Forest Ecology and Management 427 (2018) 305–316

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Managed forests provide roosting opportunities for Indiana bats in south-central Indiana

Scott M. Bergeson[a,*], Joy M. O'Keefe[a], G. Scott Haulton[b]

[a] Center for Bat Research, Outreach, and Conservation, Department of Biology, Indiana State University, 600 Chestnut Street, Terre Haute, IN 47809, USA
[b] Division of Forestry, Indiana Department of Natural Resources, 402 W. Washington Street, Indianapolis, IN 46204, USA

ARTICLE INFO

Keywords:
Endangered species
Harvest
Myotis sodalis
Patch cut
Shelterwood
Silviculture

ABSTRACT

There is an intense interest in the effects of timber harvest on forest-dwelling bats due to the potential for timber harvest to reduce available habitat. Knowledge of these effects would be especially significant for the conservation of threatened and endangered bat species, many of which are forest obligates. We conducted a study to determine how endangered Indiana bats (*Myotis sodalis*) select summer roosts within a managed midwestern forest. In the summers of 2012–2015, we tracked 4 male and 11 female Indiana bats to 49 roosts (n_{male} = 24, n_{female} = 25) in south-central Indiana, USA. We collected roost-, plot-, and stand-scale data on roosts and associated available trees, randomly located throughout the same landscape. We generated 10 matched pairs conditional logistic regression models based on *a priori* hypotheses on roost selection and ranked them using Akaike's Information Criteria. Plausible models explaining female roost selection included those describing typical Indiana bat maternity roosts (tall and solar-exposed roosts) and typical tree-cavity bat roosts (tall, solar-exposed roosts close to water and surrounded by snags). Females selected roosts under exfoliating bark on large (averaging 17 ± 2 m in height and 34.8 ± 3.0 cm in diameter) standing dead trees (snags; 72% of roosts) and in bat boxes (20% of roosts) with high solar exposure (28.0 ± 6.0% canopy closure above roosts). For males, the model describing predator avoidance (tall roosts with many available snags and live trees) was the most plausible explanation of roost selection. Males selected for roosts under exfoliating bark on tall trees (23 ± 2 m; 71% snags, 25% live trees) surrounded by snags (4.5 ± 0.7 snags/0.1 ha plot) and live trees (30.4 ± 2.7 live trees/0.1 ha plot). Roost selection models including distance to timber harvest openings were not plausible. However, females roosted in or ≤10 m from harvest openings and first-stage shelterwood cuts more than expected (15 of 25 roosts) based on their availability on the landscape. Males roosted in harvest openings as expected (3 of 24 roosts). Our results demonstrate that a managed midwestern forest provides an array of roosts for Indiana bats and that Indiana bats do not actively avoid roosting near harvest openings in this forest. This suggests that Indiana bats may be able to subsist in managed forests in south-central Indiana, provided adequate maternity roost habitat (i.e., large standing dead trees with high solar exposures) is available.

1. Introduction

The impact of forest management on threatened and endangered species is currently a subject of debate that involves stakeholders from private, corporate, and government agencies. Bats of conservation concern are often at the center of this debate, as they tend to be dependent on forests for habitat and can be impacted by forest management in both positive and negative ways (Hayes and Loeb, 2007). For example, bats may be killed when standing dead tree (snag) roosts are removed for safety reasons (Cope et al., 1973; Belwood, 2002; Hayes and Loeb, 2007). However, direct mortality is likely rare (or, at least, rarely observed), especially because snag conservation has become a common forest management goal (Garber et al., 2005; Hutto, 2006). Indirect effects on bat populations, which are likely more common, can be both positive (e.g., generating foraging or roosting habitat; Johnson et al., 2010; Womack et al., 2013), and negative (e.g., the removal of desirable habitat).

