Summer Roosting Ecology of Northern Long-eared Bats (*Myotis septentrionalis*) in the White Mountain National Forest

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ABSTRACT

We studied the summer roosting ecology of female northern long-eared bats in the White Mountain National Forest of New Hampshire, and examined the importance of snag and stand characteristics at bat roosting sites. Radio-transmitters were used to track 26 northern long-eared bats to 47 roost trees; 39 (66%) were in snags. Roosts were in 14 *Fagus grandifolia*, 13 *Acer saccharum*, 8 *Betula alleghaniensis*, 6 *Acer rubrum*, and 5 other species. Roost snags were larger in diameter (mean = 41 cm; p = 0.007), taller (mean = 14.8 m; p < 0.001), had more bark remaining (mean = 78%; p = 0.039), and were less decayed than random samples of snags in the surrounding area. Characteristics of the surrounding stand were also related to roost sites; live trees had larger diameters (p = 0.002) and there was more snag basal area (3.9 m²/ha) in roost plots than the surrounding forest. We surveyed potential roost trees (n = 104) for bat activity in 1994 using ultrasonic bat detectors; 28 had bat activity and five were visually confirmed as roost trees.

INTRODUCTION

Roosts are critical habitat for bats; their availability may limit the number and distribution of certain species (Humphrey 1975). Roosts provide sites for hibernation, mating, rearing of young, and protection from weather and predators (Kunz 1982). Although specific information is minimal concerning summer roosting ecology of many New England bat species, most roost in tree cavities, crevices, man-made structures, and occasionally caves (Godin 1977).

Bats have low reproductive rates and long regeneration times, traits that make them vulnerable to population declines caused by high mortality or low recruitment (Hill and Smith 1984). Females of several species using the White Mountain National Forest (WMNF) form large groups (maternity colonies) during the summer, while males are thought to live singly or in small groups (Godin 1977). Thus, the habitat preferences of female bats may be disproportionately more important than that of males, because loss or

alteration of the habitat used by females may reduce recruitment. Therefore, the availability and protection of roosts meeting the needs of female bats may be critical in assuring the long-term survival of bat species.

There is scant information available on the particular habitat needs of female bats in New England, and none specific to the WMNF. Therefore, it is important to study the summer roosting ecology of bats in this area to understand the impact of timber harvests and wildlife management decisions that could affect the location and availability of habitat suitable for the rearing of juvenile bats. Knowledge of the ecology of tree-roosting bats is increasing, but most research relative to species of New England has occurred in the midwest (e.g., Constantine 1966; Kunz 1973; Caire et al. 1979; Gardner et al. 1991). No studies have investigated the summer roosting ecology of the northern long-eared bat (NLE) in New England, and except for the preliminary results of Foster (1993), published roost information concerning this species in forest habitats has come from accidental locations of single colonies rather than from planned studies (e.g., Brandon 1961; Mumford and Cope 1964; Cope and Humphrey 1972; Clark et al. 1987).

METHODS

This study was conducted in northern New England on the WMNF, which consists of 304,050 ha of land, approximately 97% forest. Nearly half the forest (139,300 ha) is open to timber management. Even-aged silviculture has been the primary management tool for the WMNF in the past, although recent practices have reduced clearcut sizes to a maximum of 12 ha. Currently, only about 1% of the managed half of the forest is under uneven-aged management, but this is expected to increase to 23% in the future. The WMNF is fairly mature, with the 70–89-year-old age class dominant, comprising 33% of the timber available for management (USDA Forest Service 1986).

Brooks et al. (1987) estimated that the most abundant timber type in northern New Hampshire was northern hardwoods (48%), such as sugar maple (*Acer saccharum*), beech (*Fagus grandifolia*), and yellow birch (*Betula alleghaniensis*), with spruce/fir (*Picea* spp./*Abies* spp., 26%) and pine (*Pinus* spp., 14%) comprising most of the remaining forest stands. The majority of northern hardwood stands (63%) are in the sawtimber size class, as are spruce/fir (48%) and pine (72%) stands (Frieswyk and Malley 1985).

We captured bats using mist nets placed across old roads, trails, and streams that are used as travel corridors leading to feeding areas, such as wetlands (Kunz and Kurta 1988). Trap sites were at least 1 km from developed areas to reduce the possibility of capturing bats that roosted in buildings. Nets were set before dusk and monitored every 10 minutes until dawn or capture of two female NLE weighing >7 g. Captured bats were identified to species and sex. Their reproductive state (based on palpation of the abdomen), mass, and time of capture were noted. Individuals were classified as adult or juvenile based upon the degree of ossification of the epiphyseal plates in the finger bones (Anthony 1988).

