavus*, 7.6 percent); 54 Seminole bats (*L. seminolus*, 6.4 percent); 10 *Myotis austroriparius* (1.2 percent); 4 silver-haired bats (*Lasionycteris noctivagans*, 0.5 percent); 2 hoary bats (*Lasiurus cinereus*, 0.2 percent); and 2 Brazilian free-tailed bats (*Tadarida brasiliensis*, 0.2 percent). At Camp Mackall we captured 24 individual *C. rafinesquii* and made 76 observations of the species in trees and structures on and around the post. There were five captures in mist nets, but four of them were at a roost tree and three of the four were recaptures. Only one *C. rafinesquii* was caught in a mist net not placed near a roost. Of the 94 bats we banded, 18 were *C. rafinesquii* (4 adult males, 8 adult females, 4 juvenile males, and 2 juvenile females). We recaptured 39 percent of all banded *C. rafinesquii* (7 out of 18) with 58 percent of banded adults (7 out of 12) recaptured. We attached 11 transmitters to 9 individuals over 4 years (2 adult females were radio-tagged twice in 2 different years); bats A0798 and A0800 were lactating when radio-tagged on July 10, 2007, and pregnant when radio-tagged on May 29, 2008, and May 26, 2008, respectively. All remaining adult females fitted with radio transmitters were also reproductively active (one pregnant, two lactating, and one postlactating), but three adult males radio-tagged *C. rafinesquii* were nonreproductive.

We located 20 roosts used by *C. rafinesquii*, including 11 trees and 9 structures. Bats used an average of 3.0±0.3 (SE) roosts with a tracking duration between 3 and 7 days ($\bar{x}$ = 5) depending on year of sampling. Males (n = 3) used 3.7±0.9 roosts (range: 2 to 5), and females (n = 8) used 2.8±0.3 roosts (range: 1 to 4), although the difference was not significant (Mann-Whitney U = 11.5, P = 0.91). We recorded 31 roost switches over 38 tracking days (1 bat tracked for 1 day) or 1 switch every 1.2 days. Bats moved an average of 2.5±2.9 km (n = 18, range: 0.06 to 8.73 km) between roosts. Distances moved by bats were either < 1 km (n = 7), 1 to 2 km (n = 6), or 6 to 9 km (n = 5). Females moved greater distances than males (Mann-Whitney U = 12, P = 0.01), and pregnant females moved farther than lactating females (Mann-Whitney U = 30, P = 0.01). The number of bats observed in a roost ranged from 1 to 11. For many of the tree roosts, visual observation of bats was not possible due to small or nonexistent basal openings or because bats roosted above a bend in the tree and could not be seen. Counts of bats were taken in all structures except one building located on private property where we were denied access. However, an exit count conducted at this structure yielded seven bats. We attempted exit counts of tree roosts on Camp Mackall, but successful exit counts could not be completed due to the dense canopy. The roost housing the greatest number of bats (11 adults) was a tree that we netted in 2008, where 3 of the 4 captured were previously banded. The next largest group of bats was located in 2009 and consisted of 10 bats (building 104: 5 adult females and 5 prevolant pups). Two of the five adults were recaptures from 2007. We banded the remaining eight bats, and one adult female was radio-tagged. Mean body mass of the adult females was 8.6 g, and mean body mass of young was 5.0 g, suggesting that females were carrying 58 percent of their body mass on average when transporting pups among roosts during flight. No bat was observed in the building the following day, and the radio-tagged adult female was subsequently located in a roost tree that was 1.4 km from building 104.

We successfully located radio-tagged bats 67 percent of the time. Bats used trees and buildings similarly (47 percent and 53 percent, respectively; Mann-Whitney U = 55.0, P = 0.78). Of the 11 tree roosts, 9 were *Nyssa* spp. (6 *N. aquatica*, 1 *N. biflora*, 1 *N. sylvatica*, 1 *Nyssa* sp.), and 2 were *T. distichum*. Mean d.b.h. for all trees was 83.0 ± 6.7 cm, but *T. distichum* used as roosts were larger in diameter than *Nyssa* spp. (Mann-Whitney U = 0, P = 0.04) (table 1). Of the 11 trees, 10 were live and possessed interior cavities, i.e., live-damaged. The one snag was a *Nyssa* spp. that contained an interior cavity. Of the nine anthropogenic structures, five were aboveground and four were underground. The aboveground roosts were abandoned buildings previously used for human lodging (n = 2) or animal shelters and storage of farm equipment (n = 3). Underground roosts were a cistern and a well that both contained water, a crawl space under a concrete slab that was previously the floor of a building, and a dry concrete culvert.

