Artículos

Morphometric variability of specimens in Ground Beetle (Carabidae) communities in agrarian landscape forests and protected areas

Variabilidad morfométrica de los escarabajos terrestres (Carabidae) en paisajes agrarios, bosques y áreas protegidas

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Abstract: The change in the morphometric variable of ground beetles as well as in their volume (ellipsoidal biovolume) indicates the state of the biotope (unstable, stable), which is affected by anthropogenic activity such as forestry, agriculture and urbanisation. Between the years 2020 and 2022, we conducted research in floodplain forests, which were located in agriculturally used land and in the important European territory of Dunajské Luhy Protected Landscape Area. Using the pitfall traps method, we recorded 1319 individuals belonging to 29 species of ground beetles in six study areas representing two types of habitats (willow-poplar floodplain forest and regenerated poplar forest). We confirmed the largest average Ellipsoid Biovolume (EV) in the species *Carabus coriaceus* L. (2936 mm^3), *Carabus scheidleri* Panzer (1427 mm^3), *Carabus violaceus* L. (943 mm^3), *Carabus granulatus* L. (366 mm^3), *Cychrus caraboides* (L.) (336 mm^3), *Pterostichus niger* (Schaller) (254 mm^3), *Harpalus rufipes* (DeGeer) (123 mm^3). The redundancy analysis confirmed the predominance of apterous and brachypterous species of ground beetles in forest stands in the Dunajské Luhy PLA (important European territory). These groups of Carabidae point to the ecological stability of biotopes, because they inhabit habitats where they have optimum food. On the contrary, we confirmed the predominance of macropterous species in forest biotopes in agrarian landscape conditions, which points to biotopes cyclically disturbed by anthropogenic activity. We recorded larger individuals in groups of apterous and brachypterous species in forest stands in the conditions of the Dunajské Luhy PLA. Larger macropterous individuals were recorded in forest stands in agrarian landscape conditions. In order to preserve forest habitats of European importance, it is necessary to know the ecological interactions between the ecosystem and ground beetles.

Keywords: Bioindicator, Central Europe, Dunajské luhy, Ellipsoid biovolume, Ground Beetles.

Resumen: El cambio en la variable morfométrica de los escarabajos de tierra, así como en su volumen (biovolumen elipsoidal), indica el estado del biotopo (inestable, estable), que se ve afectado por la actividad antropogénica como la silvicultura, la agricultura y la urbanización. Entre los años 2020 y 2022, realizamos investigaciones en bosques de llanura aluvial, que se encontraban en tierras de uso agrícola y en el importante territorio europeo del Área de Paisaje Protegido de Dunajské Luhy. Utilizando el método de trampas de caída, registramos 1319 individuos pertenecientes a 29 especies de escarabajos de tierra en seis áreas de estudio que representan dos tipos de hábitats (bosque de llanura aluvial de sauces y álamos y bosque de álamos regenerado). Confirmamos el mayor biovolumen elipsoide (EV) promedio en las especies *Carabus coriaceus* L. (2936 mm^3), *Carabus scheidleri* Panzer (1427 mm^3), *Carabus violaceus* L. (943 mm^3), *Carabus granulatus* L. (366 mm^3), *Cychrus caraboides* (L.) (336 mm^3), *Pterostichus niger* (Schaller) (254 mm^3), *Harpalus rufipes* (DeGeer) (123 mm^3). El análisis de redundancia confirmó el predominio de especies ápteras y braquípteras de escarabajos de tierra en las masas forestales del PLA Dunajské Luhy (territorio europeo importante). Estos grupos de Carabidae apuntan a la estabilidad ecológica de los biotopos, porque habitan hábitats donde tienen una alimentación óptima. Por el contrario, confirmamos el predominio de especies macrópteras en biotopos forestales en condiciones de paisaje agrario, lo que apunta a biotopos perturbados cíclicamente por la actividad antropogénica. Registramos individuos más grandes en grupos de especies ápteras y braquípteras en rodales forestales en las condiciones de la PLA Dunajské Luhy. Se registraron individuos macrópteros más grandes en rodales forestales en condiciones de paisaje agrario. Para preservar los hábitats forestales de importancia europea, es necesario conocer las interacciones ecológicas entre el ecosistema y los escarabajos terrestres.