Both timber harvest and prescribed burns have the capacity to enhance foraging habitat and produce quality tree-cavity roosts (i.e., large and solar-exposed snags with exfoliating bark; Kalcounis-Rüppell et al., 2005) for a variety of bat species, provided that efforts are made to retain or produce potential roosts during management (Fisher and Wilkinson, 2005; Guldin et al., 2007; Lacki et al., 2007). However, a common viewpoint is that silviculture, timber harvest in particular, has

* Corresponding author.
E-mail address: bergesos@pfw.edu (S.M. Bergeson).

https://doi.org/10.1016/j.foreco.2018.06.009
Received 10 April 2018; Received in revised form 4 June 2018; Accepted 6 June 2018

a negative impact on bats because it reduces the density of available roosts (Lunney et al., 1988; Miller et al., 2003; Russo et al., 2010; Borkin et al., 2011). Studies conducted in intensively managed forests in western North America provide data that fuel this argument. For example, in northwestern Montana, USA, snag densities were 6–19 times lower in intensively harvested stands (i.e., those treated with clear cuts, seedtree cuts, or shelterwood cuts) than in unharvested and partially harvested stands (i.e., those treated with partial seedtree cuts and shelterwood cuts or single-tree selection harvest; Wisdom and Bate, 2008). Potentially due to a lack of roosts, bats tend to be less active and roost less often in managed forest stands when unmodified old-growth stands are available (Lunney et al., 1988; Taylor and Savva, 1988; Crampton and Barclay, 1998). Unfortunately, there are limited data on the roosting behavior of bats in actively managed forests in midwestern USA, where unmodified and old-growth forests are now rare. Thus, conducting research on bats in this region provides an opportunity to measure bat responses to different silvicultural strategies in a novel landscape.

Protection of roosting habitat for the federally endangered Indiana bat (*Myotis sodalis*) can be an obstacle to effective oak (*Quercus* spp.)-hickory (*Carya* spp.) forest management in the Midwest, where stands of these valuable species are gradually being succeeded by more shade-tolerant tree species (e.g., maples and beech; *Acer* spp. and *Fagus* spp., respectively) due to the lack of forest disturbance (Shotola et al., 1992; Aldrich et al., 2003; Rogers et al., 2008). Managers are interested in promoting oak-hickory forests because they were the dominant forest type prior to European settlement (Shifley and Woodall, 2007; Jenkins, 2013), provide a valuable food source for wildlife (McShea and Healy, 2002; McShea et al., 2007), and are economically important (Hoover, 2013). To reduce potential impacts to Indiana bat maternity colonies, the U.S. Fish and Wildlife Service provides forest managers with guidance on the timing and nature of forest disturbance. However, following these guidelines limits the use of even-aged silvicultural techniques that promote oak-hickory regeneration (i.e., prescribed burns, shelterwood cuts, and clear cuts; Sander et al., 1983). For example, the U.S. Fish and Wildlife Service suggests that forest managers in Indiana maintain ≥60% forest canopy closure in forest stands, ≥8 live trees per ha that are ≥50.8 cm dbh (diameter at breast height) and that are species typically used by Indiana bats, ≥15 live trees per ha that are ≥27.9 cm dbh, and all snags (unless they pose a serious safety concern; USFWS, 2011). The U.S. Fish and Wildlife Service also suggest no removal of trees > 7.6 cm dbh from 1 April to 30 September and no prescribed burns 15 April to 15 September. To meet these suggestions, managers are often forced to harvest during the winter, when soils/roads are saturated. Intense saturation makes soil prone to wheel ruts and erosion, damaging the soil structure and productivity (Williamson and Neilsen, 2000; Šušnjar et al., 2006). It may also be difficult to conduct economically feasible harvests while following stand canopy closure restrictions.

Despite concerns about potential habitat degradation, there are many examples of Indiana bats foraging and roosting in managed forests during the summer maternity season. For example, Indiana bats selectively forage in 0–1 year-old prescribed burn areas (14.6–18.2 ha, low-intensity burns) in Missouri oak-hickory forests (Womack et al., 2013). In another Missouri forest, 21% of roosts used by female Indiana bats were snags located in clear cuts or basal-area-retention harvests; a portion of these roosts were trees that were girdled 1–2 years prior to their use by bats (Timpone et al., 2010). In the coastal plains of Virginia, female Indiana bats roost in snags generated by late, dormant-season prescribed fires (St. Germain et al., 2017). Male Indiana bats in West Virginia roost in trees located in 1–3 year old prescribed burns (12–121 ha, low- to moderate-intensity burns; Johnson et al., 2010) and a 5-year-old patch cut (Ford et al., 2002). Additionally, males in Arkansas were either positively or neutrally affected by prescribed burns while selecting roosts in primarily mature (≥38 years old) forest stands during autumn (Perry et al., 2016). These examples suggest that female and male Indiana bats may respond to timber management in either a positive or neutral way. Understanding how Indiana bats may respond to silvicultural techniques as they select for roosts is important. However, we are unaware of any studies that have made explicit comparisons between harvest variables and other factors that may affect roost selection and, thereby, discern the variables' relative significance.