All roost trees were in bottomland hardwood forest, as opposed to anthropogenic structures which were located in upland habitats, i.e., developed and cleared upland pine forest/savanna. Of the four landscape feature distances we

Table 1—Characteristics of roost trees used by *Corynorhinus rafinesquii* and distances of roosts to selected landscape features on and around Camp Mackall, NC, 2006 to 2009

Roost characteristic	Mean ± SD	Minimum	Maximum
Nyssa sp. (n = 9)			
Diameter at breast height (cm)	75.1±5.1	56.5	104
Height of tree (m)	19.3±0.7	17	21
Taxodium distichum (n = 2)			
Diameter at breast height (cm)	119±2.8	116	121
Height of tree (m)	22.5±2.5	20	25
Diameter at breast height (cm)			
All other trees in plot (n = 152)	44.5±21.1	5.5	113
All other *Nyssa* spp. (n = 61)	43.7±18.5	19.0	96.0
All other *T. distichum* (n = 6)	63.6±35.2	16.5	112.5
All trees (m)			
Distance to capture site	938±199	60	1737
Distance to paved road	643±119	51	1210
Distance to firebreak	224±31.3	50	360
Distance to Drowning Creek	71.9±15.3	0	139
Structures (m)			
Distance to capture site	1530±742	0	5965
Distance to paved road	515±180	5	1420
Distance to firebreak	415±385	10	3495
Distance to Drowning Creek	1277±266	130	2960

SD = standard deviation.

measured, distance to capture site and distance to paved roads were not different between tree and anthropogenic structure roosts. However, tree roosts were closer than anthropogenic structures to firebreak roads (Mann-Whitney U = 87.0, P = 0.003) and Drowning Creek (Mann-Whitney U = 1.0, P < 0.0001).

Structures we selected for temperature monitoring housed at least one bat on at least one visit. The attic of building 104 possessed the highest maximum, the lowest minimum, and the highest daily mean temperatures among all structure roosts sampled (table 2); each of these statistics was outside

Table 2—Weekly maximum, minimum, and average temperatures of anthropogenic roosts of *Corynorhinus rafinesquii* from May 27 to October 1, 2008, on and around Camp Mackall, NC

Roosting site	Average weekly maximum (n =16)	Average weekly minimum (n =16)	Average for time period (n =1530)
Building 764	34.4±2.5[b]	21.9±2.5[b]	27.1±4[b]
Cistern	32.4±2.7[b]	22.7±1.9[a]	27.0±3.6[b]
House	28.7±2.5[b]	19.3±2.4[b]	24.3±3.3[b]
Building 104 attic	51.2±3.9[a]	18.3±2.9[c]	29.9±9.5[a]
Building 104 ground	31.6±2.6[b]	19.3±2.6[b]	25.4±3.8[b]
Building 104 basement	27.5±1.5[b]	21.2±1.7[b]	24.2±2.3[b]

[a,b,c] Within columns, means without common letters are significantly different ($P < 0.05$).

the 95-percent confidence limits of temperature data for all structures combined. Temperatures in the attic of building 104 spanned the greatest range (16 to 57.5 °C) among the buildings sampled. The basement of building 104 had the lowest range in temperatures (16 to 29.5 °C) of the building roost sites, suggesting it was the most thermally stable roosting location among the structures measured. The different temperature regimes within building 104 may provide important roost choices for bats at different times of the year. The only other building for which we recorded temperatures exceeding the 95-percent confidence limits was the cistern, which possessed the highest mean daily low temperatures recorded among the building roost sites.

Differences in temperatures among the three levels of building 104 were significant, and bat use varied with these temperature changes. During the day, the attic temperature was higher than the ground floor which in turn was higher than the basement temperature (fig. 1). An adult female (A0800) was observed using the attic of this roost while pregnant on May 27, 2008, where a maximum temperature of 46.0 °C and a minimum of 24.5 °C were recorded. On September 29, 2008, this individual, then postlactating, roosted in the basement of this building where the maximum temperature was only 23.0 °C and the minimum temperature was 20.5 °C. A comparison of all temperatures associated with the building in May showed a difference among levels (K = 7.12, df = 2, P = 0.03, n = 9) where the attic temperature was warmer than the basement (Bonferroni corrected significance level: 0.0167). In September, we observed a marginal difference among the temperatures in the three roosting areas of this building (K = 6.18, df = 2, P = 0.05, n = 21), where the attic temperature was warmer than the basement (Bonferroni corrected significance level: 0.0167). The pattern across sampling seasons was similar, with the attic warmer than the other levels of the roost structure (fig. 2). On October 1, 2008, we found no bat present, and there was no difference in temperatures (K = 3.55, df = 2, P = 0.17, n = 21).