Palabras clave: Bioindicador, Biovolumen elipsoide, Dunajské luhy, Escarabajos terrestres, Europa Central.

INTRODUCTION

Anthropogenic human intervention in the landscape often leads to fragmentation of biotopes, their isolation and pollution. These interventions also have an impact on hydrological, climatic and edaphic activities and, last but not least, they also affect the spread of new species in habitats (Pompeo et al., 2017; Pazourkova et al., 2021).

These changes lead to reactions of ground beetles functioning in ecosystems. They react sensitively to changes in soil moisture, soil pH, toxic substances (pesticides and insecticides), urbanisation and associated habitat changes (Kalivoda et al., 2010;Alberti, et al., 2017;Porhajášová et al., 2018). Ground beetles have a short life cycle, which allows them to quickly respond to environmental changes, which is why they have been used for a long time as bioindicators of anthropogenic activities in ecosystems. Some species are eurytopic and are represented in forests in agrarian landscape and natural habitat (Sukhodolskaya et al., 2021; Litavský et al., 2021).

Morphometry is often used to assess changes in population structure as well as species richness. Natural selection is influenced by phenotype as well as phenotypic traits, which are manifested by changes at the morphometric level. Morphometric variability also reflects the effects of other factors such as genetic, biochemical and physiological (Bulgarella et al., 2015;Rusynov & Brygadyrenko, 2017; Luzyanin et al., 2022a,b).

The body size of ground beetles depends to a certain extent on environmental factors but also on vital functions. It is also influenced by the overall morphology and physiology of the individual, life expectancy, fertility and biotic interactions, which affects the dynamics of the population, their food and ecological networks. Changes in body size have downstream consequences for habitat function and ecosystem services (Chown & Gaston, 2010; Ohlberger, 2013). Changes in morphometric features influenced by anthropogenic activity are useful as an indicator of habitat quality for assessing the state of the ecosystem (Feliciangeli et al., 2007; Smith & Lyons, 2013; Magura & Lövei, 2020, 2021; Matečný et al., 2024).

To calculate the volume of ground beetles, the Ellipsoid Biovolume (EV) is used, which was first described and used by Braun et al. (2004). EV of ground beetles is calculated based on morphometric characters (width, height and body length). Ground beetles, due to their ellipse-like body shape and morphometric characters, are suitable for EV calculation. Using this index, we can evaluate changes in body size based on habitat changes due to anthropogenic activity (Langraf et al., 2018).

In the paper, we evaluate changes in morphometric variability (body length, body height and body width), Ellipsoid Biovolume and flight capability of species from family carabidae in forest biotopes under the conditions of Agrarian landscape and Dunajské Luhy Protected Landscape Area. We investigated the following hypotheses: (1) Morphometric characters and Ellipsoid Biovolume were greater in individuals in forest biotopes in Natural Habitat in apterous and brachypterous species; (2) Apterous and brachypterous species preferred forest biotopes in Natural Habitat (Danube Alluvium); (3) Macropterous species preferred forest habitats disturbed by anthropogenic activity in Agrarian landscape.

MATERIAL AND METHODS

We conducted research over three years (2020, 2021 and 2022) in six study areas representing two types of habitats: a willow-poplar floodplain forest and a regenerating poplar forest. In each study area, five pitfall traps were placed in a line, the distance between each trap was ten m. Pitfall traps were placed throughout the year over the course of three years. We selected the material at regular monthly intervals. We used 4% formaldehyde solution as a fixative. We determined ground beetles and modified the nomenclature according to Hůrka (1996).

