The roost preference of *Nyctalus noctula* (Chiroptera, Vespertilionidae) in summer and the ecological background of their urbanization

Zoltán BIHARI
University of Debrecen, Böszörményi út 138., 4032 Debrecen (Hungary)
bihari@helios.date.hu

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ABSTRACT
The paper summarises the investigation of roost-selection of *Nyctalus noctula* in prefabricated panel buildings and trees. The noctule bats occupy only special man-made constructions which are similar in many ways to the natural hollows, providing the same or better climatic conditions than in a tree-hollow. The bats prefer similar height and width of entrances both in the trees and in the panel buildings. In summer the noctule bats prefer roosts situated on the western walls of panel buildings. The rhythm of temperature fluctuation in that side best corresponds to the daily life cycle of the bats. Because of the good roosting possibilities, the density is higher in housing estates than in natural forests. The noctule bats occupy buildings with well determined characteristics. When talking about urbanization, we do not refer to adaptation but only to the use of roosts having more advantageous conditions.

KEY WORDS
Chiroptera,
roost selection,
ecology,
urbanisation.

RÉSUMÉ
Choix du gîte estival en milieu urbain par la noctule commune (Chiroptera, Vespertilionidae).
Cet article présente une synthèse des études menées sur le choix du gîte par *Nyctalus noctula* dans les bâtiments et les arbres. Les noctules occupent uniquement les constructions qui présentent des caractéristiques communes avec les cavités naturelles, aboutissant à des conditions climatiques identiques ou meilleures que les cavités des arbres. Les caractéristiques des entrées des cavités préférées, hauteur et largeur, sont comparables en forêt et en milieu urbain. En été, les noctules préfèrent gîter sur la façade ouest des bâtiments. Le rythme des variations thermiques sur cette face correspond au mieux au rythme quotidien des chauves-souris. La meilleure disponibilité des gîtes en milieu urbain fait que la densité de population y est plus élevée qu'en milieu forestier. Les noctules occupent des bâtiments possédant des caractéristiques précises. L'urbanisation des noctules ne correspond pas à une réelle adaptation au milieu urbain, mais plus simplement à l'utilisation d'un milieu présentant des conditions avantageuses.

MOTS-CLÉS
Chiroptères,
gîtes selection,
écologie,
urbanisation.

INTRODUCTION

Several investigations and studies dealt with the habituation of wildlife and inhabitation of new habitats by animals (Eck 1975; Lancaster & Rees 1979; Bascietto & Adams 1983; Stebbings & Arnold 1987). Generalist species can find suitable climatic and nutritional conditions even in the suboptimal large towns (Erz 1963; Rachwald & Labocha 1996). Those animals having a wide tolerance-spectrum can easily colonise the human habitats and some of them increased in number. Specialist species living in urban habitats are only found in those habitats which are very similar to the natural ones (Adams *et al.* 1985). However this settlement is not determined by a real adaptation but is only due to a plastical behaviour strategy.

In the last decades more and more bats inhabited in human constructions such as buildings and bridges. Some species nearly exclusively roost these man-made constructions (e.g. *Pipistrellus pipistrellus*: Thompson 1992, *Plecotus auritus*: Entwistle *et al.* 1997). Urbanisation is influenced by two factors. On the one hand bats are forced to move into towns because of the loss of traditional roosts, and on the other hand, urban habitats ensure advantageous roosting and foraging habitats. Disappearance of old forests goes together with disappearing of roosts of forest-dwelling bats. Furthermore, deficiency of roosting possibilities is worsened by the fact that competition between birds and bats may increase while numbers of tree holes decrease (Mason *et al.* 1972).

