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BATS AT SMALL SUBTERRANEAN WINTER ROOSTS: EFFECT OF FOREST COVER IN THE SURROUNDING LANDSCAPE

ABSTRACT: The study was carried out in central and north-eastern Poland in order to assess bat occurrence in small winter roosts located in house-cellars, in relation to the share of the surrounding landscape taken by forest cover and the distance separating the different sites from forests of at least 1 km^2. Data from single checks in 2243 cellars in 1990–2007 revealed a positive relationship (R^2 = 0.33, P <0.001) between the percentage of cellars occupied by bats and the forest cover (range: 2–58%) in sections of surrounding landscape covering between 30 and 220 km^2. Forest cover in the landscape within 1 km of the cellar appeared to have a slight influence on the number of species and species diversity (Simpson's index; respectively R^2 = 0.14, P = 0.006 and R^2 = 0.13, P = 0.011). Both number of species and species diversity were progressively lower with increasing distance from the nearest forest covering an area of 1 km^2 or more (for both R^2 = 0.15, P = 0.005). *Myotis nattereri* (Kuhl, 1817) and *Barbastella barbastellus* (Schreber, 1774) were significantly more likely to colonise the cellars surrounded by landscape with a higher level of forest cover (P = 0.001 and 0.031), while *M. nattereri* was also more likely to be found in those at shorter distances from forests (P = 0.005). No such relationships were reported for either *Plecotus auritus* (Linnaeus, 1758) or *Myotis daubentonii* (Kuhl, 1817).

KEY WORDS: bat hibernation, cellars, wooded areas, landscape structure

1. INTRODUCTION

Wooded areas are environments of importance to a majority of bat species, including European ones, which meet here daytime refuges and rich foraging areas (Thomas 1988, de Jong and Ahlén 1991, Limpens and Bongers 1991, Wunder and Carey 1996, Crampton and Barclay 1998, Estrada and Coates-Estrada 2002, Meschede and Heller 2003, Kusch *et al.* 2004). In contrast, agrocoenoses support only low densities of foraging bats and low numbers of bat species (Gaisler and Kolibáč 1992). Yet even small forest complexes (1.0–3.5 km^2) located among the extensive cultivated fields in central Poland can support 8 bat species (Lesiński *et al.* 2007). Indeed, the presence of trees has been related to markedly increased densities of foraging bats (Walsh and Harris 1996, Lesiński *et al.* 2000). *Rhinolophus hipposideros* (Bechstein, 1800) creates larger breeding colonies in these parts of Austria which support higher forest cover (Reiter 2004). In England, a detailed analysis of the landscape surrounding summer roosts of *Plecotus auritus* (Linnaeus, 1758) in buildings revealed that the bats choose the roosts located closer to woodland (Entwistle *et al.* 1997).

One may expect that a landscape with a greater forest cover will be characterised by the occurrence of relatively rich assemblages of bats – in terms of both number of species and abundance. Small wintering sites are probably inhabited by relatively sedentary bats, flying in from the more immediate vicinity. Therefore, the structure of the landscape around such sites could be expected to influence the frequency in which they are colonised, as well as the species composition and numbers of wintering bats.

Small underground roosts (mostly cellars) are important bat hibernacula in some European countries, *e.g.* Estonia (Masing 1980) and Sweden (Rydell 1989). Rural areas of central and north-eastern Poland contain a great number of small cellars (built close to the farm buildings) in which bats may overwinter. Research done on these has so far revealed the presence of nine bat species, among which *P. auritus* and *Myotis daubentonii* (Kuhl, 1817) were reported most frequently (Lesiński *et al.* 2004). Preliminary analyses in turn suggest that the colonisation of cellars by bats may be related to the forest cover of the surrounding landscape (Lesiński 2006).

The aim of this work was to test the hypothesis that small, local wintering sites of bats are colonised more frequently and have higher number of species, species diversity and density of wintering individuals in more-forested landscapes taken to raise the quantitative and qualitative richness of bat assemblages. In turn, were such relationships to be demonstrated, this would confirm expectations as regards the local nature of the roosts in question.

2. MATERIAL AND METHODS

The research was carried out in central and north-eastern Poland (*ca* 25 000 km^2) in the years 1990–2007, mainly in the Mazowsze and Podlasie voivodships. The overall forest cover for these areas ranged from 22 to 30% respectively in 2005 (Polish Statistical Yearbook 2006). The research was done on bats hibernating in the small cellars widespread in the above parts of Poland and usually located close to rural buildings. The brick, stone or concrete structures in question are partly located below the ground surface, partly above it where they are covered with soil piled up to a depth of several tens of centimetres. The present study was confined to small cellars with volumes in the range 16–47 m^3.