Study Area

Study areas one, two and three belong to forest biotopes and were placed in Agrarian landscape. Agricultural crops such as *Zea mays* L., *Brassica napus* L., *Medicago sativa* L. and *Triticum aestivum* L. were grown around these forest stands. The territory falls under intensively used agricultural land. Climatic conditions include a very dry climate with dry winters, the soil type is fluvisol cultisme carbonate. According to the geomorphological division of Slovakia, it is within the Danube Plain. The examined study areas are as follows:

1) Willow-poplar floodplain forest; 110 metres above sea level; geographic coordinates: 47°54′40″ N 18°01′19″ E

2) Willow-poplar floodplain forest; 111 metres above sea level; geographic coordinates: 47°55′29″ N 17°59′42″ E

Table I.

Overview of species recorded in study areas and EV values with the number of individuals

Species	Code	F.A.	Agrarian landscape			Dunajské Luhy protected landscape area		
			1	2	3	4	5	6
			EV/N	EV/N	EV/N	EV/N	EV/N	EV/N
Leistus rufomarginatus (Duftschmid, 1812)	Leis rufo	M	0/0	0/0	0/0	26/1	0/0	0/0
Nebria brevicollis (Fabricius, 1792)	Nebr brev	M	704/7	260/2	0/0	1135/16	976/14	416/5
Notiophilus biguttatus (Fabricius, 1799)	Noti bigu	B	0/0	0/0	0/0	26/4	0/0	0/0
Carabus coriaceus Linnaeus, 1758	Cara cori	A	0/0	0/	0/0	0/0	5871/2	0/0
Carabus granulatus Linnaeus, 1758	Cara gran	B	30412/81	2328/6	422/1	3835/9	14076/41	68122/188
Carabus scheidleri Panzer, 1799	Cara sche	A	1427/1	0/0	0/0	0/0	0/0	0/0
Carabus violaceus Linnaeus, 1758	Cara viol	A	20633/19	14182/17	8548/10	0/0	0/0	0/0
Cychrus caraboides (Linnaeus, 1758)	Cych cara	A	0/0	0/0	0/0	692/2	0/0	5027/15
Brachinus crepitans (Linnaeus, 1758)	Brac crep	M	0/0	177/5	42/1	0/0	0/0	0/0
Brachinus explodens Duftschmid, 1812	Brac expl	M	39/1	0/0	0/0	0/0	23/1	0/0
Asaphidion austriacum (Schweiger, 1975)	Asap aust	M	0/0	0/0	0/0	0/0	6/2	0/0
Poecilus cupreus (Linnaeus, 1758)	Poec cupr	M	0/0	0/0	364/6	0/0	0/0	0/0
Poecilus versicolor (Sturm, 1824)	Poec vers	M	0/0	0/0	0/0	0/0	213/4	0/0
Pterostichus niger (Schaller, 1783)	Pter nige	M	1937/8	1883/7	500/1	2549/9	9820/42	35034/137
Pterostichus nigrita (Paykull, 1790)	Pter nigr	M	70/1	0/0	0/0	0/0	0/0	0/0
Calathus fuscipes (Goeze, 1777)	Cala fusc	M	142/1	110/1	0/0	0/0	2459/37	0/0
Platyderus rufus (Duftschmid, 1812)	Plat rufu	B	0/0	0/0	0/0	0/0	46/5	129/15
Anchomenus dorsalis (Pontoppidan, 1763)	Anch dors	M	0/0	0/0	0/0	0/0	25/2	77/4
Platynus assimilis Paykull, 1790	Plat assi	M	60/1	88/2	0/0	4207/53	0/0	1018/8
Amara aenea (De Geer, 1774)	Amar aene	M	0/0	0/0	170/11	0/0	25/1	0/0
Amara familiaris (Duftschmid, 1812)	Amar fami	M	0/0	972/21	51/3	58/5	139/6	0/0
Amara ingenua (Duftschmid, 1812)	Amar inge	M	0/0	0/0	0/0	0/0	882/37	0/0
Amara saphyrea Dejean, 1828	Amar saph	M	0/0	870/21	0/0	31/1	0/0	41/1
Amara similata (Gyllenhal,1810)	Amar simi	M	34/1	0/0	196/5	0/0	0/0	0/0
Harpalus affinis (Schrank, 1781)	Harp affi	M	0/0	0/0	40/1	0/0	0/0	0/0
Harpalus rubripes (Duftschmid, 1812)	Harp rubr	M	397/12	0/0	108/3	0/0	290/14	0/0
Harpalus rufipes (DeGeer, 1774)	Harp rufi	M	852/6	21925/188	15769/127	144/1	7179/50	0/0
Harpalus tardus Panzer, 1797	Harp tard	M	0/0	0/0	0/0	0/0	84/2	0/0
Drypta dentata (Rossi, 1790)	Dryp dent	M	0/0	0/0	0/0	0/0	36/2	0/0
∑ **individuals**			56708/139	42795/270	26210/169	12702/101	42151/262	109864/373