Several authors tried to describe the requirements of bat roosts. Important factors are the size of the entrance (Vaughan 1970), temperature and humidity (Fenton & Rautenbach 1986; Churchill 1991; Entwistle *et al.* 1997), surrounding landscapes (Wunder & Carey 1996), competition with birds (Mason *et al.* 1972) and linear vegetation elements (Limpens *et al.* 1989; Jones *et al.* 1995; Walsh & Harris 1996; Jenkins *et al.* 1998). A roost has to fulfil several requirements. It provides protection from the extreme environmental effects (Vaughan 1987) and predators (Fenton 1983). In a safe roost bats can devote their energies to social interactions (Morrison 1980). In the temperate zone the temperature of the roost has a strong impact on survival (Humphrey 1975). Summing up, it can be stated that characteristic features of roosts have a significant impact on survival and fitness of bats (Vohnhof & Barclay 1996). Nevertheless, it may happen that inhabiting a roost is attached to some special role of the building (Hutto 1985), for example, using of a roost may be related to the fitness-optimalization in such a way that foraging or drinking areas are not far (Tuttle 1976; Speakman *et al.* 1991; Entwistle *et al.* 1997).

Although there are many publications dealing with the biology and behaviour of *Nyctalus noctula* (Sluiter *et al.* 1973; Klawitter & Vierhaus 1975; Gaisler *et al.* 1979; Robel 1982; Heise 1985 and others), many of the ecological and behavioural relationships are still unclear. It is well known that noctule bats do not always roost in trees in summer and in winter as well (Barbu & Sin 1968; Gebhard 1983-1984; Gaisler *et al.* 1979).

In Hungary the noctule bat is the most urbanised bat species. This is the only forest-dwelling species which inhabits also the crevices of prefabricated panel buildings. Those colonies living in housing estates use these artificial roosts during the whole year. Nowadays it is common that thousands of bats live in single housing estates, and the number of individuals is increasing. In order to better understand this trend, we investigated the similarities of the natural and man-made roosts, and the environmental conditions that allow bats to inhabit in panel buildings.

MATERIAL AND METHODS

The investigation was carried out in Debrecen town (250.000 inhabitants), East-Hungary. One of the two study areas is a 103 hectare large housing estate with 195 prefabricated panel buildings. There are also trees and bushes around the blocks of flats and public buildings.

Panels are cavernous, and often separated by gap. Every long gap (horizontal or vertical) between panels can be an entrance into the panel cavity. The full length of gaps in the study area were surveyed and divided into panel-units. The term panel-unit describes a 2 meter long gap. We counted the number of panel-units occupied by bats.
The smallest building is 4 metres high and the tallest is 28 metres. The higher buildings (10 stores block of flats) were made of so called "washed" panel-type. The shorter buildings (less than 4 stores) constructed from so called "painted" panel-type are used for public purposes (school, nursery, community centre). On the whole housing estate there are 135.971 panel-units. 127.439 units from these are "washed" type and only 8.532 units belong to "painted" type. Because 131 from the 142 found roosts were in the "painted" panel, only these 131 roosts between 1997 and 1999 were analysed.
The other study area is a 30 hectare large forested park called Nagyerdő, situated close to the housing estates (1.5 km). There are several tree species, but oak trees more than 100 years old are dominant. The investigations were carried out in 1999-2000.
The main outside parameters (height, size and orientation of entrance, tree species, type of panel) of inhabited and uninhabited panels, and tree holes were taken, according to previous studies (Humphrey 1975; Kunz 1982; Rachwald and Labocha 1996).
The exact location of the roosts in the panel cavities and tree holes were determined. MINI-3 bat detectors were used and the foot of the walls were also surveyed for bat droppings. The coloration around the entrance was also helpful. By detecting the exact position of the entrance individuals flying out from the roosts were counted.
A compass was used to determine the direction of the roosts. The fact that the panels are prefabricated and thus had all the same size, helped us to estimate the height of the roost entrance. A data sheet was filled in, containing the orientation, the height, distance to corner, characteristics of the entrance and surrounding area of the roost.
The temperatures outside and inside of the both roost types were recorded by traditional and digital (DIGITEMP) thermometers (–20 ºC, 50 ºC) both on sunny and cloudy days for a week. Ten thermometers were used at the same time, and temperature was recorded every 2 hours (every hour in the first day) in three types of panel cavities: roost sites, random non roost cavities and adjacent non roost unoccupied panel cavities situated in the same wall of a roost as control samples.
In the park only the 100 cm trunk-circle trees have hollows. All dates of the inhabited and non roost holes were used for comparison.
To compare the roosts and non-roosts, usually nonparametric log-likelihood ratio tests (G-test) were used. The normal distribution was tested by Kolmogorov-Smirnov test. Analyses of correlation were performed to compare the temperatures of the different roosts. SPSS 8.0 for Windows software was used for every calculation

