Forest Ecology and Management 400 (2017) 19–27

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Effect of forest opening characteristics, prey abundance, and environmental factors on bat activity in the Southern Appalachians

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ARTICLE INFO

Article history:
Received 20 November 2016
Received in revised form 20 May 2017
Accepted 25 May 2017
Available online 6 June 2017

Keywords:
Chiroptera
Forest opening
Early successional habitat
Insect
Prey
Edge

ABSTRACT

Early successional habitat (ESH) is important for many wildlife species. Over the past century, land use changes have caused ESH to decline in hardwood forests of the eastern United States. Because of the decline of ESH and ESH dependent wildlife, ESH has recently received increased attention from land managers and scientists. Bats, which utilize ESH for foraging, are also a conservation concern, however little information is available on how ESH restoration affects bats. Our objective was to determine how ESH opening size, presence of edge, opening shape, prey abundance, vegetation structure, and environmental factors affect bat activity. In June-August 2014 and May-August 2015, we placed Anabat SD2 bat detectors at the interior and edge of small (0.2–1.6 ha), medium (2.1–5.6 ha), and large (6.2–18.5 ha) forest openings in the Nantahala National Forest, Cheoah Ranger District, Graham County, North Carolina. We used Townes-style Malaise insect traps to determine insect abundance and quantified vegetation structure. Differences in insect abundance, bat activity, and bat species richness were tested using mixed effects general linear models. Opening size and presence of edge did not affect total insect abundance, although density of trees >2 m in height and elevation had a negative effect on total insect abundance whereas mean nightly temperature had a positive effect. Similarly, overall bat activity did not vary with opening size or presence of edge, but was negatively related to density of trees >2 m high and elevation and positively related to the related circumscribing circle index (i.e., more elongated) and mean nightly temperature. Activity of open-adapted bat species was also negatively related to density of trees >2 m. These results suggest that opening size and prey abundance do not affect bat activity in the southern Appalachian Mountains. Open-adapted bats may select foraging patches with less vegetation structure because they can forage more efficiently in these environments, whereas clutter-adapted bats can forage efficiently in both cluttered and open environments. Thus, if creating ESH to benefit bats, land managers should maintain an open vegetation structure, focus on creating openings at lower elevations, and configure openings to maximize edge relative to opening area.

1. Introduction

Early successional habitat (ESH), or recently disturbed forest with an open canopy structure and a vegetation community dominated by herbaceous plants and shrubs, is an important habitat type which is receiving increased attention from scientists and land managers (Askins, 2001; DeGraaf and Yamasaki, 2003; Greenberg et al., 2011a; Swanson et al., 2011). Historically, ESH was created and maintained by natural disturbances such as wind storms, ice storms, wildfire, disease, and insect epidemics (Lorimer, 2001; Lorimer and White, 2003; Rogers, 1996; Swanson et al., 2011). After Europeans arrived in North America, large areas of land were cleared for agriculture and timber harvest (Askins, 2001) which created an abundance of ESH (Lorimer, 2001; Trani et al., 2001). By the mid-20th century, the intensity of timber harvest in hardwood forests had declined and agricultural land was allowed to regenerate into mature forest. At the same time, natural disturbance, especially wildfire, was suppressed (DeGraaf and Yamasaki, 2003; Lorimer, 2001; Trani et al., 2001). These changes in disturbance regimes led to a ~16% decline in the abundance of ESH in the eastern United States during the second half of the 20th century (Brooks, 2003; Shifley and Thompson, 2011).

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http://dx.doi.org/10.1016/j.foreco.2017.05.045
0378-1127/

The decline of ESH is of management concern because ESH is critical habitat for many species. For example, the abundance of shade-intolerant herbs and fruiting plants, which serve as sources of food for both birds and mammals, are greater in recently disturbed forests (Elliott et al., 2011; Greenberg et al., 2011b). Reptiles utilize ESH for basking (Greenberg, 2001; McLeod and Gates, 1998) and 45% of bird species associated with forest openings are in decline (Hunter et al., 2001). Recently disturbed forest is also valuable habitat for some terrestrial mammals including many species of rodents and shrews (Kirkland, 1990; Urban and Swihart, 2011).

ESH is also important for many bat species because it provides open areas in which to forage for insect prey (Loeb and O'Keefe, 2011). For example, bat activity is higher in stands that have been recently cut compared to closed canopy forests (Ellis et al., 2002; Grindal and Brigham, 1999, 1998; Krusic et al., 1996; Menzel et al., 2002). However, only a limited number of studies have examined the effect of forest opening size on bat activity. Grindal and Brigham (1998) found that bat activity did not differ significantly across openings 0.5–1.5 ha in size. In contrast, Ford et al. (2005) found that little brown bats (*Myotis lucifugus*), big brown bats (*Eptesicus fuscus*), eastern red bats (*Lasiurus borealis*), and hoary bats (*L. cinereus*) were more likely to occur in larger canopy gaps (~0.07–0.10 ha) compared to smaller gaps (~0.01–0.03 ha). However, in both of these studies, the range of opening sizes sampled was small compared to forest openings created through operational scale forest management activities.

