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DIVERSITY OF MUROID RODENT COMMUNITIES IN KEY HABITATS OF THE SKOLE BESKIDS (EASTERN CARPATHIANS)

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Diversity of Muroid Rodent Communities in Key Habitats of the Skole Beskids (Eastern Carpathians). — **Stetsula, N., Barkasi, Z., Zagorodniuk, I. —** Quantitative and qualitative analysis of the structure of muroid rodent communities has been conducted in nine biotope types of the Skole Beskids National Park. Indices of species and taxonomic richness, as well as of species and taxonomic diversity are presented. The highest taxonomic richness of muroid rodents has been revealed in beech-spruce forests, clearcuttings, and meadows. These biotopes are most capable to maintain high species diversity. The high species diversity in meadows is related to the variety of meadow cenoses according to elevation, type of neighboring biotopes, and origin. The highest taxonomic diversity characterizes hornbeam-beech, beech, and mixed forests indicating high stability and sustainability of muroid rodent communities in them, because these are biotopes with native phytocenoses. The rodents' species diversity within the park is maintained by the diversity of biotopes, their area and available trophic resources. Diversity indices have a functional relation with the taxonomic richness, which allows estimating diversity by the species richness and avoid calculations of diversity indices.

Key words: communities, species richness, taxonomic diversity, rodents, Carpathians.

Різноманіття угруповань мишуватих гризунів у ключових біотопах Сколівських Бескид (Східні Карпати). — Стецула, Н., Баркасі, З., Загороднюк, І. — Проведено якісно-кількісний аналіз структури угруповань мишуватих гризунів у дев'яти типах біотопів Національного природного парку «Сколівські Бескиди». Наведено дані про показники видового та таксономічного багатства й різноманіття. Виявлено, що максимальне таксономічне багатство мишуватих гризунів характерне для буково-ялинових лісів, зрубів та лук. Такі біотопи в найбільшій мірі здатні підтримувати високий рівень видового різноманіття. Високий ступінь видового різноманіття лук пов'язаний з різноманіттям лучних ценозів, у т. ч. за висотами, прилеглими біотопами та їх походженням. Найвище таксономічне різноманіття характерне для грабово-букових, букових та мішаних лісів, що свідчить про високу стабільність і стійкість угруповань мишуватих гризунів у них, оскільки це біотопи з корінними гірсько-лісовими фітоценозами. Видове різноманіття гризунів у межах Парку забезпечується різноманітністю наявних біотопів, їхньою площею та наявними трофічними ресурсами. Показники різноманіття мають функціональний зв'язок із таксономічним багатством, що надалі дозволяє оцінювати різноманіття за показниками видового багатства та уникати розрахунків індексів різноманіття.

Ключові слова: угруповання, видове багатство, таксономічне різноманіття, гризуни, Карпати.

Introduction

Since the middle 1900s, investigation of distribution, diversity and structure of animal communities in mountain systems has been one of the central research issues in biogeography. The main sphere of research has been the clarification of the distributional patterns of species diversity at different elevations, which largely resemble the animals' distribution at various latitudes. When the concept of insular fauna appeared (Vuilleumier, 1970; Brown, 1971, 1978), investigation of isolated montane-boreal animal communities, in particular of mammals, has been started as well.

Mountain ridges are characterized by a significant diversity (heterogeneity) of biotopes. Study results showed that the type of biotopes significantly affects species diversity of a region. Therefore, biotopes that maintain diversity on a regional scale are of key importance, and their identification and protection is necessary for species conservation (Davidar, 2001; Tews et al., 2004).

Besides the type of biotopes, species diversity in general is determined by several biotic and abiotic factors, which can be grouped into four categories (according to Diamond, 1988): (1) quality (diversity of niches and resources); (2) quantity (number of consumer individuals); (3) interactions (predation, herbivory, mutualism, parasitism, competition, disease); (4) species dynamics (extinction, immigration, speciation, temporary fluctuations in species diversity). Some factors control diversity in a non-monotonic way, i.e. increasing or decreasing diversity.

Studies on the role of factors that determine altitudinal distribution of animals, particularly small mammals, showed that the influence of biotic factors is more complex, because, on the one hand, species distribution is determined by historical events on Earth, individual peculiarities of the phylogenetic history of species, and temporal environmental conditions. On the other hand, distribution of species is also influenced by interactions with other organisms (Brown, 2001). A global analysis of altitudinal diversity trends for non-volant small mammals revealed a clear pattern of mid-elevational peaks in species richness, however the reasons of such pattern has not been fully clarified yet (McCain, 2005). Hence, investigation of the diversity and distribution of small mammals in mountain systems remains a relevant research topic.