The level of occupancy of cellars was established by single searches carried out in selected villages between December and mid - March. The discovery of a cellar potentially suitable as a wintering site for bats was followed by an interview with the building's owner and by own observation. The study as a whole took in 2243 cellars. The four categories of occupancy of cellars by bats were:

1. Present,
2. Absent, though occurring annually or almost annually,
3. Absent, though occurring in the past,
4. Absent and never reported.

Occupied cellars were taken to be those falling within categories 1 and 2 (an index of half an occupied cellar being applied in the latter case). Maps (1:200 000) were used to determine forest cover in the section of landscape surrounding given village complexes in which cellars were searched. The sections were rectangular in shape, delineated in a such a way that, with areas minimised, their sides were not closer than 1 km from the villages studied. 41 such sections of landscape covering between 30 and 220 km^2 were analysed, information on at least 25 cellars being obtained for each. The index of frequency of occupancy (FO) was calculated as number of cellars with bats per total number of cellars.

Most of the occupied cellars were checked out regularly, with at least two counts being made through the hibernation period (in late November – early December and in the first half of February). Cellars checked at least five times (N = 51) were subject to detailed analysis of the influence of forest cover in the surrounding landscape on the bats' colonisation. Results of five randomly-selected checks for each cellar were used. Forest cover in the landscape within 1 km of the cellar was determined, along with distance from the near-

Table 1. Occurrence of bat species in 51 cellars selected to particular analyses.

Species	Number of inhabited cellars	Total number of individuals		Number of individuals per inhabited cellar			
		N	%	Median	Lower quartile	Upper quartile	Maximum
Myotis nattereri	22	62	9	2	1	3	13
M. mystacinus or *M. brandtii*	3	5	1	1	1	2	3
M. dasycneme	4	4	1	1	1	1	1
M. daubentonii	40	274	38	6	2	9	24
Eptesicus nilssonii	1	2	0	-	-	-	2
E. serotinus	1	1	0	-	-	-	1
Plecotus auritus	47	352	49	5	2	11	38
P. austriacus	1	2	0	-	-	-	2
Barbastella barbastellus	8	18	3	3	1	3	4

Table 2. Relationships (regression model: square root–X) between characteristics of bat occurrence in cellars and the forest cover of the landscape or the distance from a patch of forest covering at least 1 km^2. Sample size (number of cellars) – in parentheses, statistically important differences are bolded.

Habitat factor	Number of species (51)		Species diversity (51)		Maximum number (51)		Maximal density (41)	
	R^2	*P*	R^2	*P*	R^2	*P*	R^2	*P*
Forest cover (%)	0.14	**0.006**[a]	0.13	**0.011**[b]	NS	0.259	NS	0.179
Distance from a patch of forest covering at least 1 km^2	0.15	**0.005**[c]	0.15	**0.005**[d]	NS	0.272	NS	0.553

a: $Y = 1.63 + 0.23 \sqrt{X}$ b: $Y = 1.36 + 0.12 \sqrt{X}$ c: $Y = 3.36 - 1.07 \sqrt{X}$ d: $Y = 2.32 - 0.61 \sqrt{X}$

est forest complex covering at least 1 km^2. A further indices of occupancy by bats studied in individual cellars were:

1. Number of species
2. Species diversity given by the Simpson's index (D):

$$D = 1 / \sum p_i^2$$

where i = from 1 to n, and p_i the frequency with which different species were reported (related to the total number of reported bats capable of being classified to given species), n – number of species

3. Maximum number of individuals per single survey
4. Maximal density – maximum number per cellar volume (N m^{-3})

Forest cover in the rectangular sections of landscape surrounding villages ranged from 2% to 58%, while that in the round sections of landscape surrounding individual cellars was in the range 0% to 72% (mean 18%). Distances between cellars and the nearest area of forest covering at least 1 km^2 in turn ranged from 0 to 4.5 km (mean 0.9 km).

Simple regression analysis was performed for: (1) the relationships in the rectangular sections of landscape between the frequency of occupancy of cellars and numbers of species therein, on the one hand, and the forest cover on the other, (2) the relationships for single cellars between number of species, species diversity, maximum number of individuals and maximal density of the wintering bats on the one hand, and forest cover in the area surrounding a cellar at distances of up to 1 km, as well as the distance from forest of an area at least 1 km^2, on the other. Best fits were obtained for regression where the square root–X or logarithmic models were used. Differences between the forest cover or a distance to a large forest for cellars selected and avoided by given species were assessed using the Mann-Whitney test. The accepted significance level was $P = 0.05$.