Data for temperatures of two other structures (cistern and building 764) indicate that bats used these roosts without apparent association with roost temperatures. These two roosts

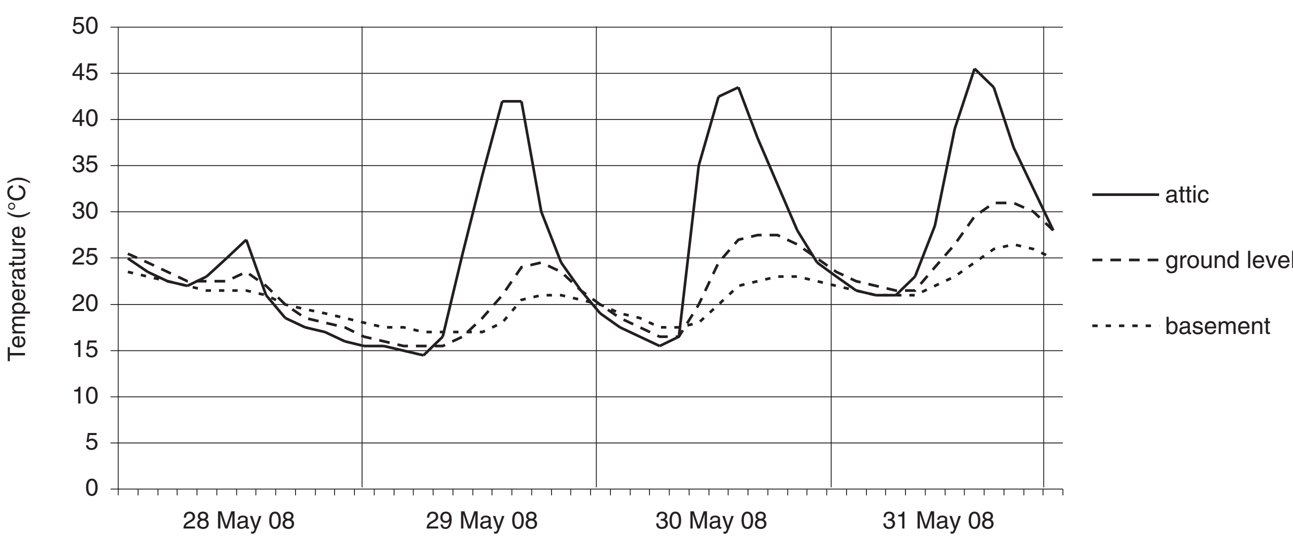
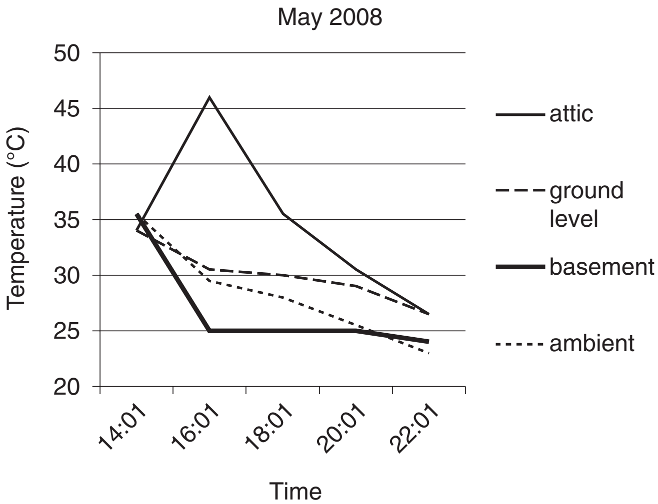


Figure 1—Temperatures in roost building 104 on 4 calendar days when bats were using the roost in May 2008 on Camp Mackall, NC. Each line represents temperature data collected with one iButton® per level.



