Theriologia Ukrainica, **20**: 3–9 (2020)
http://doi.org/10.15407/TU2003

MACROSPATIAL STRUCTURE AND BIODIVERSITY OF BAT COMMUNITIES (CHIROPTERA) OF THE EUROPEAN FAUNA IN THE FOREST-STEPPE HABITAT

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Macrospatial structure and biodiversity of bat communities (Chiroptera) of the European fauna in the forest-steppe habitat. — A. A. Bilushenko. — Twelve bat species of seven genera of the family Vespertilionidae were studied in conditions of the Central Forest-steppe of Ukraine (*Myotis nattereri, M. daubentonii, M. dasycneme, Barbastella barbastellus, Plecotus auritus, Pl. austriacus, Pipistrellus pygmaeus, P. kuhlii, P. nathusii, Nyctalus noctula, N. leisleri, Vespertilio murinus*, and *Eptesicus serotinus*). The data were collected during decade-long surveys (2007–2016) in the Central Forest-Steppe (Cherkasy, Kirovohrad, and Kyiv Oblasts, Ukraine) at 23 localities. The census route included 680 km walked along the surveyed territory. The species composition of different habitats was determined during faunal and indoor surveys, when a certain type of landscape changes to another, and also by comparing the species composition of communities in different types of habitats. For species diversity comparison, five types of habitats were selected: forest (W), towns and villages (A-W), wood lines and fields (F-W), wetland areas (A-W), and forest parks (W-P). The analysis of record localities of bats and the character of their biotopic distribution shows that most species prefer floodplains with trees (wetland areas (A-W) and forest parks (W-P)), where the maximum number of species was noted. Quite high diversity was also noted for settlements (T-W). Based on abundance, a noticeable decrease of the diversity index occurs during the transfer from the area of wetland types to fields and wood lines. Due to the character of differences between groups of local bat species, relative to spatial distribution of species on topical and trophic levels, the performed analyses helped us to outline four groups of species. The first group includes species united by open type habitats (*N. noctula* and *N. leisleri*). The second group comprises *V. murinus*, *E. serotinus*, *P. pygmaeus,* and *P. kuhlii*, which are very hard to relate to a separate type of locality. The third group includes species that prefer closed habitats: *M. nattereri, M. daubentonii*, *Pl. auritus, P. nathusii*, and *B. barbastellus*. The fourth group comprises *M. dasycneme*, a species that is relatively rare in the studied territory and is related to lakes and slow flowing water bodies.

Key words: bats, forest-steppe, bat community, Vespertilionidae.

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Introduction

Bats are the only group of mammals capable of active flight. During the last decades, the number of studies on the biotopical distribution of bats in natural environments has increased (Walsh & Harris 1996; Gaisler *et al.* 1998; Zukal & Rehak 2006; Smirnov & Vehnik 2012).

It is known that separate bat species differ by the flight peculiarities, hunting grounds, and shelter types (Norberg & Rayner 1987; Mazurska & Ruczynski 2008). These ecological differences reduce the level of competition between species, allowing other bat species to coexist in the same territory. This increases the value of these animals as limiting factor for the abundance of insects that can damage cultivated, ornamental, and forest plants or can cause discomfort to domestic animals and people. It is proven that hunting grounds of insectivorous species have almost no mosquitoes (Kuzyakin 1950). The choice of hunting grounds is also influenced by their availability for separate bat species (Verboom 1998), while hunting strategy is influenced by morphological features of particular species (Norberg & Rayner 1987; Kruskop 1996 *a–b*).

Research on bats of any region is of significant importance allowing its condition to be evaluated. Moreover, bats can be an indicator group of species (Jones *et al.* 2009). Biodiversity evaluation carried out on a single-species level often allows us to evaluate the changes occurring in a particular territory. The European bat species surveyed during our investigation are exclusively insectivorous, differing by a variety of ecological forms depending on the conditions determined by the landscape and the climate of a given area.

This research aims to demonstrate the macrospatial structure of local communities of European bat species within the landscape of the forest-steppe zone.

