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ORIGINAL PAPER

Comparison of spatial dispersion of epigeic fauna between alluvial forests in an agrarian and Dunajské luhy protected landscape area, southern Slovakia

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Abstract

The spatial distribution of the epigeic fauna of floodplain ecosystems (willow-poplar floodplain forest, regenerated poplar forest), in the conditions of the natural environment of the Dunajské luhy Protected Landscape Area (PLA, hereinafter) and agrarian landscape was studied. The Dunajské luhy PLA, hereinafter (Slovak Republic) is the part of the system of protected areas of the European Union. During the three years 2020–2022, 24,169 individuals belonging to 19 taxa at 6 locations using the pitfall traps method were recorded. Through spatial modeling, the preference of most taxa for floodplain forests located in the Dunajské luhy PLA was found. We also observed a significant difference in number of individuals of epigeic fauna in floodplain forests betvween Dunajské luhy PLA area and agrarian landscape during all three years 2020 ($p = 0.0070$), 2021 ($p = 0.0077$) and 2022 ($p = 0.04624$). Thus, agroecosystems in the neighborhood of alluvial forests had a negative impact on the taxonomic diversity and abundance of epigeic fauna. In order to maintain a balance between the production of food, wood and the preservation of natural forest stands, it is important to optimally allocate areas and set up their management. For example, by creating forest islands in agricultural crops, to increase the epigeic fauna.

Key words: floodplain forest ecosystems; number of individuals; species diversity; RDA analysis; Central Europe

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1. Introduction

The Human global population has increased significantly over the last decade, which also results in an increase in the demand for food. The predicted increase in demand is 70% by 2050. Intensively used agricultural land is supposed to satisfy this growing trend, but this may lead to the loss of natural habitats and overall biodiversity (Raven & Wagner 2021). Agricultural land is made up of arable land, man-made infrastructure, natural and semi-natural habitats. Semi-natural habitats, such as the edges of fields, serve as corridors connecting natural habitats with agriculturally used land, which are used by animals as migration routes. Due to the loss of biodiversity and natural ecosystems, semi-natural habitats (bio belts, hedges, meadow flower planting belts) are being created, which are a suitable environment for biodiversity (Brygadyrenko & Nazimov 2015c). This Semi-natural habitats with high plant diversity provide refuges for overwintering, epigeic fauna (Fusser et al. 2017; Haddaway 2018; Porhajašová et al. 2018). A key role for the preservation and stabilization of ecosystems is the protection of biodiversity (Porhajašová & Babošová 2022; Putchkov & Brygadyrenko 2022).

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Epigeic fauna (living on the surface of the soil) communities are influenced by the water regime such as surface floods and groundwater (Kolesnikova et al. 2016; Litavský et al. 2018; Avtaeva et al. 2021b). Other important environmental factors are temperature and humidity, which also interact with vegetation (Brygadyrenko 2015a; Stašiov et al. 2017). Several epigeic fauna such as Coleoptera, Araneida, Opilionida, Hymenoptera serve as suitable bioindicators for monitoring ecological changes and disturbance of ecosystems (Skłodowski 2014; Klimaszewski et al. 2018; Langraf et al. 2020; Stašiov et al. 2021).

Epigeic fauna is an important part of terrestrial ecosystems, which participates in the cycle of nutrients in the soil. Its presence increases the production of aboveground plant parts and also facilitates the decomposition of waste substances (Faly et al. 2017). These processes take place through the interaction between epigeic fauna, microorganisms and plants (Brygadyrenko 2015b). The local diversity of epigeic fauna has a significant impact on ecosystem processes at the local, landscape and global levels (Avtaeva et al. 2021a). The occurrence of epigeic fauna is also influenced by the structure of vegetation in the herbaceous and shrub layer (Gordienko & Sukhodolskaya 2022; Lavelle et al. 2022; Potapov et al. 2022). Due to the high sensitivity to environmental changes, the epigeic fauna is suitable as a bioindicator of ecosystems. Predators and parasitic species also serve as biological control against pests, which is considered the very important regulatory service for biodiversity. To improve pest control, it is necessary to observe the ecological relationships of co-occurrences of taxa, predator and prey (pest) (Guo et al. 2020).