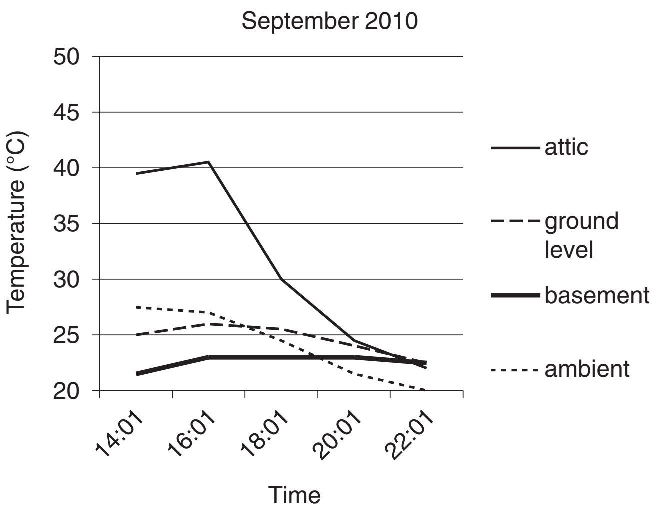


Figure 2—Temperature profiles associated with building 104 on days when a female *Corynorhinus rafinesquii* was roosting inside on Camp Mackall, NC. iButton® was placed at noon on May 27, 2008, so first hour of the top graph represents acclimation to the environment.

were used by the same bat a few days apart and were checked on 2 days when no bats were present (table 3). On May 30, 2008, one male (A0701) and one pregnant female (A0798) *C. rafinesquii* (both radio-tagged) were found roosting in the cistern when the average roost temperature was lower than the average ambient temperature ($t = 3.2$, $P = 0.018$) and where maximum and minimum temperatures of 27 and 19 °C were recorded in the roost, respectively. The cistern was again cooler than ambient the next day ($t = 3.97$, $P = 0.007$) where maximum and minimum roost temperatures of 29 and 22 °C were recorded, but only the male was present (the female had moved to the barn). The male then moved to concrete building 764 on the third day where there was no difference between the building temperature and the outside air ($t = 0.72$, $P = 0.5$), and a maximum temperature of 32.0 °C and a minimum of 25.5 °C were recorded in the roost. The cistern was checked on 2 days during the summer, but no bat was observed on either day. There was no difference between the cistern and ambient temperatures on July 18, 2008 ($t = 0.34$, $P = 0.75$) or on July 22, 2008 ($t = 0.39$, $P = 0.71$).

DISCUSSION

During a 6-year study at Camp Mackall and Fort Bragg, we documented the presence of 10 bat species. We discovered a colony of *C. rafinesquii* only at Camp Mackall. Only a single *C. rafinesquii* was captured during extensive netting efforts within suitable habitat, with all other captures of this species made in or near roost sites. Monitoring population sizes of a highly mobile species that switches roosts often can be difficult (Clark 2000, Clark and others 1997, Gooding and Langford 2004, Lance and others 2001, Trousdale and others 2008). Relative to overall capture effort, however, our recapture rate was high, suggesting that the population of *C. rafinesquii* in the study area was small. The largest group we observed had 11 individuals; a small but not uncommon colony size across the range of the species (Barbour and Davis 1969, Jones and Suttkus 1975). The apparent local rarity of *C. rafinesquii* at Camp Mackall may be due to one or more factors including scarcity of food resources, higher rates of mortality, or limited roost availability. Future studies identifying availability of food resources and predation pressures would contribute to an understanding of the limits to the size of this population. We suggest that observations made in this study support the limited roost availability hypothesis. Several adult females were recaptured in multiple years, but no banded juvenile was identified after initial capture. Recapture of adults and not juveniles may indicate low survival rates or dispersal of juveniles out of the population. A study by Jones and Suttkus (1975) supports our conclusion of a small colony size at Camp Mackall by documenting recaptures of both adults and juveniles in larger colonies of *C. rafinesquii* in Louisiana and Mississippi.

Limited availability of natural roosts has been suggested as a reason for use of artificial roosts throughout the southern range of the species (Bennett and others 2008); however, it is likely that *C. rafinesquii* has used anthropogenic structures as long as structures have existed in the range of the species (Audubon 2003, Dalquest 1947, Handley 1959). Many buildings potentially used by bats were once scattered across Camp Mackall, as evidenced by the presence of numerous concrete foundations, but were removed after acquisition of the property by the military. In addition to the loss of anthropogenic roosts, many large trees were removed from the study area as part of the extensive timber harvests conducted

Table 3—Average daytime temperatures and SD (0800 to 2000 hours; *n* = 7 readings) of selected roosts of *Corynorhinus rafinesquii*, with and without bats present, on, and around Camp Mackall, NC, 2008