Material and Methods

The study is based on data collected during a decade-long survey (2007–2016) in the Central Forest-Steppe (Cherkasy, Kirovohrad, and Kyiv Oblasts, Ukraine) (Fig. 1). Surveys were carried out at 23 localities on a total route of 680 km. Field data were analysed using Statistica for Windows 6.0 Stat-Soft, Inc., 2001.

Shannon`s biodiversity index (H_s) and evenness index (E) were calculated in Past v.3 according to the algorithm given below (1, 2):

$$Hs = -\sum_{i=1}^{S} \left(\frac{ni}{N}\right) \ln \left(\frac{ni}{N}\right), \quad (1)$$

n_i — the number of individuals (respectively $N1$, $N2$, ….); N — total number of individuals; S — number of species.

Uniformity of distribution (evenness):

$E = H_s / H_{max}$ (2)

$Hmax$ — the maximum value of the diversity with an equal number of individuals of all species.

The main quantitative characteristics of bat species in their communities, such as relative abundance, were determined according to the previously applied methodology (Pesenko 1982; Strelkov & Illin 1990).

Two methods were used for bat surveys. The main method is stationary based on direct contact (catching with mist net, without the removal animals from their natural habitats). As an additional method of distant research, the ultrasonic detector Petterson D200 was used during route surveys a few hours after sunset, as well as to find gathering places of bats in time of their hunting on insects. The remote method does not provide as exact data as stationary, but it allows some bat species to be identified in certain habitat types.

Fig. 1. Location of the study area.

Рис. 1. Територія досліджень.

To calculate the abundance of bat species, we mostly used the contact method and only partly the remote method, which allowed us to register some bat species that are not recorded by the contact method (but depending on the detector model's capacity and on habitat types). For example, *M. dasycneme* can be easily identified above the water surface in open areas by detector, but this species is usually not recorded when using the contact method. Both methods are used to calculate indices of species diversity and fauna similarity.

The species composition of different habitats was determined during faunistic and indoor surveys. Beta-diversity was determined by evaluating the change of alpha-diversity. As a measure of comparative evaluation of diversity of bat communities and their diversity, we used the Chekanovsky-Serensen index (Pesenko 1982), which can also serve as a measurement of transformation comparison of selected types of surroundings.

For species diversity, five habitat types were selected and compared: forest (W), towns and villages (A-W), wood lines and fields (F-W), wetland areas (A-W), and forest parks (W-P).

According to the survey results considering the fact that all of the local bat species are exclusively insectivorous, we divided the bats into groups depending on their spatial distribution on topical and trophic levels using the method of multidimensional scaling (Daveson 1988; Dzeverin 2012). This research algorithm can be used for any territory of the forest-steppe region.

This division is adapted to the landscape conditions of the surveyed territory and can also be used in other countries with landscapes of similar type:

I — open space (above the top of trees and in places with no trees),

II — semi-open space (between buildings and trees without dome),

III — closed space (under the dome of trees, above and on the level of bushes and young trees),

IV — wetland and above-water space.

Results and Discussion

Thirteen species of the family Vespertilionidae were recorded in the territory of forest-steppe of Ukraine. During the survey, 1216 specimens were caught and studied: *Myotis nattereri (M. n), M. daubentonii (M. d), Barbastella barbastellus (B. b), Plecotus auritus (Pl. au), P. austiacus (Pl. as), Pipistrellus pygmaeus (P. p), P. kuhlii (P. k), P. nathusii (P. n), Nyctalus noctula (N. n), N. leisleri (N. l), Vespertilio murinus (V. m),* and *Eptesicus serotinus (E. s).* The only species that was recorded by ultrasound detector was *Myotis dasycneme (M. ds)*. All of the recorded bats belong to the widely distributed European bat species (Battersby 2010).