RESULTS

Buildings

On the study area 142 panel units were occupied by noctules, 131 roosts were found in "painted" panel, and only 11 were in "washed" panel. Bats significantly prefered panels of the "painted" type ($G = 651.28$, $df = 1$, $p < 0.001$). Further investigations were carried out only with these 131 units in the "painted" panels.
The size of entrances along the gaps between panels and broken panel edges play a very important role, because the morphology of bats determine the smallest entrance where the bats can get in. The mean entrance of roosts was 24 mm (min.: 19 mm, max.: 28 mm, n = 131).
There was a significant preference for the height in panels ($G = 218.64$, $df = 14$, $p < 0.001$). There wasn't any roost below three metres high (Fig. 1). The most preferred roosts were between the height of 6 and 8 metres (64% of the roosts).
In summer 36.9% of the roosts were on the western side (n = 48), whereas the other roosts are situated in an equal proportion (20.8-21.5%) on

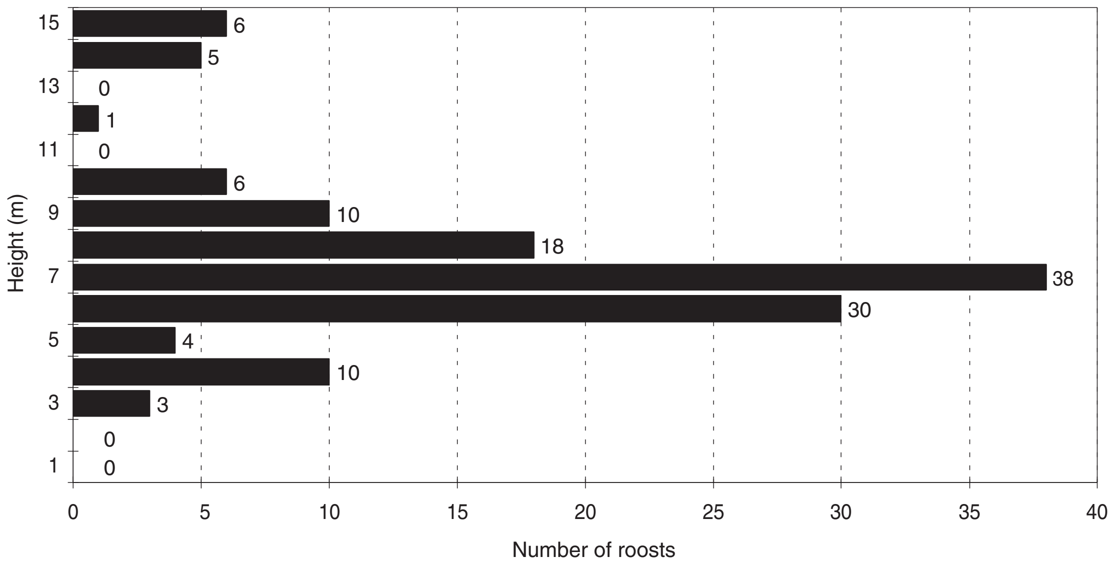

FIG. 1. — Height of roosts of *Nyctalus noctula* in prefabricated panel buildings of Debrecen (Hungary) (n = 131).

