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FOREST ROADS USED BY COMMUTING AND FORAGING BATS IN EDGE AND INTERIOR ZONES

ABSTRACT: We hypothesized that the flight activity of bats in forests is higher in parts closer to edges due to the presence of species roosting in trees and foraging mostly outside as well as those coming to forage from outside. The aim of our study was to test this expectation using bat netting on roads in a forest belt 4–5 km wide in Kampinos National Park near Warsaw (central Poland). Tree stands were mostly coniferous. Ten full-night study sessions were done between the end of July and the beginning of September in the years 2007–2009. During each session, bats were netted at two sites situated in two zones designated as “edge” (100–500 m from forest edge) and “interior” (1750–2250 m from forest edge). The study revealed twelve species, among which *Eptesicus serotinus* (Schreber), *Nyctalus noctula* (Schreber) and *Barbastella barbastellus* (Schreber) were by far most abundant. Total bat abundance recorded at ten pairs of netting sites differed significantly between the edge zone (ca. 2.5 times higher numbers) and the interior zone. Among individual species, a statistically important difference was shown only for *Plecotus auritus* (L.), which was more abundant close to the forest edge, though a similar tendency was noted in other species, mostly *E. serotinus*. The frequency of each species in the bat assemblage as well as species diversity of bats flying along forest roads did not differ between the two zones.

KEY WORDS: Chiroptera, habitat use, spatial activity, edge effect, wooded areas

1. INTRODUCTION

Many species of bats tend to commute and forage along forest roads, including both strictly forest-dwellers and synanthropic species roosting in human settlements situated outside wooded areas (Lesiński et al. 2007). These linear landscape elements enable bats to penetrate dense tree stands and offer easily available food base (Grindal and Brigham 1998, 1999). Bats are mobile mammals using various habitats in a mosaic landscape. Radio-tracking studies have revealed different patterns of habitat use with commuting distances between roosts and foraging areas up to several or even more than 10 kilometres (Catto et al. 1996, Limpens et al. 1999, Shiel et al. 1999). Nevertheless, the results of some studies suggest that bats’ hunting activity is usually focused on areas situated close to roosts if foraging habitats are present nearby (Degn 1983). Some forest species that usually forage over open fields or water bodies roost in areas closer to edge zones than could be expected from randomly distributed potential roosts (Ormsbee and McComb 1998, Boonman 2000, Kunz and Lumdsen 2003).

We expected that bat penetration of large forests is uneven with greater densities in sites situated close to the edges. This could
result from the fact that synanthropic species roosting outside forests (in villages) have longer distances to fly to the forest interior. On the other hand, some species roosting in trees and foraging outside forest could avoid roosts situated in the forest interior. The rules of optimal feeding should force bats to shorten distances between roosts and foraging areas (if possible) in order to save energy. Accordingly, we also made assumptions about an increasing proportion of synanthropic bats and higher species diversity in edge zones. The aim of this study was to confirm or reject these expectations.

2. MATERIAL AND METHODS

The study was conducted in Kampinos National Park near Warsaw, central Poland. This park (total area 38,500 ha, forest cover 73%) was established to protect a landscape in which two broad latitudinal belts of dunes covered by forests are separated by open wetlands. A fragment of the forest in the form of a belt ca. 4–5 km wide and ca. 20 km long situated in the northern part of that area was selected for the study (Fig. 1). The tree stands of this belt (62 years old on average, 30% older than 100 years) were mostly composed of pine trees (72.4%), and deciduous species: oaks, common alders, and birches, with a small admixture of other species.

Ten study sessions were conducted in late summer between 2007 and 2009, the exact dates being July 30/31, 2007; Aug 1/2, 2007; Aug 3/4, 2007; Aug 4/5, 2007; Aug 22/23, 2007; Aug 11/12, 2008; Aug 26/27, 2008; Sep 9/10, 2008; Aug 12/13, 2009; and Aug 13/14, 2009. During each session, bats were netted on one road perpendicularly crossing the forest complex. A full night’s netting, starting a quarter before sunset and ending at a quarter after sunrise, was performed simultaneously at two sites, one in the edge zone (100–500 m from the forest edge) and one in the interior zone (1750–2250 m from the forest edge) (Fig. 1). Two nets per site were used, 100–200 m apart, placed according to the scheme in which the net blocked the full width of the road, its upper edge touching the “roof” of tree branches. The lower edge of each net was placed not higher than 1.2 m above the ground.