We examined the relative importance of silvicultural techniques used to promote oak-hickory regeneration, compared to other selection factors, as they affect Indiana bat roost selection in managed forests in south-central Indiana. We conducted sex-specific analyses, as female and male tree cavity-roosting bats tend to select for different types of roosts (Hamilton and Barclay, 1994; Broders and Forbes, 2004; Perry and Thill, 2007). In general, bats select roosts that facilitate positive energy balance (Sedgeley, 2001), are easily accessible (Vonhof and Barclay, 1996), and facilitate predator avoidance (Fenton, 1983, Lima and O'Keefe, 2013), among other factors. Prior work has demonstrated the importance of these factors to female Indiana bats in the midwestern USA (e.g., Gardner et al., 1991; Kniowski, 2011). Additionally, in the Midwest, Indiana bats roost in openings generated by timber harvest (Gardner et al., 1991; Timpone et al., 2010). Therefore, we hypothesized that female and male Indiana bats would not avoid roosting near forest openings generated by forest management (harvest openings). Specifically, we predicted that distance to harvest openings of various ages and types (i.e., patch cuts, clear cuts, and shelterwood cuts) would not be an important factor in roost habitat selection. We also predicted that females would select large solar-exposed roosts to reduce the costs of endothermy (Sedgeley, 2001) and promote juvenile development and milk production (Tuttle, 1976; Racey, 1973), while males would select smaller and more shaded roosts that facilitate the use of daily torpor (Henshaw and Folk, 1966; Hamilton and Barclay, 1994; Perry and Thill, 2007).

2. Material and methods

2.1. Study area

We conducted this study in and around 2 Indiana State Forests (Morgan-Monroe State Forest, N39.335, W86.421; Yellowwood State Forest, N39.127, W86.347) located 25 km apart in south-central Indiana, USA. These state forests were purchased between 1929 and 1947 and converted from farmland to forest (mean stand age: Morgan-Monroe State Forest = 87 years old, Yellowwood State Forest = 91 years old). Since acquisition, they have been managed mainly with uneven-aged management, primarily single-tree selection harvest (Carman, 2013; Jenkins, 2013). However, even-aged management has recently been applied in this landscape as part of the Hardwood Ecosystem Experiment (Kalb and Mycroft, 2013). During this study, the combined state forest landscape (~26,000 ha) consisted of 2.2% harvest openings (< 20 years old) and first-stage shelterwood cuts, 7.1% agriculture, and 90.7% relatively intact forest intermittently treated with single-tree selection harvest (hereafter, forest matrix; example over-story basal area: live trees = 31.9 ± 0.7 m^2/ha, snags = 3.2 ± 0.1 m^2/ha; M. Saunders, Purdue University, unpublished data). Harvest openings in the forests were generated through both even- and uneven-aged silvicultural techniques. Even-aged stands included clear cuts (mean cut area = 3.9 ± 0.2 ha, range = 2.7–4.4 ha; post-harvest over-story basal area: live trees = 4.3 ± 1.3 m^2/ha, snags = 1.4 ± 0.7 m^2/ha) and shelterwood cuts. Shelterwoods (the gradual removal of portions of a stand through a series of partial cuttings or thinnings) had received a preparatory cut (i.e., late-rotation understory and midstory thinning; stage 1 of 3; Smith et al., 1997) in the winter of 2008–2009. (Kalb and Mycroft, 2013). Therefore, shelterwood cuts had not yet produced harvest openings (mean cut area = 4.1 ha expected after stage 3 is complete; current over-story basal area: live trees = 22.9 ± 2.5 m^2/ha, snags = 1.4 ± 0.6 m^2/ha). Uneven-aged stands were created through patch cuts with a mean cut area of 1.2 ± 0.1 ha (range = 0.2–2.6 ha) and a post-harvest over-story basal area of