Females weighing >7 g were fitted with 0.65–0.8-g radio-transmitters

(Holohil Systems Inc., Carp, Ontario, Canada) glued on a shaved portion of the bat's upper back using Skin Bond (Pfizer Hospital Products Group Inc., Largo, Florida, U.S.A.; Wilkinson and Bradbury 1988). Each bat was located at a day roost using a Model TR-4 radio-telemetry receiver (Telonics, Mesa, Arizona, U.S.A.) and two- or three-element Yagi antennae. We counted bats leaving roost sites at dusk to estimate colony size and confirm roost location. The minimum distance between NLE roost and foraging area was estimated by measuring the distance from the site where a bat was captured to its roost tree (Brigham 1991).

Vegetative characteristics of roost sites were measured using variable-radius plots determined with a 10 basal area factor prism. Plot size varies with this technique based on the distance from the centre of the plot to the tree being measured. The diameter at breast height (DBH), height, and snag class of each roost were measured. A clinometer was used to measure tree height to the nearest 0.3 m. To be considered a snag, a tree had to be completely dead with no live branches. The percentage of bark remaining on the tree was visually estimated. Numerous studies have assigned snags into decay classes based on external characteristics of the snag in relation to wildlife use (e.g., Runde and Capen 1987; Welsh and Capen 1992; Bull and Holthausen 1993). Snags were placed into one of five classes based on the degree of decay of the tree (Table 1, modified from Cline et al. 1980 and Carbonneau 1986).

Measurement of the surrounding stand and forest included three levels of sampling. Roost-tree plots were centred on the roost, or if there were two roosts within 10 m of each other, the plot was centred between them. Four plots (stand plots) were located 60 m north, south, east, and west of the roost tree. Data from roost plots and associated stand plots were also combined to represent the roost stand. In cases where roost trees were within 60 m of each other, they were considered to be within the same stand, and the four stand plots were used for all roosts within that stand. Live and dead trees in the forest around the roost tree were sampled with four 1-km transects within the 1 km² around the roost. If several roost sites were within the same 1-km² block, the same transect plots were used for comparison with all roost plots and roost stand plots within that block. Transect plots were sampled every 200 m along the transect, yielding a total of 24 plots/km².

Species and diameter of all trees >10 cm DBH were recorded in all plots. All snags were measured using the same methods as for roost trees. Percentage of canopy coverage in each plot was measured with an ocular

TABLE 1 *Characteristics of snag classes based on increased degree of decay used to classify snags in the White Mountain National Forest, 1993–1994 (modified from Cline et al. 1980 and Carbonneau 1986).*

Class	Description
1	Recently dead. Still retains small twigs and branches.
2	No longer has small twigs.
3	Retains large branches >2 m in length.
4	No large branches and is >6.5 m tall.
5	No large branches and is <6.5 m tall.

tube; one estimate was recorded 5 m from the centre of the plot in each of the cardinal directions. The average canopy coverage for the entire plot was calculated from these four measurements.

Basal area (m²/ha) of live and dead stems was computed for roost-tree plots, roost stands, and the surrounding forest. Measurements of basal area for each roost-tree plot within a single stand were treated as separate samples, and a composite basal area was computed from them to represent the basal area of the roost-tree plot of each stand. The same was done for the roost stand plots and forest transect plots.

Differences in snag DBH, height, bark remaining, and snag class in roost plot, roost stand plot, roost stands, and forest transect plots were tested using the General Linear Model ANOVA module of the Systat for Windows statistical package. Comparisons of live tree diameter, canopy closure, and basal area between these groups were similarly made with this program. Pairwise comparisons between groups were made using Tukey tests. Differences in colony size and foraging distance were also made using the General Linear Model ANOVA. Statistical significance for all tests was set at the $p < 0.05$ level. We present data as means ± 1 SE.

A pilot study was initiated in 1994 to investigate the usefulness of bat detectors as tools for locating roost trees. Broadband ultrasonic bat detectors (Anabat II) linked with sound-activated microcassette tape-recorders were used to sample bat activity at potential roost trees (Krusic 1995). These systems were contained within watertight boxes and were raised into the air with ropes slung over snag branches as close to cavity openings as possible. Detectors were placed at snags about 45 minutes before dusk and left in place for one hour. Tapes were then analyzed for the presence of bat vocalizations. At snags with bat activity, observers returned the next night to perform an exit count to confirm bat roosts. Echolocation calls were recorded at confirmed roost trees with more sensitive tape-recorders, and bats were identified to genus using the Bat Tools software program developed by C. Neefus and R. Krusic at the University of New Hampshire.