Roost	Date	Bat	Temperature (°C)		*P*-value
Cistern			Cistern	Ambient	
	May 30, 2008	F[a], M[b]	23.6±3.4	27.8±5.5	0.02
	May 31, 2008	M	25.7±3.1	30.2±4.9	0.01
	July 18, 2008	No bat	27.6±1.6	27.3±2.5	0.75
	July 22, 2008	No bat	31.2±3.2	32.1±6.1	0.71
Building 764			Building 764	Ambient	
	June 1, 2008	M	28.9±2.3	31.0±7.1	0.50

[a] F = pregnant female; [b] M = adult male.

in bottomland hardwood forests across the Southeastern United States (Tiner 1984). The forests on Camp Mackall were extensively logged up to the early 1980s.[1] The presence of large stumps throughout the area suggests that historical vegetation included large trees that likely provided more suitable roosts for *C. rafinesquii*. Roost trees used by this species at Camp Mackall were the largest trees measured. Trees in the current forest may just now be reaching sufficient size to develop cavities used as roosts by this species. Mean d.b.h. of roost trees were smaller than reported in some studies (129±7.3 cm, Carver and Ashley 2008; 120±3.5 cm, Gooding and Langford 2004) but similar to others (59 to 103 cm, Lance and others 2001; 81.9±25.4 cm, Rice 2009; 79.4 cm, Trousdale and Beckett 2005). The colony of *C. rafinesquii* at Camp Mackall may be either a recently established colony or a remnant population from a historically larger assemblage. Assuming the number and condition of anthropogenic structures remain the same and the forest continues to mature and additional roosts become available, a larger population of *C. rafinesquii* may be supported on Camp Mackall, especially if roost availability is the limiting factor to population size of this species in the area.

Anthropogenic structures may be important for maintaining populations of *C. rafinesquii* where natural roost sites are severely limited. The ratio of natural to anthropogenic roosts used by *C. rafinesquii* varies considerably across the range of the species (Carver and Ashley 2008, Clark 1990, Clement and Castleberry 2008, Harvey and others 1999, Jones 1977, Lance and others 2001). The ratio of trees to structures used as roosts by *C. rafinesquii* in this study was 11 to 9, a ratio consistent with Trousdale and Beckett (2005) (14 trees to 11 structures) but unlike those of any other reports cited. Furthermore, an area on Fort Bragg (Overhills) containing > 20 abandoned buildings adjacent to a reservoir bordered by very young stands of *T. distichum* ($\bar{x}$ d.b.h. ca. 21 cm) never housed *C. rafinesquii* during searches from 2004 to 2009. These observations along with other studies (Clark 1990, Lance and others 2001, Trousdale and Beckett 2005) support the hypothesis that anthropogenic structures are functional as roosts of *C. rafinesquii* only in association with natural roosting habitat.

Radio-tagged *C. rafinesquii* were not located on 33 percent of transmitter days, i.e., one transmitter active for one day, but signals were often heard following a period of absence. Bats may have used underground structures in upland habitats on days when a radio signal was not detected (England and others 1990, Hoffmeister and Goodpaster 1963, Martin and others 2006). We found roosts for *C. rafinesquii* in four underground structures on the base. Cisterns and other underground structures that could be used by bats were widely scattered across the landscape and difficult to locate. The role that underground structures serve in the study area, as a component of the functionality of anthropogenic roost structures, is not fully understood and is a subject in need of further study.

Anthropogenic structures may offer similar temperature conditions to tree roosts (Rice 2009) but provide more space for maneuverability to escape predation (Clark 1990), greater roosting choices for thermoregulation within the same roost (Hoffmeister and Goodpaster 1963), and potential to switch thermal environments during day roosting without exposure to daytime predators. Regardless, temperature regimes of roost sites and the effect on roosting behavior of *C. rafinesquii* remain poorly understood. For example, two pregnant females during late May used two very different roosts with regards to temperature. Bat A0800 roosted in the hot attic of building 104 while bat A0798 used the much cooler cistern. The following day, bat A0798 moved to the barn where temperatures were probably more similar to building 104. We suggest this movement between thermally different roosts may have occurred to avoid prolonged torpor conditions. Similarly, *C. rafinesquii* may use the same roost throughout the year but use thermally different portions of the roost among seasons (Hoffmeister and Goodpaster 1963, Hurst and Lacki 1999). Bat A0800 that roosted in the hot attic of building 104 demonstrated this behavior by choosing the cooler basement within the building later in