TABLE 1. — Orientation of panel units in Debrecen (Hungary) and roosts of noctule bats in summer.

orientation	number of panel units	number of roosts in summer
North	2659	27 (20,8%)
East	2596	27 (20,8%)
South	1525	28 (21,5%)
West	1752	48 (36,9%)
	n = 8532	n = 130

the other sides (Table 1). Bats did prefer the western walls of the buildings ($G = 24.64$, $df = 3$, $p < 0.001$). The inner temperature of panel cavities varied during the day on the differently orientated walls. There were no considerable differences among daily maximum temperatures in random panel cavities on differently orientated walls, but temperature ranged differently on each wall during a day (Fig. 2). The temperature of the southern walls ranged very similarly to the outside temperature. They quickly warmed up parallely to the outside temperature and reached a maximum at 1 p.m. The panel cavities in the western wall warmed up slowly and cooled down later. The temperature peaked three hours later then in the southern wall (4 p.m.). Eastern wall roosts warmed up quickly in the morning, but cooled down earlier in the afternoon, while the temperature in the northern wall roosts followed the outside temperature changes.

We defined bats staying in one roost a “split-community”. Split-communities living in one building or buildings close to each other form one colony as the animals often change their roost even for one night. Bats flying in and out of roosts were counted, thus we may say that a split-community usually consists of 15-30 individuals (median: 26, min.: 1, max.: 98, n = 106) and a colony is formed by about 100-150 individuals. In a same time 95 roosts were occupied, so the density of bats in the study area was 24.0 ind./ha.

TREES

A total of 594 trees with more than one metre trunk-circle were counted in the park. We found 97 hollows in 7 of the 22 tree species (Table 2). Data suggest that the choice of roosts was not dependent of the tree species ($G = 4.48$, $df = 6$, $p = 0.652$). Nearly every fourth hollow was occupied by bats. The hollow entrances were situated between the height of 0,5 and 15 metres (Fig. 3). The

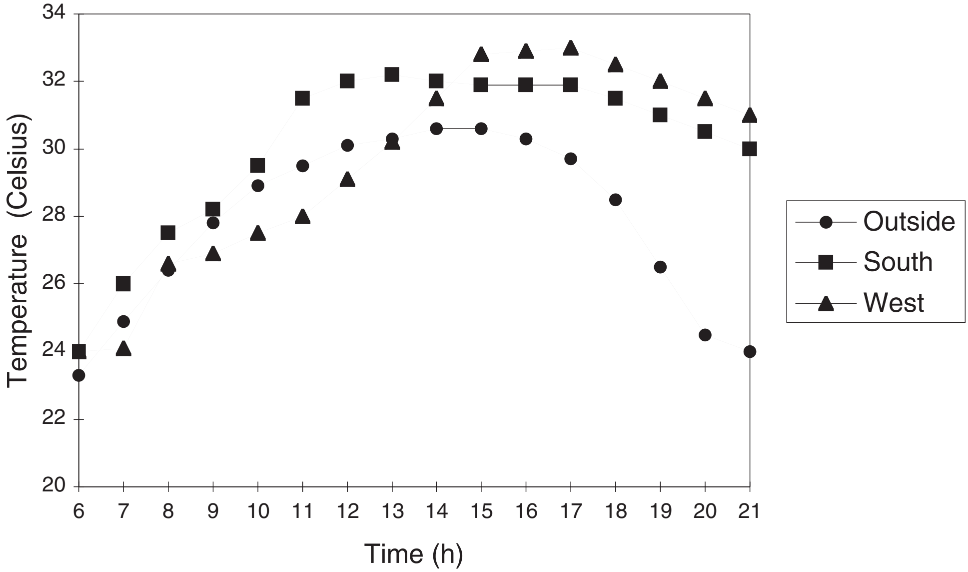

FIG. 2. — Temperature recorded in western and southern sides of the panel roosts (n = 2 x 10) and outside on a sunny summer day (June 7, 1999).