Based on 1993 roost-tree data, five criteria were used to describe potential roost trees:

1. The tree was completely dead.
2. DBH was >25 cm.
3. Snag height was >6.5 m.
4. The snag retained branches from which to hang detector boxes.
5. There was a visible cavity or crevice.

Transects were laid out through the forest at elevations similar to 1993 roost sites to identify snags that met these characteristics. The DBH, height, and snag class were measured on potential roost trees. We located 104 snags (53 softwood, 51 hardwood) along 31 transects totalling about 4 km in length.

RESULTS

We trapped 281 bats during 87 nights at 18 sites during a total of 752 net-hours. The most common species were the little brown bat (108

individuals, 71%) and northern long-eared bat (75 individuals, 27%). Three big brown bats (*Eptesicus fuscus*), two red bats (*Lasiurus borealis*), two hoary bats (*Lasiurus cinereus*), and one silver-haired bat (*Lasionycteris noctavagans*) were also captured.

One pregnant *M. septentrionalis* was captured in 1993 (7 July); eight pregnant individuals were captured from 8 June to 1 July, and a lactating female was captured on 11 and 25 July 1994. The first juvenile *M. septentrionalis* was captured on 3 August 1993 and on 22 July 1994. Based on this information, we estimated the date of parturition as 2 July. There were no captures of reproductive *M. lucifugus*, but maternity colonies existed because juveniles were captured on 26 July 1993, and 23 and 31 July 1994.

We affixed radio-transmitters to 32 *M. septentrionalis* of which 26 (81%) were relocated at their roost sites. Forty-seven roost trees were found; 14 beech, 13 sugar maple, 8 yellow birch, 6 red maple (*Acer rubrum*), 2 big-tooth aspen (*Populus grandidentata*), and 1 each of black cherry (*Prunus serotina*), hemlock (*Tsuga canadensis*), paper birch (*Betula papyrifera*), and white ash (*Fraxinus americana*). Sixty-six percent (39) of the roosts were in snags. Some roost sites were "clustered" together, rather than dispersed in a random pattern throughout the forest.

Bats tended to move often between roost sites, which presumably affected the number of bats observed at exit counts. Bats were relocated an average of 4.5 times (range 1–16) over 1–19 days (mean = 8 ± 5.2); the mean number of roost sites per bat was 2.2 (range 1–5). Two roosts located in 1993 were also used by similarly sized groups in 1994. At roosts where bats were observed and exit counts were performed more than once, 38% were occupied more than half the time, only 17% were used continuously. The mean distance between *M. septentrionalis* foraging areas and roost trees was 602 m (SE 66.6, range 60–1719 m).

We performed exit counts at 43 of 47 roost trees. Bats were only seen at 29 of 47 sites because foliage obscured visibility at certain trees. Thirty-five (75%) roosts at which exit counts were done were used by <10 bats, 11% were used by 11–24 bats, and 15% were occupied by >24 bats. The maximum group size was 36 bats observed at two separate roosts. There were no significant differences in DBH, bark remaining, height, or snag class between snags used by groups of more than 10 bats than those used by smaller groups. There was no difference in maximum group size in live versus dead trees, but five of seven roosts with >24 bats were in snags. The average group size significantly decreased after parturition, falling from 10.8 ± 2.6 to 3.5 ± 1.6; p = 0.021.

Roost snags had larger diameters, greater height, more bark, and lower snag-class values than did available snags (Table 2). Live trees in roost-tree plots had larger DBH than did live trees in transect plots (Table 2). Canopy closure of roost stands was significantly lower than in available stands (p = 0.019), most roost trees were located in stands that had >75% canopy cover. Snags in roost stands were taller and had lower-class values than snags in available stands. There was no difference in mean snag DBH between roost plots, stand plots, and transect plots, although mean DBH of live trees in roost stands was greater than that in available stands (Table 2).