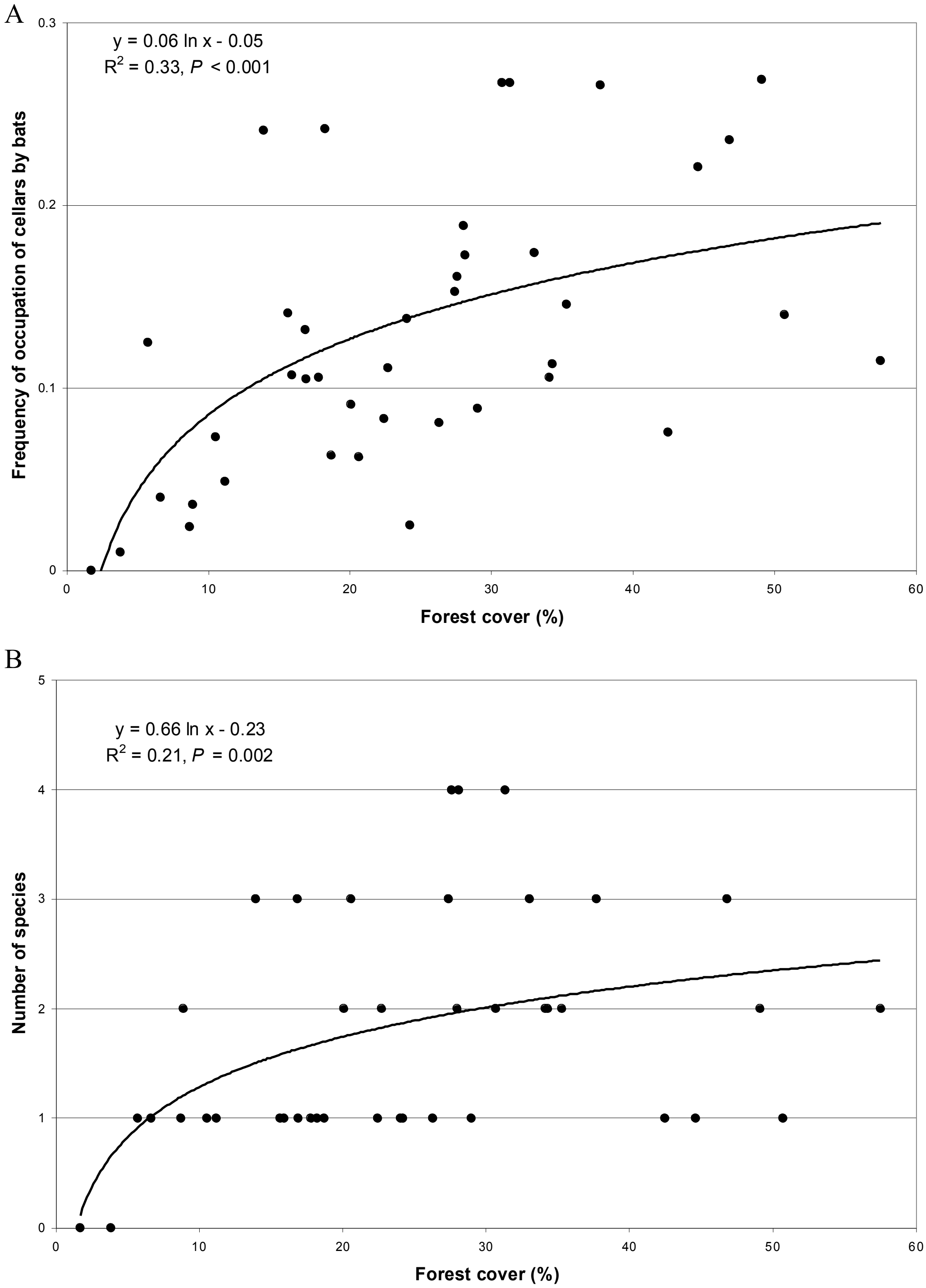

Fig. 1. Increasing frequency of occupancy (FO: number of cellars with bats to total number of cellars) of cellars by bats (A), and number of bat species (B), with greater forest cover in sections of landscape surrounding the villages checked (N = 41).

3. RESULTS

The forest cover in the sections of landscape under study influenced the occupation of cellars by hibernating bats. A stronger relationship was demonstrated for the frequency of bat occurrence in cellars than for the number of species present (Fig. 1). It emerged that the functions describing the regression curves were logarithmic, which is to say that the rates of the changes affecting the dependent variables declined, while they increased far more rapidly at low values for forest cover.

Within the study area, the numerically dominant species were *P. auritus* (49% of all bats successfully identified to species) and *M. daubentonii* (38%). The following species have been also reported: *Myotis nattereri* (Kuhl, 1817), *Barbastella barbastellus* (Schreber, 1774), *Myotis mystacinus* (Kuhl, 1817) or *Myotis brandtii* (Eversmann, 1845), *Myotis dasycneme* (Boie, 1825), *Eptesicus nilssonii* (Keyserling *et* Blasius, 1839), *Plecotus austriacus* (Fischer, 1829), *Eptesicus serotinus* (Schreber, 1774). *P. auritus* was the most widespread of the species, being present in 47 of the 51 cellars, and the most numerous per single cellar (Table 1).