A number of factors may affect use and selection of foraging patches by bats, one of which is wing morphology. Bats with high wing aspect ratios and high wing loads (long narrow wings) are adapted for straight line, long distance flight (Norberg and Rayner, 1987). These open-adapted species may select larger openings that reduce the need to engage in costly aerobatic flight. Alternatively, bats with low wing aspect ratios and low wing loads (short broad wings) are adapted for short distance, agile flight. These clutter-adapted species may be equally active in openings of all sizes because aerobatic flight maneuvers are less costly. Bat wing morphology may also affect which parts of a forest opening a species may prefer. Bat activity at opening edges is higher than at opening interiors (Grindal and Brigham, 1999) and, although not statistically significant, peak activity of open-adapted species tends to be farther from the edge than that of clutter-adapted species (Jantzen and Fenton, 2013). Other factors that may affect selection of foraging patches include distance to water (Brooks, 2009; Krusic et al., 1996), elevation (Grindal and Brigham, 1999), and prey abundance (Morris et al., 2010; Tibbels and Kurta, 2003) although the relationship between bat activity and insect abundance is equivocal (e.g., Grindal and Brigham, 1998; Muller et al., 2012).

Understanding how bats select forest openings is important because many species of bats are in decline. Currently, the most serious threat facing bats in North America is white-nose syndrome (O'Shea et al., 2016) with infected populations declining as much as 75–90% (Turner et al., 2011). Wind energy is also a serious threat to bats (O'Shea et al., 2016) with an estimated 600,000 bats killed in 2012 due to interactions with wind turbines in the United States (Hayes, 2013). The emerging threats of WNS and wind energy are in addition to ongoing threats faced by bats such as habitat loss and fragmentation, intentional killing, and environmental contaminants (O'Shea et al., 2016).

Our objective was to determine how opening size, opening shape, presence of edge, prey abundance, and environmental factors affect bat activity in forest openings. We hypothesized that: (1) open-adapted bats (big brown bats, silver-haired bats [*Lasionycteris noctivagans*], hoary bats, and eastern red bats) would be more active in large openings than in small openings while clutter-adapted species (tri-colored bats [*Perimyotis subflavus*] and *Myotis* spp.) would not respond to differences in opening size, and (2) activity of open-adapted bats would be greater at opening interiors while activity of clutter-adapted bats would be greater at opening edges. We further hypothesized that (3) bat activity would be positively related to opening elongation, insect abundance, and nightly temperature, and (4) negatively related to vegetation clutter, elevation, and distance to water.

2. Methods

2.1. Study area

The study took place in the Nantahala National Forest, Cheoah Ranger District, Graham County, North Carolina (Fig. 1). The Cheoah Ranger District is located in the southern Appalachian Mountains which are characterized by ridge and valley topography with high mountain peaks. The dominant vegetation type is mixed hardwood forest interspersed with pine stands and mountain balds. Common tree species include oaks (*Quercus*), maples (*Acer*), poplars (*Liriodendron*), hickories (*Carya*), and pines (*Pinus*). From May to August 2014 and 2015, the average monthly temperature was 21.4 °C and average monthly precipitation was 91.1 mm. Elevation in the Cheoah Ranger District ranges from 530 m to 1658 m above sea level.

2.2. Study design

We sampled 33 forest openings, however one opening was dropped from the analysis due to equipment failure. All openings had an open canopy structure and were dominated by shrubs, herbaceous plants, and bare ground. Openings included timber harvests, areas treated after a southern pine beetle (*Dendroctonus frontalis*) infestation, prescribed burns, and wildlife openings. Timber harvests were classified by the U.S. Forest Service as either shelterwood establishment or two-age shelterwood establishment harvests and were completed <5 years prior to sampling. Southern pine beetle areas were clear cut, burned, and replanted with shortleaf pine (*P. echinata*) and were <14 years old. Wildlife openings were clearings maintained for the benefit of wildlife through regular mowing. Prescribed burn openings were areas where high intensity fire had removed the understory and overstory. Prescribed burns were completed <7 years prior to sampling.

Prior to sampling, we examined the size distribution of available openings and, based on this preliminary analysis, defined three size classes: small (0.2–1.6 ha), medium (2.1–5.6 ha), and large (6.2–18.5 ha). In each sampling period, we selected one small, medium, and large opening to sample simultaneously. The three openings were chosen to minimize travel time between openings and were considered a block. The average distance between openings was 1.1 km with a range of 0.01–12.4 km.

2.3. Acoustic sampling

We used Anabat SD2 (Titley Scientific, Columbia, MO) acoustical bat detectors to measure bat activity in each opening from June 4 to August 2, 2014 and May 22 to August 13, 2015. The detector microphones were enclosed in weatherproof housings mounted atop 3.7 m poles. The microphones were connected to the detectors, which were enclosed in waterproof containers at the base of the poles, via a 6.1 m cable. Prior to the start of each field season, the sensitivities of the Anabat SD2 detectors were equalized to a detector with an internal sensitivity setting of 30 using the Anabat Equalizer (Titley Scientific, Columbia, MO).

We placed an Anabat SD2 detector near the edge and interior of each opening. The edge detector was positioned 5 m into the