Environmental changes in the past played a key role in emergence of biodiversity patterns, and current environmental changes are responsible mainly for maintaining of these patterns (Brown, 2001). Therefore, evaluation and conservation of biodiversity are priority strategies for ensuring sustainable development of territories, including protected areas as well (Ємельянов, 1999).

The Skole Beskids National Nature Park is located in the Outer Eastern Carpathians, in the territory of Ukraine. The region is characterized by high level of forest cover, mosaic and diverse ecosystems, as well as altitudinal zoning. All these factors influence the formation of different key habitats and, consequently, various faunal assemblages. There have been several research dedicated to the diversity of faunal communities (mainly of invertebrates) in different biotope types of the Beskids' region (Різун, 2000; Чумак та ін., 2007; Гірна, 2013), but data on diversity of small mammal communities in the Skole Beskids are much less available.

Communities consisting of species of different higher taxa are naturally more heterogenic compared to those that include species of a single higher taxon, and they determine the value of the biotope type in which they exist. Investigation of taxonomic capacity and uniqueness of the biotopes of the Skole Beskids is a relevant research topic. Such studies are based on evaluations of diversity and on coherent taxonomic and morpho-ecological differentiation of communities and allow studying the structure of taxonomic relations between species in a community.

The main goal of the present study is to estimate the richness and diversity indices of rodents of the superfamily Muroidea common for key biotopes of the Skole Beskids NNP with the aim to compare biotopes with native and transformed phytocenoses. In addition, we aim to determine the role of different biotope types in maintaining of high species richness and taxonomic diversity of muroid rodent communities.

Material and methods

Materials used in this study were collected during 2004–2008 in nine types of biotopes in the territory of six forestry districts of the park (Pidhorodtsivske, Maidanske, Zavadkivske, Butyvlianske, Skolivske, Krushelnytske). These districts are located at elevations 500 to 1268 m a.s.l. All of the biotope types where rodent sampling was carried out are tagged by the following abbreviations: BEF — beech (*Fagus sylvatica*) forests, BSF — beech-spruce (*Fagus sylvatica*, *Picea abies*) forests, HBF — hornbeam-beech (*Carpinus betulus*, *Fagus sylvatica*) forests, SFF — silver fir (*Abies alba*) forests, MIX — mixed forests (*Quercus robur*, *Carpinus betulus*, *Tilia* spp., *Betula* spp., *Picea abies*), CCU — clearcuttings, MEA — meadows.

For animal sampling the transect method with Hero traps was used, which is considered to be effective for interpretation of the structure of small mammal communities, as well as their distribution and relative abundance (Загороднюк та ін., 2002; Pearson, Ruggiero, 2003). Obtained results were partly published in some of our earlier contributions (Барабаш, Стецула, 2007; Стецула, Обух, 2011; Стецула, 2012). It should be noted that species names are used according to the "Taxonomy and nomenclature of mammals of Ukraine" (Загороднюк, Ємельянов, 2012).

To compare muroid rodent communities two kinds of diversity indices have been used: the Shannon-Weaver index and the Simpson index (Бигон та ін., 1989). Two variants of indices have been calculated: species diversity (H and D) and taxonomic diversity (H_t and D_t).

Estimating species diversity indices, the following quantities have been used as variables: p_i — proportional abundance of species, S — species richness (the number of species) according to sampling results on the trap-lines. Species evenness indices (Shannon, J and Simpson, E) have been also calculated for each biotope type. The meaning of these indices is shown in tab. 1.

Taxonomic diversity indices (H_t) have been calculated similarly to the species diversity indices (Загороднюк та ін., 1995; Ємельянов та ін., 2008). The concept of taxonomic diversity requires the following actions: firstly, we have estimated the taxonomic richness of communities in each biotope (i.e. the sum of taxonomic ranks), and, secondly, we have calculated the taxonomic diversity index and taxonomic evenness index. The meaning of these indices is shown in tab. 1 as well. The variables in case of taxonomic diversity are: p_i — proportion of i-th taxonomic rank, N — number of ranks (species, genus, family, order).

Results

The obtained results we present separately for species diversity and taxonomic diversity.

Species richness and diversity

It is known that different types of biotopes are inhabited by communities that differ from one another in species composition and proportional abundance of these species. Data on the number of species and their relative abundance obtained during investigations in different biotope types of the Skole Beskids National Nature Park are represented in tab. 2 (Барабаш, Стецула, 2007; Стецула, Обух, 2011). These data were used for estimations of diversity indices — the Shannon-Weaver and Simpson species diversity (H, D) and species evenness (J, E) indices.