TABLE 2. — Occupation of trees by noctule bats in Nagyerdő park according to tree species, number of old trees and tree hollows.

Tree species	Old trees	trees with hollow/ number of hollows	Inhabited hollows
Quercus robur	216	60/75	18
Pinaceae	127		
Acer ssp.	40		
Robinia pseudoacacia	35	3/3	
Juglans nigra	32	5/10	2
Tilia ssp.	30		
Celtis occidentalis	28	1/1	
Ailanthus altissima	23		
Quercus rubra	15		
Salix chrysocoma	11	4/4	1
Platanus hybrida	9		
Sophora japonica	7		
Populus alba	5		
Pyrus pyraster	4	1/3	
Populus nigra	3		
Populus italica	2		
Fraxinus ssp.	2		
Prunus avium	2		
Morus alba	1		
Gleditsia triacanthos	1		
Catalpa bignonioides	1	1/1	
Total:	594	75/97	21

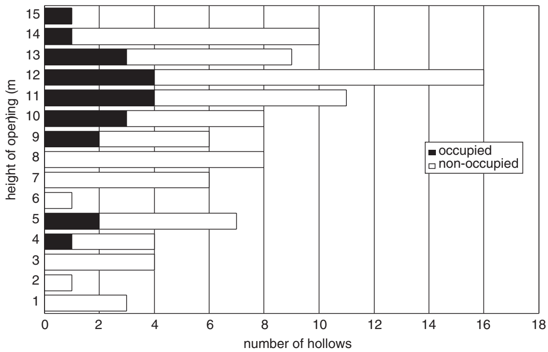

FIG. 3. — Height of entrances of occupied and non-occupied tree hollows in Nagyerdőpark (Debrecen, Hungary).

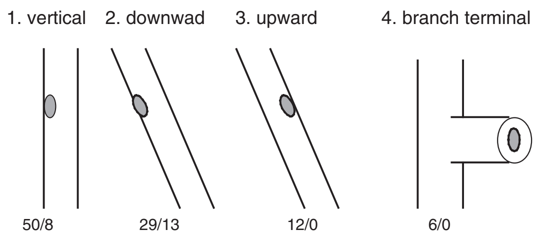

FIG. 4. — The four main positions of entrances of tree hollows in Nagyerdőpark (total number/occupied hollows).

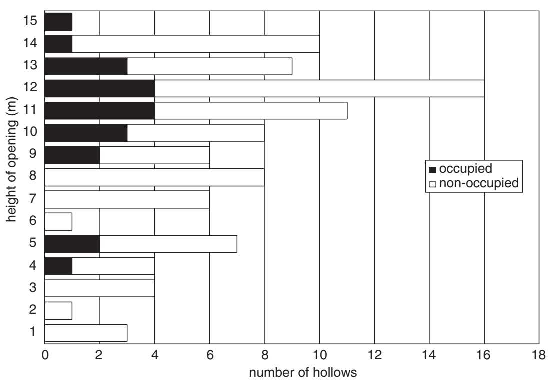

FIG. 5. — Inner temperature in a tree hollow and in the different sides of a panel on June 9, 1999).

entrances of the roosts were found at a 4-15 metres height. No significant preference was detected at any height (G = 18.89, df = 14, p = 0.169), even 18 from 21 roosts were located above 8 metres.

From the investigated 97 hollows, 26 had northern, 32 southern, 22 eastern, 17 western entrances. From the 21 roosts, 6 had northern, 8 southern, 4 eastern, 3 western entrances. The direction of the roost entrances showed no significant preference of the point of the compass (G = 1.26, df = 3, p = 0.740).