Natural biotopes such as floodplain ecosystems in the Dunajské luhy PLA are biotopes of European importance. This territory belongs to the system of protected areas of the member countries of the European Union "Natura 2000". In Europe, there are few areas with floodplain forests. Most of this habitat has been destroyed and turned into agricultural land or built over. Many remaining fragments are in poor condition and dependent on simulated flood management. These ecosystems are among the most threatened ecosystems in Europe (Litavský et al. 2021). The structure of the Dunajské luhy PLA consists of mosaic-like habitats of wetlands, watercourses, streams, alluvial floodplain meadows and floodplain forests.

The goal of our work was quantify the spatial distribution of epigeic fauna of floodplain forests (willow-poplar floodplain forest, regenerated poplar forest) in the conditions of an agrarian landscape and natural area Dunajské luhy PLA.

2. Material and methods

2.1. Sampling sites with in an agrarian landscape

Three sampling sites were located at intensively used agricultural land (Fig. 1). In the surroundings the following agricultural crops were grown: *Triticum aestivum* L. (summer wheat), *Medicago sativa* L. (lucerne sown), *Brassica napus* L. (oil-seed rape), *Zea mays* L. (Corn sown) and *Hordeum vulgare* L. (Barley sown). The territory belonged to the Alpine-Himalayan system, the Pannonian Basin subsystem and the Danube Plain. Soil types were riverain soils made from carbonate alluvial sediments. The climate was warm with mild winters with an average temperature of –3 °C in winter and 25 °C in summer.

Location 1 – **willow-poplar floodplain forest** (47°54'40" N 18°01'19" E, 110 m a.s.l.) represented a fragment of an alluvial forest with a predominance of *Salix alba* L. and *Populus canadensis* Moench. in the tree layer.

Location 2 – **willow-poplar floodplain forest** (47°55'29" N 17°59'42" E, 111 m a.s.l.) represented a diverse fragment of an alluvial forest with a predominance of *Salix fragilis* L., *S. alba* L. and *Populus canadensis* Moench.

Location 3 – **regenerated poplar forest** (47°55'32" N 17°59'52" E, 109 m a.s.l.) represented the restoration of the *Populus canescens* [Aiton] Sm. stand. The vegetation was free of trees and shrubs.

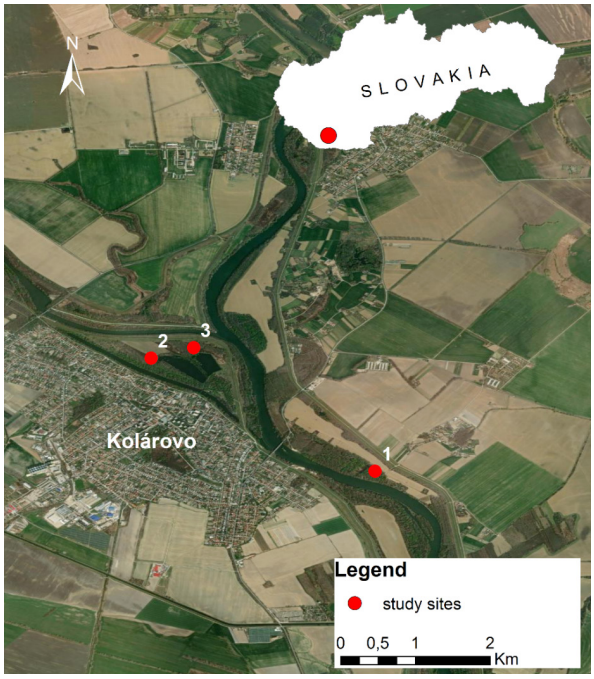


Fig. 1. Investigated localities in the agrarian landscape.