Most of the recorded species are closely related to areas with deciduous vegetation. On the topical level, the comparison of shelter types used by bats (natural and anthropogenic shelters in the forest-steppe of Ukraine) showed significant differences s ($\chi^2 = 113.95$; $p < 10^{-6}$; $n = 186$). Moreover, the degree of usage of anthropogenic shelters is higher on the species level, the major influence on which is made by synanthropic bat species (*P. kuhlii* and *E. serotinus*).

Although, due to the number of findings, undoubtedly, the natural shelters play the most important role for bats in this territory (Bilushenko 2015). Especially, it concerns species that belong to forest communities: *M. nattereri, M. daubentonii, B. barbastellus, Pl. auritus, P. pygmaeus, P. nathusii, N. noctula,* and *N. leisleri*. Besides, the aptitude to the synanthropic way of life of the mentioned species in the forest-steppe habitat can be regarded as gradual adaptation of these animals to anthropogenic transformation of natural habitats.

During the review of the general bio-diversity of investigated types of places, especially, changes (beta-diversity), we managed to track the range of regularities. The analysis of places of findings of bats and the character of their biotopic distribution shows that most species prefer closed areas with trees. In that way, the highest value of Shannon's diversity index of relative abundance of investigated bats (n = 1216) was determined for forest and wetland areas. Wetland areas also play an important role as hunting grounds and watering places (Fig. 2).

In such types of areas, we registered the maximum number of bat species common for forest-steppe habitats. High species diversity was revealed in residential areas, which was determined not by the number of species, but by the uniformity of determiners of their partial participation in the community (E = 0.4063). It should be pointed out that the pattern of habitats distribution plays a crucial role for a clear zonation starting from central parts of cities surveyed to their green areas. This primarily refers to big cities and urban habitats in general. It should be emphasized that a major role here is played by the mosaic structure of bat habitats, which overlaps on well-defined zonation from the central parts of the surveyed residential areas to their green areas, which is mainly related to large cities and urban habitats.

According to species abundance, a noticeable reduction in the diversity index occurs at the transition from wetland areas to fields and wood lines, although it remains high compared to residential areas because of the high index of uniformity (E = 0.9218). It can be explained by the degree of domination of separate species during the survey (Fig. 2). Although, according to our research, this type of locality attracts bats despite the fact that fields and wood lines may be richer in insects, and, according to many experts, may become a fruitful place for hunting (Gaiser & Kolibae 1992).

The analysis of values of relative abundance of bats by different habitats types showed significant differences (Table 1). While comparing the flight activity (based on survey results) of 13 species in five habitat types, three clusters could be distinguished. The first cluster unites species that are more related to residential areas and agricultural landscapes (fields and wood lines). The second cluster comprises species that are mainly confined to wetlands and parks. The third cluster includes species that are confined to forests and most of which are members of forest bat communities: *Myotis nattereri, M. daubentonii, Barbastella barbastellus, Plecotus auritus, Pipistrellus pygmaeus, P. nathusii, Nyctalus noctula,* and *N. leisleri.*

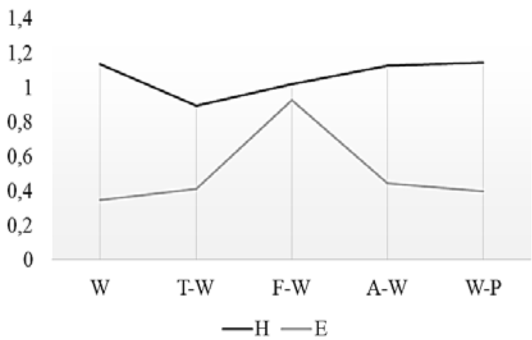

Fig. 2. Beta-diversity of communities of European bat species in the territory of the central forest-steppe of Ukraine by habitat types and relative abundance according to survey results (H — Shannon's Index, E — evenness index).

Рис. 2. Бета-різноманіття угруповань європейських видів рукокрилих поширених на території Центрального Лісостепу України за типами місцевості і показнику відносної рясності за результатами відловів (H — індекс Шеннона, E — індекс вирівняності).