Table 1. Species and taxonomic diversity indices evaluated in this study

Таблиця 1. Показники видового і таксономічного різноманіття, оцінені в цій праці

Estimation	Shannon-Weaver index	Simpson index
Species diversity index (p_i — proportional abundance of species)	$H = -\sum p_i \times log_2 p_i$	$D = 1 / \sum (p_i)^2$
Species evenness (S — species richness, the number of species)	$J = H' / log_2 (S)$	$E = D / S$, де H'
Taxonomic diversity index (p_i — proportion of ith taxonomic rank[1])	$H_t = -\sum p_i \times log_2 p_i$	$D_t = 1 / \sum (p_i)^2$
Taxonomic evenness (N — number of ranks: species, genus, family, order)	$J = H_t / log_2 N$	$E = D_t / N$

[1] Proportion of i-th taxonomic rank — unlike estimation of species diversity, when the proportional abundance of i-th species in the general sample is taken into consideration, in case of taxonomic diversity index the variables are the proportions of corresponding taxonomic ranks from the sum of all taxa represented in the sample. For instance, when a sample contains 5 species of 3 genera of 2 families, proportions of these taxa, respectively, are 0.5, 0.3, and 0.2. These values will be the variables in the formula. For more details about the concept of taxonomic diversity see Загороднюк та ін., 1995; Ємельянов та ін., 2008.

Table 2. Proportional abundance of muroid rodent species in different biotopes of the Skole Beskids NNP and evaluation of species richness and species diversity indices (data for 2004–2008)

Таблиця 2. Частки трапляння мишуватих гризунів у різних біотопах НПП «Сколівські Бескиди» та оцінки видового багатства та видового різноманіття (дані за 2004–2008 рр.)

Species and indices	n	BEF	BSF	HBF	SFF	MIX	CCU	MEA	Total
species									
Micromys minutus	4	0.012	–	0.013	–	–	0.029	0.003	0.005
Apodemus agrarius	30	–	0.081	–	0.017	0.005	0.029	0.064	0.034
Mus musculus	5	–	0.027	–	–	0.010	0.029	0.003	0.006
Sylvaemus tauricus	156	0.369	0.162	0.506	0.183	0.272	0.171	0.019	0.178
Sylvaemus sylvaticus	79	0.119	0.054	0.052	0.117	0.218	0.229	0.008	0.090
Myodes glareolus	205	0.405	0.270	0.299	0.550	0.422	0.229	0.027	0.235
Arvicola scherman	71	–	0.054	–	0.033	–	–	0.179	0.081
Terricola subterraneus	97	0.048	0.189	–	0.033	0.029	0.029	0.205	0.111
Microtus agrestis	17	–	0.027	–	0.017	–	0.029	0.037	0.019
Microtus arvalis	210	0.048	0.135	0.130	0.050	0.044	0.229	0.456	0.240
sums									
Total individuals, N	874	84	37	77	60	206	35	375	874
Total species, S	10	6	9	5	8	7	9	10	10
indices									
Shannon-Weaver index, H		0.578	**0.846**	0.513	0.610	0.591	**0.791**	0.665	0.826
Evenness, J		0.742	**0.887**	0.734	0.675	0.699	**0.829**	0.665	0.826
Simpson index, D		3.136	**5.978**	2.736	2.817	3.302	**5.258**	3.464	5.770
Evenness, E		0.523	**0.664**	0.547	0.352	0.472	**0.584**	0.346	0.577

N o t e : n — total number of individuals of species sampled in all biotopes.

Calculations have revealed that the highest species diversity, according to the Shannon-Weaver index, characterizes the two following biotopes: BSF (0.846) and CCU (0.791). The Simpson index shows similar patters — BSF (5.978) and CCU (5.258). These diversity indices (both Shannon-Weaver and Simpson) are well agreed, the correlation between them is r = 0.97.

In total, nine species of muroid rodents have been recorded in these biotopes. The correlation between Simpson's diversity index and the number of revealed species is quite relevant (r = 0.67). The two mentioned biotopes are also characterized by the highest values of species evenness indices, while the highest evenness was discovered in beech-spruce forests (BSF) — the Shannon's evenness is $J = 0.887$ and Simpson's evenness is $E = 0.664$. Among the triad of the richest biotopes (BSF, CCU, and MEA), meadows notably stand out with the highest species richness (10 species) and relatively high species diversity — $H = 0.66$, and $D = 0.66$.

