Forest Ecology and Management 257 (2009) 1200–1207

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Site-occupancy of bats in relation to forested corridors

Cris D. Hein [1], Steven B. Castleberry *, Karl V. Miller

D.B. Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA 30602, USA

ARTICLE INFO

Article history:
Received 19 May 2008
Received in revised form 25 September 2008
Accepted 29 September 2008

Keywords:
Bats
Bat activity
Corridors
Forest management
Occupancy
Pine plantation
South Carolina

ABSTRACT

Although use of corridors by some wildlife species has been extensively examined, use by bats is poorly understood. From 1 June to 31 August (2004–2005), we used Anabat II detectors to examine bat activity and species occupancy relative to forested corridors on an intensively managed forest landscape in southern South Carolina, USA. We compared bat activity among corridor interiors, corridor edges, and stands adjacent to corridors. We also compared models relating occupancy of bat species to site-level characteristics using an information theoretic approach. We identified 16,235 call sequences of 8 species and detected bat presence at 89% ($n = 320$) of sites sampled. Our results indicate higher occupancy rates for bats along corridor edges compared to interior corridor or adjacent stands. Although we found few differences among species with respect to site-level characteristics, occupancy of all bat species was positively associated with corridor overstory height and negatively associated with adjacent stand age. The presence of roads adjacent to corridors positively influenced occupancy of *Eptesicus fuscus*, *Lasiurus seminolus*, and *Perimyotis subflavus*. Our results suggest management practices designed to create and enhance corridors may represent an ecologically sound method for maintaining important bat habitat features (i.e., edge) across managed forest landscapes.

1. Introduction

The southeastern United States is undergoing unprecedented landscape changes caused by rapid growth in human population and urban expansion (Wear and Greis, 2002). Although the area covered by industrial forests in the southeastern United States is expected to remain relatively constant for the next 20 years (National Commission on Science for Sustainable Forestry, 2005), habitat alteration may continue if existing forest lands are converted to more intensively managed plantation systems that produce timber products more efficiently and economically (Wear and Greis, 2002). Increased intensity of forest management often results in shorter harvest rotations, loss of late-successional forests, and declining species diversity in local vegetation communities (Allen et al., 1996).

Creating forested corridors is a suggested approach for maintaining forest heterogeneity across fragmented landscapes. Juxtaposition of late-successional corridors within a mosaic of younger forests may help conserve native flora and fauna, provide wildlife habitat, protect water quality, enhance aesthetics, and facilitate wildlife movement (Hobbs, 1992). For bats, linear landscape features may provide greater insect abundance and availability, navigational references, protection from wind and predators, and roost sites (Limpens and Kapteyn, 1991; Verboom and Huitema, 1997; Estrada and Coates-Estrada, 2001; Hein, 2008; Hein et al., 2008).

Previous studies have identified positive associations between bats and linear landscape features (i.e., tree lines, hedgerows, streamside management zones, forested corridors). Two decades of field studies in The Netherlands indicate most bat species fly along linear landscape elements instead of crossing open areas (Limpens and Kapteyn, 1991; Verboom and Huitema, 1997; Verboom and Spoelstra, 1999; Verboom et al., 1999). In Britain, Walsh and Harris (1996) similarly report bats using linear features across a range of land classes and ownerships. Hedgerows and vegetated stream corridors provide connectivity for commuting and foraging bats to isolated forest patches in Mexico (Estrada and Coates-Estrada, 2001). In the southeastern United States, Hein (2008) document selection of corridors as roost-sites for both cavity- and foliage-roosting bats. However, the influence of forested corridors on bat activity in this region is still unknown.

Information on bat responses to various forest management practices in the southeastern United States is limited (Menzel et al., 2002; Elmore et al., 2005; Miles, 2006). Miller et al. (2003) recommended conducting research across an array of forest

* Corresponding author. Tel.: +1 706 542 3929; fax: +1 706 542 8356.
E-mail address: scastle@warnell.uga.edu (S.B. Castleberry).
[1] Present address: ABR, Inc., P.O. Box 249, Forest Grove, OR 97116, USA.

0378-1127/$ – see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.foreco.2008.09.054

landscapes to examine impacts of different harvest strategies on bat populations. Our goal was to investigate the relationship between bats and forested corridors in an intensively managed landscape. Because corridors are relatively narrow features, bat activity is likely impacted by adjacent stands. Furthermore, bat activity may be influenced by nearby roads and distance to water. Therefore, we examined the influence of site-level characteristics to determine which corridors provide suitable habitat for bats. Based on ecomorphology of bat species (Aldridge and Rautenbach, 1987), we predicted less maneuverable bats that use low-frequency echolocation would have higher occupancy in open habitats (i.e., open-canopy adjacent stands). We predicted higher occupancy for high-frequency, highly maneuverable bats in forested corridors. Finally, we predicted greater occupancy of all bat species along edges.

2. Methods

2.1. Study area

We conducted our study on MeadWestvaco Corporation's South Region in southern South Carolina, USA. The area is located in the Lower Coastal Plain physiographic province and is characterized by flat topography (slopes <2%) and elevations ranging from 20 to 30 m above mean sea level. Summers are warm and humid; monthly temperatures and precipitation average 27 °C and 186 mm, respectively (NOAA-National Climatic Data Center, http://www.ncdc.noaa.gov).