Table 1. Differences in the analyses of distribution of values of relative abundance of bat species in different types of habitats (Chi-square test, $p < 0.05$) (n = 1216)

Таблиця 1. Відмінність в аналізі розподілу показників відносної рясності видів рукокрилих в різних типах місцевості (Chi-square test, $p < 0.05$) (n = 1216)

Habitat	W	T-W	F-W	A-W	W-P
W	$\chi^2 = 0.0$, $p = 0.0$	$\chi^2 = 293.66$, $p < 10^{-6}$	$\chi^2 = 385.6$, $p < 10^{-6}$	$\chi^2 = 46.657$, $p < 10^{-6}$	$\chi^2 = 79.238$, $p < 10^{-6}$
T-W	$\chi^2 = 293.66$, $p < 10^{-6}$	$\chi^2 = 0.0$, $p = 0.0$	$\chi^2 = 17.581$, $p = 0.0035$	$\chi^2 = 107.41$, $p < 10^{-6}$	$\chi^2 = 117.77$, $p < 10^{-6}$
F-W	$\chi^2 = 385.6$, $p < 10^{-6}$	$\chi^2 = 17.581$, $p = 0.0035$	$\chi^2 = 0.0$, $p = 0.0$	$\chi2 = 51$, $p < 10^{-6}$	$\chi^2 = 71.804$, $p < 10^{-6}$
A-W	$\chi^2 = 46.657$, $p < 10^{-6}$	$\chi^2 = 107.41$, $p < 10^{-6}$	$\chi^2 = 51$, $p < 10^{-6}$	$\chi^2 = 0.0$, $p = 0.0$	$\chi^2 = 30.43$, $p = 0.0003$
W-P	$\chi^2 = 79.238$, $p < 10^{-6}$	$\chi^2 = 117.77$, $p < 10^{-6}$	$\chi^2 = 71.804$, $p < 10^{-6}$	$\chi^2 = 30.43$, $p = 0.0003$	$\chi^2 = 0.0$, $p = 0.0$

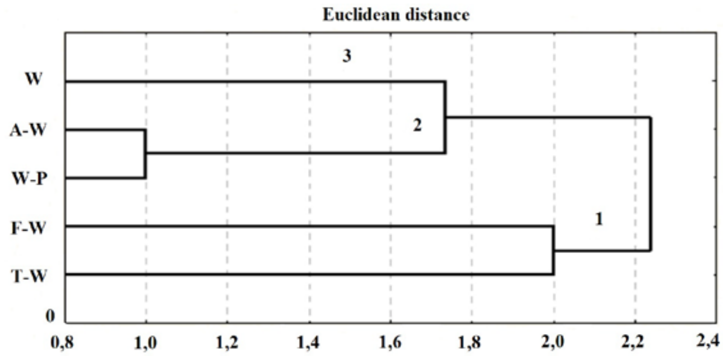

Fig. 3. Dendrogram of similarity of species composition of bat communities indifferent habitat types.

Рис. 3. Дендрограма подібності видового складу угрупувань рукокрилих за різними типами місцевості.