After a bat was caught, the species and sex were determined, time of the capture was noted, the animal was individually marked

![Fig. 1. The forest under study with marked pairs (I–X) of study sites (circles). 1 – forests, 2 – villages, 3 – main roads](image-url)
on the wing with a permanent pen in order to avoid an overestimation of bat numbers in case retraps were counted. Bats were released at the study site as soon as possible. We had permission for bat netting from the Polish Ministry of the Environment (DLOPiK-op/ogiz-4200/IV.D-11/3693/06/aj).

Species diversity of bats was calculated using the Shannon-Wiener formula:

\[ H' = -\sum p_i \ln p_i \]

where \( p_i \) is the frequency of each species determined among the netted individuals, and \( i \) is the number of species.

The ratios of the number of individuals of each species to the number of individuals of the remaining species were calculated to estimate differences in the structure of the bat assemblage in both zones and sex ratios were compared with the \( \chi^2 \) test (with Yates correction if at least one number was below 10). The Wilcoxon matched pairs test was used to compare pairs of results obtained at each study session. In all analyses the significance level was \( P = 0.05 \).

3. RESULTS

The netting revealed the presence of 271 individuals belonging to 12 species of bats in the forest, including 9 in the edge zone, and 10 in the interior zone. Markedly more individuals (nearly 2.5 times) were caught in the edge zone. The number of bats netted at individual sites ranged between 4–67 (edge) and 1–20 (interior). The two designated zones did not differ with regard to the proportion of each bat species, with *Eptesicus serotinus* (Schreber), *Nyctalus noctula* (Schreber) and *Barbastella barbastellus* (Schreber) being most abundant (Table 1). This resulted in similar species diversity (\( H' \)) of 1.67 for the edge zone and 1.70 for the interior zone.

A pair-wise comparison of results from the edge and interior zones confirmed differences in the total number of bats netted. Among individual species, a difference was shown only for *Plecotus auritus*. However, the medians of all the most abundant species were higher close to forest edges. The greatest similarity in numbers between the analysed zones was noted for *N. noctula* (\( P = 0.68 \)) (Table 2).

There were no statistically significant differences in sex ratio between the two forest zones for the most abundant species: *N. noctula* – 12 ♀♂♀♀♀♀♀♀ (edge) vs. 5 ♀♂♀♀♀♀♀♀ (interior), \( \chi^2 = 0.2, \text{d.f.} = 1, P = 0.69; E. serotinus – 26 ♀♂♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀♀女足

### Table 1. Species composition of bats netted in edge and interior zones. N – total number of individuals netted in each zone over the study period.

<table>
<thead>
<tr>
<th>Species</th>
<th>Edge zone</th>
<th>Interior zone</th>
<th>Difference*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>%</td>
<td>N</td>
</tr>
<tr>
<td><em>Myotis myotis</em></td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><em>M. nattereri</em></td>
<td>5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><em>M. brandtii</em></td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><em>M. daubentonii</em></td>
<td>8</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><em>M. dasycneme</em></td>
<td>8</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><em>Eptesicus serotinus</em></td>
<td>71</td>
<td>37</td>
<td>29</td>
</tr>
<tr>
<td><em>Pipistrellus pygmaeus</em></td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td><em>Nyctalus leisleri</em></td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><em>N. noctula</em></td>
<td>52</td>
<td>27</td>
<td>17</td>
</tr>
<tr>
<td><em>Plecotus auritus</em></td>
<td>18</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td><em>P. austriacus</em></td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td><em>Barbastella barbastellus</em></td>
<td>27</td>
<td>14</td>
<td>17</td>
</tr>
</tbody>
</table>

*Difference between proportions of the number of individuals of each species to the overall number of individuals of remaining species.*
4. DISCUSSION