2.2. Sampling sites within Dunajské luhy PLA

Three sampling sites were located in the Protected Landscape Area Dunajské luhy PLA in Western Slovakia with an area of 122.8 km^2. The Danube floodplains were among the most important European biotopes included in "Natura 2000". The main goal was the preservation of the European natural wealth – the rarest and the most endangered biotopes and species on the territory of the EU states. The territory belonged to the Alpine-Himalayan system, the Pannonian Basin subsystem and the Danube Plain. The soil types were clayey-loam riverain soils formed by the alluvium of the Danube River. The climate was warm with mild winters with an average temperature of –3 °C in winter and 25 °C in summer. The three study sites established in the Protected Landscape Area (PLA) of the Dunajské luhy PLA were (Fig. 2):

Location 4 – **willow-poplar floodplain forest** (47°53'31" N 17°30'25" E, 114 m a.s.l.) represented a diverse fragment of alluvial forest with a predominance of *Salix fragilis* L. and *S. alba* L. in the tree layer.

Location 5 – **willow-poplar floodplain forest** (47°53'29" N 17°28'57" E, 115 m a.s.l.) represented a diverse fragment of alluvial forest with a predominance of *Salix alba* L., *Populus canadensis* Moench, *Acer negundo* L. in the tree layer.

Location 6 – **regenerated poplar forest** (47°53'52" N 17°27'26" E, 118 m a.s.l.) represented the restoration of the *Populus canescens* [Aiton] Sm. stand. The vegetation was free of trees and shrubs.

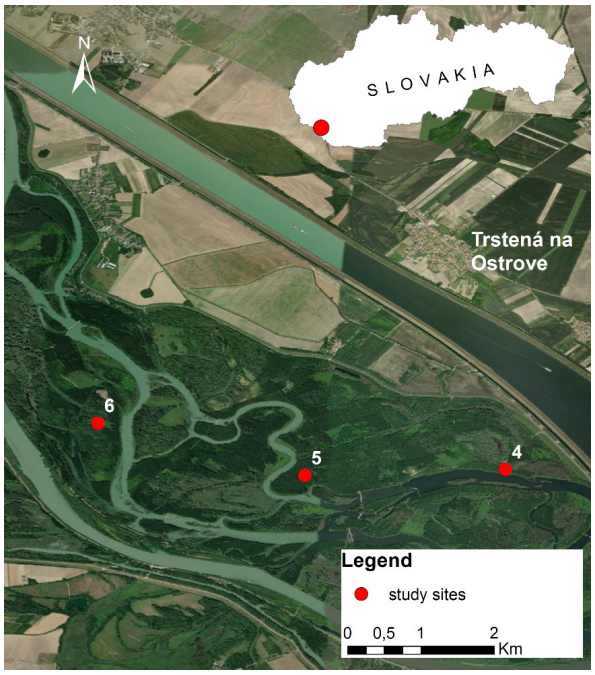


Fig. 2. Investigated localities in the Dunajské luhy PLA.

2.3. Epigeic fauna sampling

Epigeic fauna sampling took place during the three years 2020–2022 at 6 locations representing two types of habitats (willow-poplar floodplain forest, regenerated poplar forest). The Pitfall traps that capture epigeic fauna living on the soil surface were chosen as the sampling method (Fig. 3a, b). At each site, 5 pitfall traps were placed in a row, 10 m apart. The total length of one study area was therefore 50 m. The first trap was placed 40 m from the edge of the forest. A total of 30 traps were placed year-round at all 6 sites during all 3 years. The 4% formaldehyde solution was used for fixation. Traps were collected at regular monthly intervals. According to the work, we established the nomenclature of the epigeic fauna of Schierwater & DeSalle (2021).



Fig. 3. (a) Location of pitfall traps on the studieds sites, (b) A representative of the Araneida taxon, whose individuals were recorded in pitfall traps.

2.4. Statistical analysis

Spatial distribution of epigeic fauna based on the influence of land use (agrarian landscape, Dunajské luhy PLA; (explanatory data)) was determined by redundancy analysis (RDA). We tested the statistical significance of land use using the Monte Carlo test (iteration 499) in the Canoco5 program (Ter Braak & Šmilauer 2012). Analysis in the statistical program R 4.1.3. was aimed at determining the normality of data distribution using the Shapiro-Wilk W-test. Based on the normal distribution of data ($p = 0.0941$), we used the parametric test multifactorial ANOVA to determine the difference in the number of individuals between forest biotopes and land use (agrarian landscape, Dunajské luhy PLA), during the years 2020–2023. We compared taxonomic diversity using rarefaction curves.