The 41,365 ha study area was intensively managed for wood and fiber products and consisted of even-aged stands of loblolly pine (*Pinus taeda*) in various successional stages. Plantation stands typically were clearcut at 20–25 years of age. Silvicultural practices included chemical and mechanical site preparation and planting of cleared stands, 1–2 commercial thinnings, and vegetation management via prescribed fire. Approximately 25% of the area was young stands and regeneration areas (≤5 years), 15% was closed-canopy plantations (6–11 years), and 33% was mid-rotation stands (12–22 years). Mature forest stands (≥23 years) included pine (6%), mixed pine-hardwood (10%), and hardwood (8%). The remaining the 3% of the area was water or anthropogenic structures. At the time of our study, MeadWestvaco employed a forest management system known as Ecosystem-Based Forestry that was designed to increase diversity of forest structure and composition across the landscape (Constantine et al., 2005). This approach maintained a system of approximately 100–200 m wide corridors comprised of mature forests within a mosaic of younger plantation stands. Three types of corridors were retained in harvested areas: visual corridors located along public roads, water quality corridors designed to protect wet areas and reduce soil erosion, and habitat diversity corridors intended to enhance biodiversity and wildlife habitat. Forested corridors composed of mature pine, mixed pine-hardwood, or hardwood habitat constituted 11% of the total study area.

2.2. Acoustic detection and analysis

From 1 June to 31 August (2004–2005), we recorded bat echolocation sequences using Anabat II detectors (Titley Eectronics, Ballina, New South Wales, Australia) coupled to Zero-Crossing Analysis Interface Modules with CF memory card storage (Anabat CF Storage ZCAIM). We calibrated detectors to minimize variation in reception zones prior to field sampling (Larson and Hayes, 2000). Detector systems were housed in waterproof plastic containers atop tripods 1.5 m above the ground with the microphone oriented at a 45° angle (Weller and Zabel, 2002). We programmed detectors to begin recording 15 min prior to sunset and end 15 min after sunrise. We avoided sampling on nights with moderate to heavy rain.

We randomly selected one habitat diversity and one water quality corridor with similarly aged adjacent stands for simultaneous sampling for two consecutive nights. We chose a subset of 32 pairs of corridors systems and sampled each pair once during the study. We placed one detector system in the corridor interior, one along each corridor edge, and one in each adjacent stand for a total of 10 sample sites per night (5 detectors/corridor system × 2 corridor systems). To maximize independence of observations and reduce edge effects, we positioned detectors in the center of each corridor and at least 40 m from adjacent stand edges (Grindal and Brigham, 1999). We oriented detectors in the corridor interior and on edges along corridor axes. Detectors in adjacent stands were oriented away from the corridor. To maximize number of calls and standardize area sampled by detectors, we oriented detectors away from structural clutter (Grindal and Brigham, 1999; Weller and Zabel, 2002).

We analyzed echolocation sequences using Analook v4.9j software (Titley Electronics, Ballina, New South Wales, Australia). We used a customized filter to retain sequences of ≥5 calls and remove all recordings not consistent with properties of search-phase echolocation call sequences (Britzke and Murray, 2000). We used Analook to calculate 10 parameter values for each call in a sequence (Britzke, 2003). We quantitatively identified each call sequence using a discriminant function analysis (DFA) model based on an extensive call library of bats in the eastern United States (Britzke, 2003). We calculated the percent of call sequences that were correctly identified (accuracy rate) and the percent of sequences that were misidentified by species (Britzke, 2003). Species identification can be difficult when multiple species use similar search-phase calls. However, as the number of sequences identified for a species increase at a site, so does the accuracy rate of identification, particularly if few calls of a similar species are recorded at that site (Britzke et al., 2002). Therefore, we considered a species present at a site if accuracy rates were ≥80% and ≥2 call sequences from that species were recorded. Species with accuracy rates <80% were considered present if ≥4 call sequences were recorded. Hoary bats (*Lasiurus cinereus*), Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) and northern yellow bats (*Lasiurus intermedius*) were excluded from the DFA model prior to analysis. Hoary bats migrate through the region and are considered rare in summer (Menzel et al., 2003). Northern yellow bats are rarely encountered and Rafinesque's big-eared bats are difficult to detect acoustically with zero-crossing systems.

2.3. Habitat metrics

At each survey site, we recorded habitat type (corridor, edge, or adjacent stand), corridor type (habitat diversity or water quality), age of adjacent stands, and presence/absence of an adjacent road. We used ArcView 3.2 (ESRI, 2000) to measure distance (km) from each site to the nearest available water source (pond, river, drainage ditch). For each corridor, we used the point-centered-quarter method to determine basal area (BA), and mean height of overstory (≥10 cm) and midstory (3–10 cm) trees (Cottam and Curtis, 1956).

2.4. Model selection

We developed logistic regression models to estimate proportion of sites occupied (ψ) by each bat species using 9 explanatory variables (Table 1) with detection/non-detection as the binary response. Prior to model analysis we conducted correlation tests to ensure no pairs of variables were highly correlated (Spearman's r