[1] Personal communication. 2010. Steve Riley, retired Forester, Ft. Bragg, NC 28310.

the year after her pup was presumably volant. Pregnancy is energetically expensive (Racey 1973), so this bat may have chosen the warmer roosting conditions to passively rewarm prior to exiting the roost to feed at night (Winchell 1990). As with other species (Parkinson 2008), female *C. rafinesquii* may select warmer roosting conditions to avoid torpor when pregnant. Bats in torpor have a slower metabolic rate and, therefore, contribute fewer resources to a growing fetus under such conditions (Racey and Swift 1981). Later in the year, when the young are volant and the demands of reproduction have ceased, warmer roosts may be unnecessary or even counterproductive. Cooler roosts selected by bat A0800 later in the year may have provided an energy savings by permitting this bat to enter torpor during a period of lower temperatures when food availability was likely reduced.

Although roost quality depends in part on temperature regime, distances to landscape features used as flight corridors or feeding and drinking sites are also important (Clark 1990, Kurta and others 2002, Watrous and others 2006). Roost trees were located closer to Drowning Creek and firebreak roads than anthropogenic roost structures were to these features. This was due to buildings not being placed within the bottomland hardwood forest along Drowning Creek to avoid the potential of flooding. Nevertheless, proximity to permanent water has been suggested as an important habitat characteristic in selection of roosts by *C. rafinesquii* by enhancing access to food resources and drinking water (Clark 1990, Gooding and Langford 2004). Permanent water in the form of creeks or rivers can also provide flyways for these bats. Firebreak roads may provide flight corridors for commuting between roosts and foraging areas. Thus, roosting closer to these features should be advantageous to these bats. We suggest that use of anthropogenic structures by *C. rafinesquii* on Camp Mackall, situated farther from water and firebreak roads, may offset these distance constraints through advantages in maneuverability inside roosts and access to diverse temperature regimes.

We found distances that bats moved between roosts varied between sexes and reproductive condition classes. For example, males moved shorter distances between roosts than females. It is possible that males have fewer constraints and, thus, can use roosts that are less suitable for females. Roosts with lower temperatures may allow males to enter torpor and provide an energy savings advantage not available to reproductively active females that require warmer roosts for fetus development (Racey and Swift 1981). Thus, males may have more roosts available to them than females, and the need for longer movements is unnecessary. As documented in other species (Kurta and others 2002), lactating females moved shorter distances between roosts than pregnant females. Females with nonvolant young may move shorter distances due to the additional weight of the young. At least one female was documented transporting a pup exceeding 50 percent of her body mass > 1 km to another roost. This is consistent with a report by England and others (1990) who observed that female *C. rafinesquii* transport large juveniles (5 g) when disturbed or to seek more favorable roost temperatures.

Extensive habitat loss has placed bat populations at risk by reducing their population sizes to levels that will likely have difficulty resisting threats such as white-nose syndrome (*Geomyces destructans*) (Zimmerman 2009) and the rapidly growing use of wind turbines as an energy source (Baerwald and Barclay 2009, Cryan and Barclay 2009, Johnson and others 2003). A better understanding of habitat requirements is essential for creating and applying more effective protection strategies for remaining bat populations. Forests provide food and shelter to many bat species, but in light of extensive logging practices and urban development throughout the range of *C. rafinesquii* in the last century (Marks and Marks 2006), management and preservation of anthropogenic structures and construction of artificial roosts will likely play an important role in the protection of populations of this species in human-altered environments. For example, bat houses specifically designed for *C. rafinesquii* erected near existing roost trees are used more readily than ones placed farther from known tree roosts (Bayless 2008). We found that bats moved farther from tree roosts and Drowning Creek to roost in anthropogenic structures on Camp Mackall and suggest that placing artificial roosts in the vicinity of known tree roosts may be beneficial in providing additional roosting habitat. Structure roosts alone, without a suitable forest component, are not likely to provide long-term support for the population of *C. rafinesquii* on Camp Mackall as demonstrated by the uninhabited buildings and unsuitable trees at Overhills on Fort Bragg. Due to the limited availability of bottomland hardwood forest at Camp Mackall, we encourage land managers to consider sustaining large (d.b.h. > 85 cm) hollow trees of appropriate species, such as *T. distichum* and *Nyssa* spp. We believe such an approach can be integrated into the management practices currently in use and will provide suitable roosting habitat needed to maintain future populations of *C. rafinesquii* on Camp Mackall.

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