3. Results

Our results recorded 24,169 individuals belonging to 19 taxa on the localities. Moreover 5,546 individuals (22.95%) and 13 taxa in the forest stands of the agrarian landscape were also observed. More than 10% of eudominant individuals belonged to the taxa Collembola (30.57%), Isopoda (13.33%), Coleoptera (11.47%) and Hymenoptera (10.6%). In addition, the dominant representation (5.0–9.9%) of Acarina (6.96%), Araneida (6.5%) were recorded. In the case of subdominant representation (2.0–5%) those were taxa of the taxa Julida (4.74%), Lithobiomorpha (3.33%), Polydesmida (2.43%), Dermaptera (2.30%), Stylommatophora (2.29%), Opilionida (2.25%) were observed, however, the taxon Lumbricida (1.94%) represented a recedent taxon. The taxa Orthoptera (0.94%), Nematoda (0.24%), Siphonaptera (0.06%), Glomerida (0.02%), Pseudoscorpionida (0.02 %), Geophilomorpha (0.01%) amounted subrecedent taxons (less than 1%) (Table 1).

Through multivariate analysis (redundancy analysis (RDA), SD = 0.5 on the second ordination axis) the link between taxa and land use (agrarian landscape, Dunajské luhy PLA) was captured. The explained variability of taxa was 76.18% on the first axis and 84.83% on the second cumulative axis. The variability of taxa explained by land use was 89.8% on the first axis and 92.0% on the second cumulative axis. A statistically significant influence on the spatial distribution of taxa was confirmed in the agrarian landscape (p = 0.046) and the Dunajské luhy PLA (p = 0.008).

A spatial distribution of taxa was organized in two clusters (Fig. 4). The first cluster demonstrated taxa preferring forest biotopes (willow-poplar floodplain forest (locations 4, 5)) and regenerated poplar forest

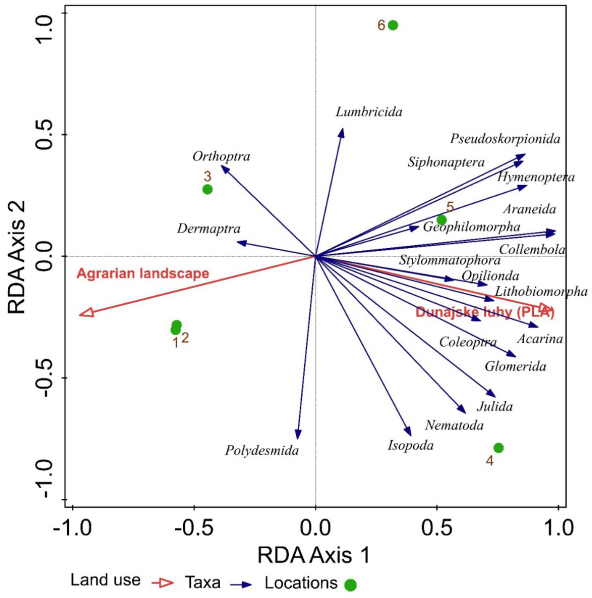


Fig. 4. RDA analysis of epigeic fauna and land use.

(location 6) in Dunajské luhy PLA. The cluster was represented by 16 taxa, namely Lumbricida, Pseudoscorpionida, Siphonaptera, Hymenoptera, Geophilomorpha, Araneida, Collembola, Stylommatophora, Opilionida, Lithobiomorpha, Coleoptera, Acarina, Glomerida, Julida, Nematoda and Isopoda. The second cluster was presented by taxa correlated with forest biotopes (willow-poplar floodplain forest (locations 1, 2)) and regenerated poplar forest (location 3) in agrarian landscape. Taxa preferring these conditions were as follow Orthoptera, Dermaptera and Polydesmida.

Table 1. Overview of the taxa of the investigated sites.