The highest species diversity in beech-spruce forests is apparently related to significant diversity of resources in this type of biotope, mainly feeding resources for both granivores-frugivores (seeds of beech and spruce trees, fruits of shrubs) and herbivores (well-developed herbaceous underlayer), but also substrate resources (for making shelters and burrows).

Clearcuttings have the second highest diversity indices. The large number of species discovered in this biotope is related to the peculiarities of the structure of small mammal communities in this type of biotopes. Earlier studies showed that in clearcuttings drastic shifts occur in the structure of communities and trophic groups, and the species diversity and abundance immediately after deforestation is minimal (Bryja et al., 2002). From the time of planting the deforested area (or when natural succession begins), species diversity and abundance gradually increase and reach the maximum approximately at the fifteenth year post-clearcutting. However, non-forest species, which appeared in clearcuttings at the initial stages of succession due to abrupt changes of ecological conditions (mainly from neighboring habitats, but also more distant biotopes through various ecological corridors), disappear approx. during the next five years (Kirkland, 1977; Wołk, Wołk, 1982).

The high species diversity of muroid rodent communities in meadows is caused by in-migration of species from neighboring biotopes (because of small area of meadows). On the other hand, it is due to the location of this biotope type at different altitudes, which means that the general diversity is higher for each meadow separately from lower to higher elevations. Besides, the largest number of species has been revealed in this biotope type (all species known within the Park), as well as in 2-30 times more individuals trapped compared to other biotopes (tab. 2). Therefore, the probability to reveal occasional and rare species here is 2–30 times higher, because the large number of trapped individuals increases the possibility to reveal rare species.

Finally, the lowest species diversity characterizes hornbeam-beech forests (HBF, 5 species, Shannon index 0.513, and Simpson index 2.736), which allows suggesting the low diversity of existing resources. Hence, this type of biotopes seems unable to maintain the Park's general species richness. In silver fir, beech and mixed forests the species richness and diversity (6 to 8 species, Shannon index is 0.578 to 0.610, and Simpson index is 2.817 to 3.302) is more stable. These biotopes are common for mountain ecosystems and they are considered among the key biotopes[1] of the Skole Beskids National Nature Park.

Taxonomic richness and diversity

The concept of taxonomic diversity was developed by I. Zagorodniuk and co-authors in the 1990s (Загороднюк та ін., 1995). Communities are characterized by not only a certain set of species, but also these species represent different higher taxonomic ranks, hence some communities are taxonomically more diverse than other ones. This fact cannot be ignored and, consequently, must be estimated. The gist of the concept is to reveal the level of progression of taxonomic relations within a community, and it is based on the correlation between levels of taxonomic and morphological differentiation. Obviously, taxonomic diversity is higher when the number of registered species is larger, and when they represent more superspecies taxonomic ranks. Research results in a number of cases showed that decrease of species richness of cenotically similar assemblages is accompanied by increase of taxonomic diversity due to increased monotony of higher ranks.

For quantitative estimation of taxonomic diversity it was proposed to use already well-known indexes of diversity, i.e. it is similar to calculations of species diversity. To analyze the taxonomic diversity of muroid rodents in different biotopes of the Park, first it is necessary to clarify the taxonomic richness of communities, which is defined as the sum of taxa represented in the community. Data on taxonomic richness and diversity of communities existing in different biotope types of the Skole Beskids NNP is summarized in tab. 3.

The analysis of taxonomic richness and diversity indices of muroid rodent communities in the studied biotopes of the Park has revealed the following.

Firstly, according to taxonomic richness indices of muroid rodent communities the biotopes make the following line:

MEA (20 taxa) > *CCU* = *BSF* (18) > *SFF* (16) > *MIX* (15) > *BEF* (13) > *HBF* (11).

Secondly, both diversity indices (Simpson-Weaver and Shannon) are highly correlated ($r = 0.81$), and each of them has a functional connection with the taxonomic richness ($r = -0.99$ for the Shannon-Weaver index and $r = -0.78$ for the Simpson index). It allows avoiding calculations of diversity indices during monitoring research in the future and estimate diversity by the richness.

Thirdly, taxonomic diversity indices give the same rating values as richness indices, but in reverse order (because the correlation is reverse): the first triad according to both Shannon-Weaver index and Simpson index includes HBF > BEF > MIX. In both cases, hornbeam-beech forests (HBF) and beech forests (BEF) take the first ranks. These biotope types are typical for the region and they have rodent assemblages common for mountain forests.

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[1] Primeval beech forests in the region of the Skole Beskids are practically absent. Beech forests of the region are transformed in the result of forest management and economic use, or they are secondary forests because of artificial planting of spruce, which naturally grows here only at high elevations.