Comparison of all snags in roost plots, roost stand plots, and forest transect plots revealed significant differences in snag height and snag-class values (Table 2). Bats roosted in plots with taller snags than found in the

TABLE 2 *Comparison of physical characteristics of* Myotis septentrionalis *roost and available sites in the White Mountain National Forest, 1993–1994.*

Level of comparison	Snag DBH (cm)		Snag height (m)		Snag bark (%)		Snag class		Canopy (%)		Live DBH (cm)		Snag basal area (m²/ha)	
	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
Snag														
Roost	40.9	2.8	14.8	1.0	78	5.6	2.8	0.3	83	1.4	n/a	n/a	n/a	n/a
Available	33.0	1.0	8.8	0.4	66	1.9	3.7	0.1	86	3.5	n/a	n/a	n/a	n/a
p-value	0.007		< 0.001		0.039		0.001		0.513		n/a	n/a	n/a	n/a
Plot														
Roost	36.4	2.0	12.2[a,b]	0.7	71	4.0	3.2[a]	0.2	83	3.5	30.8[a]	0.6	3.9[a,b]	0.3
Stand	32.2	1.7	8.0[a]	0.6	68	3.5	3.6	0.2	82[a]	2.2	29.8	0.4	2.3[a]	0.3
Transect	33.5	1.3	8.6[b]	0.5	64	2.6	3.8[a]	0.1	88[a]	1.7	28.8[a]	0.3	1.9[b]	0.3
p-value	0.254		< 0.001		0.138		0.02		0.06		0.001		< 0.001	
Stand														
Roost	34.0	1.3	10.4	0.5	71	2.6	2.8	0.1	82	1.9	30.1	0.3	n/a	n/a
Available	33.5	1.3	8.6	0.5	64	2.6	3.4	0.1	88	1.7	28.8	0.3	n/a	n/a
p-value	0.754		0.01		0.08		0.04		0.019		0.001		n/a	n/a

[a,b] Tukey test indicated a significant difference between these groups ($p < 0.05$).

surrounding stand ($p = 0.002$) or forest ($p < 0.001$). There was no difference in the degree of decay of snags in roost and roost stand plots, but roost plots had less decayed snags than did forest transect plots ($p = 0.014$). Live trees in roost plots were significantly larger than those in forest transect plots ($p = 0.002$; Table 2).

There were differences among snags used for the above comparisons. Hardwood snags were taller (mean 11 m ± 0.3) than softwood snags ($p < 0.05$), but softwood snags (mean 3.1 ± 0.2) were less decayed than hardwood snags (mean 3.7 ± 0.1; $p = 0.003$). However, there were no significant differences in snag height or bark remaining between hardwood and softwood snags.

There were no differences in the amount of hardwood, softwood, or total live-tree basal area between roost plots, roost stands, and the surrounding forest, but there was significantly more total snag basal area in roost plots than elsewhere. Bat-roost stands had significantly more live hardwood (mean 18.1 m²/ha ± 1.5) than softwood basal area (mean 8.8 m²/ha ± 3; $p < 0.001$).

We placed bat detectors at 104 snags from mid-July through mid-August 1994. Echolocation calls were recorded at 28 snags (27%), of which five (5%) were visually confirmed to be roost sites. Three of the confirmed roosts were in hardwood trees (yellow birch, paper birch, and red maple). Two roosts with confirmed use by *Myotis* bats were in white pine (*Pinus strobus*) and hemlock, both having low canopy closures (25% and 0%). When only confirmed roosts were considered, 3 of 41 (8%) snags > 45 cm DBH were used, while only 2 of 64 (3%) snags < 45 cm were used. Although our sample size was too low for statistical analysis, bats seemed to avoid small, older snags; class three and four snags < 45 cm DBH were not used.

DISCUSSION

The species of trees used by northern long-eared bats mirrored the basic composition of the forest in the White Mountains, which is dominated by northern hardwoods, such as beech, maple, and yellow birch. Females consistently roosted in areas with snags which were larger in diameter, greater in height, had more bark remaining, and were less decayed than those randomly available in the forest. Diameter and height of the roost tree are important characteristics of roosts of several vespertilionids (Barclay et al. 1988; Campbell 1993; other papers in this volume). The 1983 U.S. Forest Service inventory of timberland in northern New Hampshire (Brooks et al. 1987) found that 26% (sampling error = 8%) of hardwood trees >12.7 cm DBH with observed cavities were snags, However, 66% of *M. septentrionalis* roosts and most of those with high exit counts were in snags. Although snag preference is presumed, *M. septentrionalis* also roosted in locations with higher mean live-tree diameters, indicating that snag characteristics alone may not adequately describe their roosting ecology, and that stand-level characteristics may play an important role in roost choice. Because of the relative abundance of tree cavities, areas with large tree diameters are associated with increased bat activity and species diversity (Gerrell 1988; Thomas 1988).

Although *M. septentrionalis* used roost stands with lower canopy closure than those available, this may not be biologically significant because most of their roosts had >75% canopy closure. Measurements at ground level may overestimate the amount of canopy coverage at the roost cavity if small trees that shade the ground do not reach above the cavity. These visual estimates, as well as those of bark remaining on snags, may not have been discriminating enough to accurately measure these variables.