Taxa	Agrarian landscape			Dunajské luhy PLA			Total individuals
	1	2	3	4	5	6	
Acarina	27	38	34	830	682	70	1,681
Araneida	121	142	176	421	400	311	1,571
Coleoptera	237	564	251	653	664	403	2,772
Collembola	0	0	0	4218	1925	1246	7,389
Dermaptera	159	73	41	70	4	210	557
Geophilomorpha	0	0	0	0	3	0	3
Glomerida	0	0	0	2	2	0	4
Hymenoptera	124	154	412	660	638	575	2,563
Isopoda	668	489	254	819	659	333	3,222
Julida	148	81	64	462	306	84	1,145
Lithobiomorpha	86	90	17	228	230	153	804
Lumbricida	96	55	73	70	72	104	470
Nematoda	0	0	0	58	0	0	58
Opilionida	69	68	48	99	187	74	545
Orthoptera	19	29	103	23	11	41	226
Polydesmida	185	100	36	102	142	22	587
Pseudoscorpionida	0	0	0	1	1	2	4
Siphonaptera	0	0	0	2	8	5	15
Stylommatophora	68	108	39	100	140	98	553
Total individuals	2,007	1,991	1,548	8,818	6,074	3,731	24,169

Note: 1 – location 1 (willow-poplar floodplain forest), 2 – location 2 (willow-poplar floodplain forest), 3 – location 3 (regenerated poplar forest), 4 – location 4 (willow-poplar floodplain forest), 5 – location 5 (willow-poplar floodplain forest), 6 – location 6 (regenerated poplar forest).

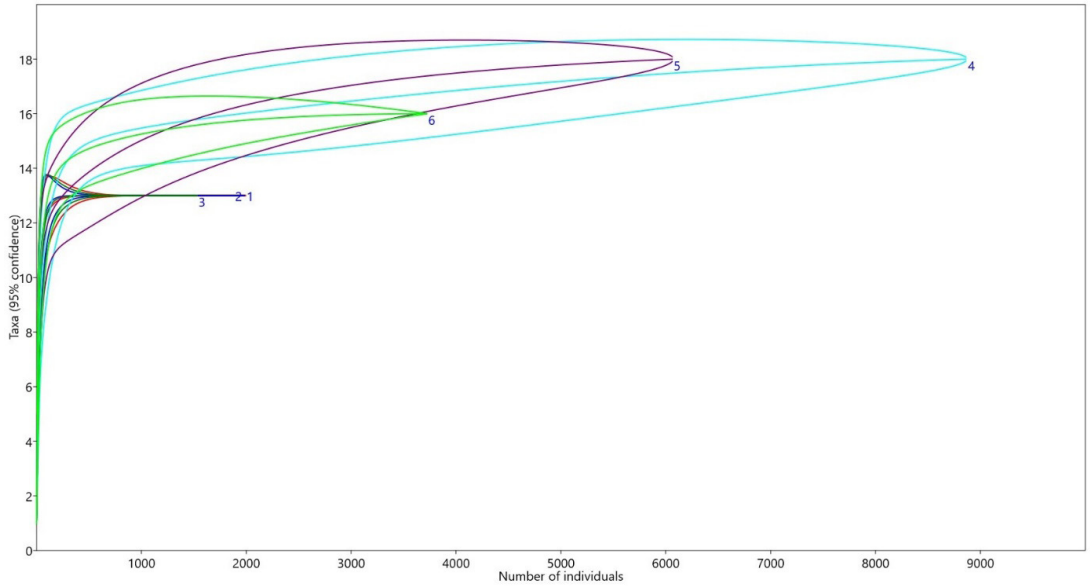


Fig. 5. Individual rarefaction (marginal lines) and extrapolation curve (middle lines) of the total taxonomic richness of the studied sites. Explanations: agrarian landscape: X1 = location 1, X2 = location 2, X3 = location 3, natural area Dunajské luhy PLA: X4 = location 4, X5 = location 5, X6 = location 6.

A higher number of taxa and individuals was recorded in the floodplain forests located in the Dunajské luhy PLA, which may be influenced by higher humidity, since the territory was not disturbed by crop monocultures and has a larger area. Therefore, the taxa had a more diverse and larger food supply in these forests. Many taxa are predators such as Araneida, whose prey are other taxa. The Carabidae family from the Coleoptera order feeds on, for example, Lumbricida, Stylommatophora and other smaller invertebrates. At higher humidity, leaves and other parts of plants on the surface of the soil, also pieces of wood decay more quickly, which serves as a suitable place for various decomposers in nature.