Our study confirmed the expectation that the number of bats in areas closer to the forest edge is higher than that inside a forest complex. However, this finding is not easy to interpret. The flight activity of strictly forest species could be similar in both zones. Nevertheless, there are other groups of bats, i.e. those coming to the forest or leaving it during foraging. Morris et al. (2010) found that forest edges were used more frequently by foraging aerial-hunting bat species. Some bats normally roosting in trees commute to foraging areas situated over open spaces, including N. noctula (Stutz and Haffner 1985–1986, Kronwitter 1988, Rachwald 1992), or waters, including Myotis dasycneme (Boie) and M. daubentonii (Kuhl) (Sluiter et al. 1971, Swift and Racey 1983). Data collected by Boonman (2000) suggest that these species prefer roosts situated closer to a forest edge, probably to reduce the time and energetic costs of commuting flights (Kunz and Lund 2003). The results for P. auritus, which was significantly more abundant in edge zones of the study area, suggest its closer connection to day roosts in villages, although it ranks among the most eurytopic species of European bats (Swift 1989). The commuting distances of E. serotinus are longer (even over 10 km – Catto et al. 1996), but, in our study, there was a trend (statistically not confirmed) towards a focusing of its activity in the edge zone of the forest under study (median 5.5 individuals per study site and night compared to 1.5 for the interior zone – Table 2).

Some strictly forest species, like Nyctalus leisleri (Kuhl) (Bogdanowicz and Ruprecht 2004), as well as those connected to built-up areas, like Plecotus austriacus (Fischer) (Flückiger and Beck 1995), were netted rarely as their proportions (at least the first one) in a bat assemblage were very low. Our study probably underestimated the number of individuals belonging to species usually flying over tree crowns and rarely using forest roads. Bats of the genus Pipistrellus were rarely netted but they are known to be more abundant in a bat assemblage of the study area, especially P. nathusii (Keyserling et Blasius) (Lesiński 2003).

The absence of differences in the proportions of all species between the two zones indicates a high level of mobility of the bats. It is possible that many species use their roosts situated both in the forest and human settlements. The commuting distances of B. barbastellus, a species associated with wooded habitats that roosts and forages inside forests, are longer (up to 8.2 km – Russo et al. 2010) than the width of the forest belt under study.

Further support for the hypothesis tested in this paper is furnished by the results of our study on the frequency of bats in the tawny owl’s (Strix aluco L.) diet. Bat predation of this raptor is opportunistic and higher in areas with more abundant assemblages of potential prey. Individuals living inside wooded areas (over 500 m from the edge) rarely catch bats compared to individuals occupying sites close to the edge (up to 500 m inside or outside forests). In Poland, the respective medians of the proportion of bats within the owls’ vertebrate prey were 0.08% and 0.63% (Lesiński et al. 2009). These figures could have resulted (at least partly) from the differences described in our study.

Sex-related differences in the pattern of habitat use were not confirmed, which partly resulted from the small samples of bats captured. The recording of more males of E. serotinus in the forest interior could be a genuine finding (although not confirmed statistically) and indicate that their habitat use may differ as compared to

<table>
<thead>
<tr>
<th>Species</th>
<th>Median</th>
<th>Difference</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eptesicus serotinus</td>
<td>5.5</td>
<td>1.5</td>
<td>1.40</td>
<td>0.16</td>
</tr>
<tr>
<td>Nyctalus noctula</td>
<td>1.0</td>
<td>0.5</td>
<td>0.42</td>
<td>0.68</td>
</tr>
<tr>
<td>Plecotus auritus</td>
<td>1.0</td>
<td>0</td>
<td>2.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Barbastella barbastellus</td>
<td>2.5</td>
<td>1.5</td>
<td>1.18</td>
<td>0.24</td>
</tr>
<tr>
<td>Total</td>
<td>15.5</td>
<td>6.5</td>
<td>2.09</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 2. Difference in median number of individuals of four most abundant species and overall number of bats (per one study site and night) between edge and interior zones in pairs from the same roads (N = 10, Wilcoxon matched pairs test). Statistically significant differences in bold.
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females. Such differences are known in bats, for example in *M. daubentonii* (Encarnação et al. 2005). Single individuals of *E. serotinus*, mostly males, roosting in boxes have been found inside forests in Germany (Stratmann 1973, Heise 1983, Schmidt 2000) and Poland (Szarlik et al. 2005, unpubl. data).

Taking into account the results of this study, we expect that bats are among those animal taxa which should not be so much sensitive to forest fragmentation and increasing length of edge zones in forests. A study conducted in central Poland pointed out that even small forests 1–3 km² in size supported relatively rich bat assemblages. With regard to the number of species and relative density of commuting and foraging individuals, they were only slightly poorer compared to those in a forest 18 km² in size (Lesiński et al. 2007). As most European bats show synanthropic features, the mean density of foraging bats in forests larger than the forest under study might be lower, and the flight activity of most species should be focused on areas situated less than two kilometres from the edges.

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