The analysis of the landscape surrounding different bat-occupied cellars revealed significant but weak (R^2 from 0.13 to 0.15) relationships between the number of species and species diversity on the one hand and forest cover or distance to large forest complexes on the other. No similar trends were obtained for maximum number of species of wintering bats or maximal density in relation to forest cover or the distance to large forest (Table 2).

Statistically significant relationships were obtained from comparisons of the occurrence of different bat species in cellars whose surroundings supported different levels of forest cover and were situated at different distances from a large patch of forest. The species concerned were *M. nattereri* and *B. barbastellus*, the cellars occupied by them differing from those from which they were absent in being surrounded by a higher level of forest cover. A statistical significance was also found for differences in the distances from a large patch of forest at which cellars in which *M. nattereri* was present or absent lay. No such relationships were found in the case of *M. daubentonii* and *P. auritus* (Table 3).

4. DISCUSSION

The results of this study suggest that small winter roosts located amongst woods do support bat assemblages of rather higher species richness than those in deforested areas. The low values for the R^2 coefficients may merely suggest that other factors not considered are also of importance, examples perhaps concerning the presence or absence of crevices in cellar walls that are preferable by some bat species during hibernation (Kokurewicz 2004), and specific thermal characteristics taking into account the preferences of individual species (Harmata 1969).

It is also probable that forest cover, as a factor impacting upon the colonisation of cellars, operates on a scale wider than that of their immediate (1 km) vicinity. Support for this idea comes with the stronger relationships appearing in larger sections of landscape covering several tens of square kilometres or more. Individuals of even the most

Table 3. Occurrence of selected bat species in cellars in relation to forest cover of the surrounding landscape and the distance from a patch of forest covering at least 1 km^2.
Number of occupied cellars in parentheses (total number of cellars – 51). M+ – median for cellars occupied by a species, M– – median for cellars not occupied by a species, U – value of the Mann-Whitney test statistic, statistically important differences are bolded.

Species	Forest cover (%)					Distance from a patch of forest covering at least 1 km^2 (km)				
	Range	M+	M–	U	*P*	Range	M+	M–	U	*P*
B. barbastellus (8)	6–47	25	12	89	**0.031**	0–1.2	0.4	0.6	108	0.094
M. nattereri (22)	3–56	22	11	145	**0.001**	0–2.6	0.4	0.6	173	**0.005**
M. daubentonii (40)	0–56	16	9	172	0.271	0–2.6	0.6	1.0	169	0.237
P. auritus (47)	0–72	12	23	68	0.362	0–4.5	0.5	0.6	91	0.902

sedentary of bat species may move much more than 1 km from a breeding area to wintering grounds (Swift 1998, Kowalski *et al.* 2002, Parsons and Jones 2003, Horáček and Đulić 2004).

An influence of forest cover in the landscape on the densities of bats hibernating in cellars could not be demonstrated, most probably on account of the surplus of sites available to be occupied. Landscapes with proportionally greater forest cover, most probably with richer bat assemblages, are associated with greater frequencies of occupancy of cellars (Fig. 1), but not with greater numbers of individuals hibernating in given sites.

A study done in central Poland (Lesiński *et al.* 2007) has pointed to the impoverishment - in terms of both number of species and abundance of bats - that characterises woods covering less than 1 km^2, as compared with larger forest complex. This is in line with a trend towards the smaller number of overwintering species and lower species diversity found for the bats in cellars more and more remote from the nearest piece of forest (Table 2). Those species whose choice of wintering site reveals a dependent relationship as regards forest cover in the landscape or distance from a larger expanse of trees (*i.e. M. nattereri* and *B. barbastellus*) are indeed quite closely associated with forest habitat (Sierro 1999, Siemers and Schnitzler 2000, Topál 2001). *M. nattereri* is common in Polish forests, in which it often spends the day in bird- or bat-boxes (Kowalski and Lesiński 1994), while *B. barbastellus* has been captured in good numbers where nets are set out along forest lane (Lesiński *et al.* 2007).

Similar results were obtained for northern Poland, when occupancy of small cellars within or beyond forest complexes was compared (Marzec 2003). *B. barbastellus* was found to occur significantly more frequently within forest areas, *M. daubentonii* beyond them, while neither *M. nattereri* nor *P. auritus* were affected significantly either way. The results obtained for small wintering sites in both central and north-eastern Poland (this study) would in turn seem to support the contention that *P. auritus* is one of the most eurytopic species, being encountered in landscapes whose forest cover differ very markedly (Swift 1998, Horáček and Đulić 2004).

The relationships obtained by this study offer indirect confirmation of the idea that bat abundance in the landscape reflects the level of forest cover, or - to put it another way - that forests form one of the key habitats for many European bats.

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