The highest taxonomic diversity in habitats in Dunajské luhy PLA (locations 4–6) and the lowest in habitats in the agrarian landscape (locations 1–3) using rarefaction curves were found. The decrease in diversity was confirmed in the direction of locations 4, 5 (willow-poplar floodplain forest), 6 (regenerated poplar forest), locations 1, 2 (willow-poplar floodplain forest) and 3 (regenerated poplar forest). The number of individuals, direction of locations did not change based on the diversity (Fig. 5).

A significant difference in the number of individuals between biotopes (willow-poplar floodplain forest, regenerated poplar forest) and land use (agrarian landscape, Dunajské luhy PLA) analyzed by Multifactorial ANOVA was recorded during years 2020 ($p = 0.0070$), 2021 ($p = 0.0077$) and 2022 ($p = 0.04624$) (Fig. 6). A higher average number of individuals in both habitats in Dunajské luhy PLA than in the agrarian landscape was observed.

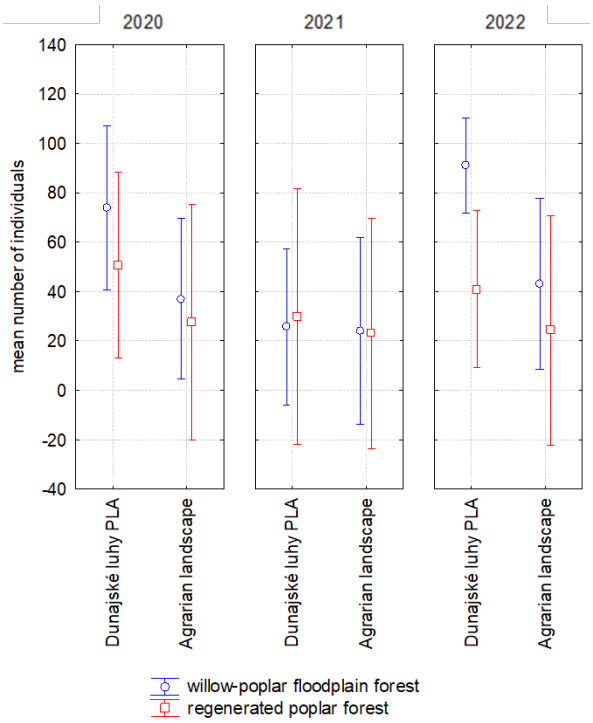


Fig. 6. The average number of individuals of the epigeic fauna of the studied biotopes and land use during years 2020–2022 with a 95% confidence interval.

4. Discussion

From the results of our research, we found that the floodplain forests adjacent to the fields, we confirmed a lower taxonomic diversity, as well as a smaller number of individuals compared to the floodplain forests in the protected area of the Dunajské luhy PLA. The same results were also confirmed by Porhajašová & Babošová (2022) and Putchkov & Brygadyrenko (2022) in areas where agricultural crops were grown, which negatively affected taxonomic diversity in cultural and natural forests in their surroundings. This may be because of pesticides, fertilizers, ruderal and adventitious plants spreading under the forest canopy, change in the regime of accumulation of precipitations and water evaporation (Bote & Romer 2012; Kolesnikova et al. 2016). Such changes in the living conditions cannot leave invertebrates and vertebrates unaffected (Boháč & Jahnova 2015; Brygadyrenko 2015b). Designating a single ecological factor for the community of terrestrial animals was unrealistic and communities of epigeic fauna were affected by several factors at once (Brygadyrenko & Nazimov 2015c; Briones & Schmidt 2017).

From the RDA analysis, we can see that predatory invertebrates preferred floodplain forest conditions in the Dunajské luhy PLA over the agrarian landscape. Saprophages and to a lower extent, phytophages of the grass stand and soil make up the food base for predatory invertebrates, which was also noted in our work. The same fact was also confirmed by Litavský et al. (2021) and Avtaeva et al. (2021a) who found that in floodplain forests, rates of changes in communities of terrestrial animals vary across the areas (agrarian landscape and Dunajské luhy PLA). The similar conditions of moisture, light, litter thickness are to the forest ecosystem and the more similar the epigeic fauna is to the natural floodplain forests. Forest-type circulation of compounds (by contrast to the circulation of compounds in agrocoenoses) necessarily need continuity of moistening of the soil layer of organic foliage. Such a constant moisture favors stable communities of fungi and bacteria, which in turn become a food substrate for litter saprophages.