All roosts had a round entrance made by woodpeckers with a diameter of 4-5 cm (median: 4.6, min.: 4.0, max.: 5.0, n = 21). None of the hollows with bigger entrance was occupied by bats.

Entrances on the trunks and branches were in different positions, that we divided into four groups (Fig. 4). Noctule bats tended to choose entrances more or less pointed to the ground ("downward" position) (G = 14.35, df = 3, p = 0.002), and to avoid the "upward" position.

The position of the entrances could be orientated differently, but the shadow of the tree foliage always inhibited the sun radiation to heat directly the hollows. In every hollows similar temperatures were measured, without any dependence from the position.

The average daily temperature of 10 tree-hollows was compared to the temperature of different orientated panel hollows (Fig. 5). The strongest correlation was found with the western wall (r = 0.882, df = 7).

Within the 30 ha park, 21 occupied hollows were recorded. In a single hollow an average of 17 bats formed a colony (median: 17, min: 1, max.: 100, n = 13). This indicates that ca. 357 noctule bats roosted in the park, which is equivalent to 11.9 ind./ha.

DISCUSSION

Between 1997 and 1999 131 roosts were explored in "painted" panel buildings. The results showed noctule bats do not roost below the height of 3 metres. They prefer the height between 6-8 metres. This height is quite similar as the height of the tree hollows in the park (4-15). Ryberg (1947) found them at 5-8 metres and Stratmann (1978) at 3-12 metres height on trees in Germany. Gaisler *et al.* (1979) found the roosts of noctule bats at an average height of 5.1 metres in forests of the Czech Republic.

There are small, only few centimetres large spaces in the panel cavities and tree hollows. Both types of roosts have entrances on a vertical object (wall, tree). Entrances narrower than 1.9 cm make it impossible for the bats to occupy panel or tree hollows. The bats also do not like entrances wider than 5 cm. Heerdt and Sluiter (1965) also found that noctule bats prefer narrow entrances and narrow inner spaces in tree hollows.

Bats living in forests occupied only the shaded hollows, because there were no sun-exposed ones. In the housing estates noctule bats had the choice, so they prefered the western walls, where the correlation of the temperature fluctuation was the strongest with those in the tree hollows. In the roosts situated on the western walls the fluctuation of temperature was suitable for the life-rhythm of bats: in the morning, when bats spent their daily rest and were in torpor, the roost was coolest. The temperature inside roost located at the western wall reached it's maximum in late afternoon. This was exactly the time when bats became more active and warmed up their bodies. The warmer roost heleds in this process, so bats could save energy. The temperature change corresponded very well to the requirements of bats in trees and in panels, but the panel was warmer, which could help saving energy. We know that the temperature of roosts can have strong impact on the bat colonies. Bats reduce their thermoregulation costs to select warmer roost (Entwistle *et al.* 1997). *P. auritus*, weighing 8 grams, can save 1 kJ energy per day (4%) from the 25.5 kJ energy necessary for resting if the roost is 1.2 °C warmer. A warm roost is particularly important during pregnancy (Racey & Swift 1981) and breeding time (Tuttle 1975) when it helps their survival (Ransome 1989).

We did not investigate the influence of the availability of vegetation around the buildings on roost selection because noctule bats usually hunt several kilometres far from the roosts and they flew up to 50-100 metres high just after the emergence. It was asserted that the noise of traffic did not disturb the bats.

If bats find all necessary conditions, they can form stable colonies. The density in housing estates (24.0 ind./ha) and in the park (11.9 ind./ha) was higher than in a natural forest (0,06-2 ind./ha) (Gaisler *et al.* 1979), indicating that the study area allowed excellent roosts for noctule bats. Density in both the housing estate and in the park was very similar to the density (18.3-24.1 ind./ha) which was estimated by Cerveny and Bürger (1987) in a favourable park.

These results suggest that noctule bats occupy only special man-made constructions which are similar in many ways to the natural hollows, offering the same or better climatic conditions than tree hollows.

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