Our study represents an initial documentation of the use of a softwood (hemlock) tree as a roost site by *M. septentrionalis* bats. This tree represented only one of 47 *M. septentrionalis* roosts located via radio-telemetry, and an overall preference for hardwood snags is evident. Softwood basal area was only about half that of hardwoods and only a small percentage of that was attributable to snags. Hardwood snags also had larger diameters than softwoods; large diameter was a significant characteristic of roost trees of *M. septentrionalis.* The elevation of softwood stands may also preclude bats from using them as roost sites in this region because northern hardwoods generally predominate below 850 m, where most bats were captured (Leak and Graber 1974).

A northern long-eared bat and a little brown bat used the same yellow birch roost tree on different days in this study (Sasse 1995). While it is not unusual for several species to share hibernacula or roost sites in man-made structures, it is not often observed in tree-dwelling bats, and has only been reported once before for *M. septentrionalis* (Kunz 1982; Foster 1993). However, this behaviour may be more common than previously thought. The practice of conducting exit counts at tree roosts to determine colony size may require detection and identification of species-specific echolocation calls so as to discriminate between multiple species using the same roost site.

As the majority of bats captured on the WMNF were little brown bats, it is likely that the two *Myotis* roosts located with bat detectors were used by this species. Each of these roosts was located in an area with low canopy coverage, unlike those of *M. septentrionalis*, but similar to those of other *Myotis* bats near the extreme edge of their range (Kurta et al. 1993). Until the software used in analysis of bat vocalizations is capable of accurate identification, species determination will require capture of bats as they leave the roosts or internal examination of the roost.

Few studies have been performed in which individual trees were examined for bat use due to the difficulty of determining bat presence, as well as the small percentage of trees occupied at any one time. Gardner et al. (1991) scanned over 2,000 potential roost trees with a bat detector while creating a disturbance, but found only one Indiana bat roost. However, they later determined that bats do not always vocalize after a disturbance; thus, their results were likely conservative. Barclay et al. (1988) found 32 different silver-haired bat roosts by visually searching bark folds and other exterior crevices in trees within a 2 km² area in Manitoba. However, the total number of trees examined and the number of trees searched more than once was not given, so an estimate of usage rates cannot be made. Gysel (1961) studied animal use of 989 cavities in Michigan and estimated that 10% of cavities in beech/maple stands and none of those in oak/hickory stands were used by bats (species not reported). Silver-haired bats roosted behind the loose bark of only 2% of snags examined in a study on wildlife use of cavities in the upper Piedmont of South Carolina (Carmichael and Guynn 1983).

The underlying assumption of our pilot study was that snags without recorded bat activity are not roost sites, which may not be true in all cases. Since each potential roost tree was only surveyed once, it is possible that they were used on other occasions. If placement of the detector was such that it did not record the echolocation calls of bats departing from a tree, we may have overlooked roost sites. This could occur if a snag had multiple cavities or if the bat exited a cavity that was outside the detector's sensing range. This did happen on one occasion when a hand-held detector failed to record vocalizations from a bat exiting a cavity at the top of the tree, while picking up signals from bats leaving a cavity near the base. A false negative could also be obtained if the bats moved to a different roost after their calls were recorded the first night; thus, no bats would be observed at that snag when we returned on the following evening. Unwarranted follow-up exit counts are also caused by bats flying near the detector rather than exiting from the snag being studied.

The 5% occupation rate (based on actual observation) is probably lower than the true rate of potential roost-tree use. Results of our radio-telemetry data and other studies indicate that tree-dwelling bats often move between several roost sites, and although a particular snag is not occupied on one day, it may be occupied on another (Lewis 1995). Additionally, the sources of false negative results outlined above make it likely that more than 5% of potential roosts may be in use at any one time. The criteria we used in choosing snags to survey may not have been descriptive enough of potential roost trees, and with refinement to limit the number of snags that need to be surveyed, this technique could prove useful in locating roost trees of several different bat species.

Information about external attributes of roosts used by female northern long-eared bats will allow identification of habitat suitable for use by maternity colonies of this species, and perhaps other cavity-dwelling bats. Conservation efforts should focus on maximizing snag basal area in stands near foraging areas, such as wetlands, thereby providing bats with a number of tall, large-diameter snags with a range of microclimates and physical traits. Further research concerning the availability and distribution of suitable roosting habitat in managed and unmanaged areas of the forest in relation to elevation and foraging habitat may be warranted, and could necessitate changes in existing forest management standards for retention of snags and other wildlife trees in order to maintain bat population levels.

ACKNOWLEDGEMENTS

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