Similarity of dominant species of trees in ours study, was not a guarantee for the formation of identical taxonomic composition of the mesofauna. Both the taxonomic diversity and the number of individuals were higher in floodplain forests in the conditions of the Dunajské luhy PLA compared to the agrarian landscape. Potentially similar living conditions (similar positions of ecosystems on the geomorphological profile, similar mechanical composition of soils and plant cover, etc.) can provide the environment for various communities of animals which they also confirmed Brygadyrenko (2015a, 2015b) and Guo et al. (2020). They observed an influence on it of pesticides in low concentrations on the most sensitive groups of microorganisms and invertebrates, what they found in their study Porhajašová et al. (2018) and Kozak et al. (2020).

The mosaic like representation of biotopes in the Dunajské luhy PLA showed a greater number of taxa and the number of individuals. They also confirmed the same fact Lenoir & Lennartsson (2010); Faly et al. (2017); Fusser et al. (2017); Haddaway (2018); Avtaeva et al. (2021b) and they claim that, one of the factors encouraging the greatest diversity of fauna of epigeic invertebrates is the spatial variety of the living conditions: local depressions and several-meter-high elevations, the places for the accumulation of leaf foliage, where invertebrates can successfully live through summer drought or winter soil frosts. Variability of the conditions in forests was not the same in various parts of a river floodplain. The greatest positive effect on the diversity of forest fauna was generated by variety (mosaic pattern) of the living conditions in the forest-steppe and steppe zone, where during the summer drought, populations of many forest species survive because of local terrain depressions.

The highest diversity of animal communities and number of individuals in our studies was observed in the places not subjected to the influence of agrocoenoses (Table 1). Previous Laboratory experiments revealed that low concentrations of many herbicides, fungicides and insecticides, used in agriculture, can lead to death of epigeic fauna (Kozak et al. 2020). In the natural conditions, negative effects of pesticides could be amplified by fluctuations of other ecological factors. The importance of the classic floodplain forests preservation in Europe, which have not yet been disturbed by agricultural production in neighboring territories is very high. Floodplain forests are places of concentration of many species of organisms, which were formerly distributed over a large territory (Brygadyrenko 2015b; Stašiov et al. 2017; Litavský et al. 2018; Putchkov & Brygadyrenko 2022).

5. Conclusions

The results of our research, which took place on two types of biotopes (willow-poplar floodplain forest, regenerated poplar forest) in the conditions of an agrarian landscape and Dunajské luhy PLA, showed up a significant difference in the abundance of epigeic fauna between the areas under different land uses. During the three years 2020–2022, 24,169 individuals belonging to 19 taxa were recorded. Spatial modeling (RDA analysis) revealed the correlation of most taxa to floodplain forest habitats in the Dunajské luhy PLA. Taxonomic diversity using rarefaction curves also confirmed greater diversity and abundance in this area compared to biotopes situated in the agrarian landscape. Multifactorial ANOVA we also recorded a greater number of individuals in forest biotopes for the territory of Dunajské luhy PLA during

all three years 2020–2022 compared to agrarian landscape. This fact can also be influenced by the higher humidity in the floodplain forests of the Dunajské luhy PLA, which were not disturbed by agricultural crops and have a larger continuous area. Due to the higher humidity, various decomposers, which are prey for predatory species, have better conditions. Also, these conditions offer a better food optimum for other taxa. Based on our results, we can confirmed that agroecosystems of intensively used agricultural land had a negative effect on the taxonomic diversity and abundance of epigeic fauna of alluvial forests. In order to preserve ecosystems of European important biotopes, it is necessary to find out the ecological links between biodiversity and its spatial distribution, which plays an important role in maintaining the ecological stability of these ecosystems. On the other hand, the production of food and wood is also important, so settings for optimal ratios between agricultural/economic forests and protected areas are necessary. A suitable alternative is, for example, the creation of islands with various trees and shrubs in agricultural crops, which would support the biodiversity of the epigeic fauna and preserve at least fragments of natural forest habitats. It would be appropriate to apply this knowledge for subsequent research in this area.

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