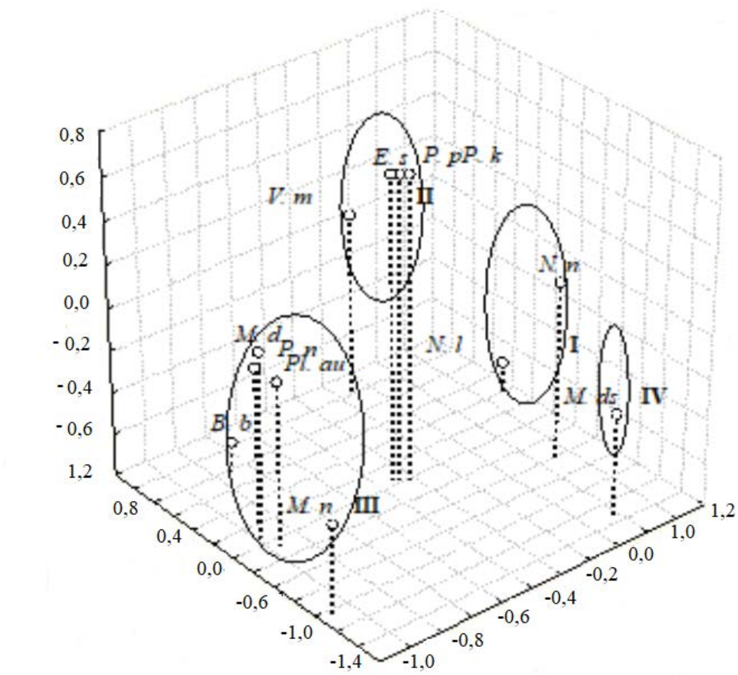

Fig. 4. Division of bat species into groups in the forest-steppe relative to space on topical and trophic levels (Dim 1, Dim 2, Dim 3 — measurement of multidimensional scaling).

Рис. 4. Розподіл видів рукокрилих на групи в лісостеповому середовищі існування відносно простору на топічному і трофічному рівнях. (Dim 1, Dim 2, Dim 3 — виміри багатомірного шкалювання).

Due to the character of differences between groups of local bat species relative to spatial distribution of species on topical and trophic levels, the performed analyses allowed us to distinguish four groups of species (Fig. 4).

The first group includes species united by open spaces (χ^2 = 38.88; p = 0.023; n = 150). It includes representatives of the genus *Nyctalus* (*N. noctula* and *N. leisleri*), what was known earlier (Muller *et al.* 2013). These species have low flight maneuverability, which differentiate them from other species of the family Vespertilionidae relative to feeding strategy along with morphological factors (Kruskop 1996*b*). It is relatively well-known that the wing morphology in bats (length, width) has a rather strong influence on the choice of hunting grounds (Jung *et al*. 2012; Muller 2012). They mostly forage in open environments (above the trees, lawns, meadows, forest edge).

The second group comprises representatives of three genera: *Vespertilio* (*V. murinus*), *Eptesicus* (*E. serotinus*) and *Pipistrellus* (*P. pygmaeus, P. kuhlii*). These species are very hard to be related to a particular habitat type because of the lack of data on preferred habitats. We only know that these species avoid closed habitats (Sologor & Petrusenko 1973; Sologor 1980; Bauerova & Ruprecht 1989) and that their ration differs, which indicates different foraging strategies (Robinson & Stebbings 1993; Goiti *et al.* 2008; Arutyunyan *et al*. 2015).

The third group includes representatives of four genera: *Myotis* (*M. nattereri*, *M. daubentonii*), *Plecotus* (*P. auritus*), *Pipistrellus* (*P. nathusii*) and *Barbastellus* (*B. barbastellus*).

This third group is united by the open type habitat ($\chi^2 = 30.55$; $p = 0.020$; $n = 72$). Although, their abilities are not limited, mostly because of the given type of space and because of the same reason as the previous group of species (Norberg & Rayner 1987; Georg & Bauerova 1987; Shiel *et al.* 1991; Kruskop 1996*b*), which also is proven by the differences in morphological features (Norberg & Rayner 1987; Kruskop 1996 *a–b*; Jung *et al*. 2012; Muller 2012).

The fourth group comprises species that are rare in the surveyed territory, *M. dasycneme*, which has, according to the survey results, a narrow differentiation in forest-steppe environment. This differentiation is determined by favouring stable and lagging waterbodies. We noted only a few sporadic registrations.

The above bats differ from one another by different flight patterns, hunting grounds, and foraging specifics. Such differentiation between those species reduces competition in the forest-steppe environment and allows the species to coexist in one large area.

As a conclusion, it is important to mention that despite the fact that bats prefer different types of habitats, open and closed habitat types are the least attractive to them (McAnney & Fairley 1988; Kusch *et al*. 2004). Despite these arguments, our survey showed that there are species that use these habitat types. This fact can be related to local landscape structure.

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