Table 3. Taxonomic richness and taxonomic diversity of muroid rodent communities in different biotope types of the Skole Beskids National Nature Park

Таблиця 3. Таксономічне багатство і таксономічне різноманіття в угрупованнях мишуватих гризунів за різними біотопами в НПП «Сколівські Бескиди»

Taxa and indices	BEF	BSF	HBF	SFF	MIX	CCU	MEA
Species	6	9	5	8	7	9	10
Genera	5	7	4	6	6	7	8
Families	2	2	2	2	2	2	2
Taxonomic richness	13	**18**	11	16	15	**18**	**20**
Shannon-Weaver's diversity index, H_t	**1.46**	1.38	**1.49**	1.41	**1.43**	1.38	1.36
Evenness, J	3.06	2.89	3.12	2.95	2.99	2.89	2.85
Simpson's diversity index, D_t	**2.60**	2.42	**2.69**	2.46	**2.53**	2.42	2.38
Evenness, E	0.87	0.81	0.90	0.82	0.84	0.81	0.79

Finally, the reverse correlation between taxonomic richness and taxonomic diversity in the studied biotopes may indicate the presence of uncommon species in biotopes with high level of taxonomic richness. This, particularly, is characteristic for muroid communities of meadows (MEA, 20 taxa), clearcuttings and beech-spruce forests (CCU and BSP, 18 taxa in each), which have been formed in the result of biotope transformation (or at least a significant part of them), and immigration of species from neighboring biotopes.

The structure of rodent communities in these biotopes is also influenced by a high portion of adventive species (e. g., *Mus musculus*), as well as due to dispersal of lowland species (e. g., *Microtus arvalis* and *Apodemus agrarius*) into mountain communities through these biotopes and other ecocorridors (river valleys, roadsides, etc.) as well.

Discussion

Muroid rodent species are key elements in the structure of biotic assemblages and trophic pyramids of ecosystems of the Skole Beskids National Nature Park. They are both primary consumers and food supply for a number of guilds of tetrapods (e.g., carnivore mammals, birds of prey, some reptiles) in the same time. Hence, species and taxonomic richness and diversity indices are important indicators of the ecological value of ecosystems. Besides, they also have practical significance in development and implementation of monitoring of ecosystems in the Skole Beskids NNP, as well as for reasoning the selection of networks of biodiversity monitoring areas.

It has been discovered that the highest species and taxonomic richness characterize communities that combine species of relatively diverse systematic groups, particularly various genera and families. In key biotopes of the Skole Beskids NNP, the highest taxonomic richness of muroid rodents has been revealed for meadows (MEA), clearcuttings (CCU) and beech-spruce forests (BSF), which are biotopes with transformed phytocenoses.

These types of biotopes are highly available to muroid rodent species to settle, and provide them appropriate ecological conditions (foremost food supply). In terms of existing species richness and taxonomic diversity, these biotopes have a high value. They are characterized by not only a set of species common for the territory of the park, but also by species that in-migrated from neighboring communities or assemblages (in particular, lowland and synanthropic species, e. g. *Microtus arvalis, Apodemus agrarius,* and *Mus musculus*, respectively).

Meanwhile, hornbeam-beech forests (HBF) have the lowest species diversity index, but high taxonomic diversity index. The high taxonomic diversity in hornbeam-beech (HBF), beech (BEF), silver fir (SFF) and mixed forests (MIX) indicates the high stability and sustainability of muroid rodent communities that exist in these biotopes. According to the concept of taxonomic diversity, it can be explained by the relevant abundance and dominancy of a small number of species in these forests, such as the yellow-necked mouse *Sylvaemus tauricus*, wood mouse *Sylvaemus sylvaticus* and bank vole *Myodes glareolus*.

Conclusions

The taxonomic diversity index reflects the qualitative side of the organizational level of a community. It is higher when recorded in the studied are species represent more superspecies taxonomic ranks. Among key biotope types of the Skole Beskids National Nature Park, the highest taxonomic richness of muroid rodents has been revealed in meadows, clearcuttings and beech-spruce forests. These biotopes are most able to maintain high species diversity due to significant heterogeneity and diversity of sources they provide, in particular food supply, substrate use, etc.

The highest taxonomic diversity characterizes hornbeam-beech, beech, and mixed forests that are biotopes with primary phytocenoses and such biotopes are common for the mountain ecosystems of the region in general. The resource potential of these biotopes ensures the existence of indigenous fauna. In beech-spruce forests, clearcuttings, and meadows the taxonomic diversity index is the lowest because of the presence of species that mostly represent lower taxonomic ranks (in particular, species and genera).

Acknowledgements

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