Notes: F.A.= flight ability of the carabids: apterous (A), brachypterous (B), macropterous (M); N= number of individuals; EV= ellipsoid biovolume (mm3).

3) Regenerated poplar forest; 109 metres above sea level; geographic coordinates: 47°55′32′′ N 17°59′52′′ E

Study areas four, five and six belong to forest biotopes and were located in the important European territory of Dunajské Luhy Protected Landscape Area. The area is 122.8 km^2 and the habitats belong to the "Natura 2000" list, which includes the rarest and most endangered habitats in Europe. According to climatic conditions, it belongs to a very dry climate with dry winters, the soil type is carbonate floodplain sediments or clay-loamy river soil. According to the geomorphological division of Slovakia, it is within the Danube Plain. The examined study areas are as follows:

4) Willow-poplar floodplain forest; 114 metres above sea level; geographic coordinates: 47°53′31′′ N 17°30′25′′ E

5) Willow-poplar floodplain forest; 115 metres above sea level; geographic coordinates: 47°53′29′′ N 17°28′57′′ E

6) Regenerated poplar forest; 118 metres above sea level; geographic coordinates: 47°53′52′′ N 17°27′26′′ E

Computation of the Carabidae Ellipsoid Biovolume (EV)

We measured the following morphometric features using a Koolerton (model: ADSM301, Company: Shenzhen Andonstar Technology Co., Country: China, year 2017) LCD digital microscope (accuracy 0.1 mm):

body length – dorsal length between the upper lip (labium) and the end part of the elytra;

body height – maximum dorsoventral thickness of the left side of the body

body width - dorsal length between the maximum width of the elytra

To minimize the error, we measured each morphometric character three times and the final value is their arithmetic mean. Subsequently, Ellipsoid Biovolume (EV) for each individual was calculated separately according to Braun et al. (2004). The formula for calculating Ev is as follows:

$EV_{i=1} = (\pi/6) \times L \times H \times W$

where L = body length, H = body height, W = body width

Statistical Analyses

We determined the connection of species to land use (Agrarian landscape and Dunajské Luhy Protected Landscape Area) using the multivariate analysis (Redundancy Analysis (RDA)). We determined statistical significance using the Monte Carlo permutation test (499 iterations) in the Canoco5 programme (Ter Braak & Šmilauer, 2012).

In the statistical program R version 4.1.3 (R Core Team, 2020), we did an analysis focused on a heatmap, which helped us discover the similarity of study areas based on Ev ground beetles. Based on the intact distribution of the data, which we tested using the Shapiro-Wilk (SW) test, we used a parametric multifactorial ANOVA to test the difference in EV, length, height, and body width based on flight ability (apterous, brachypterous, and macropterous) and land use (Agrarian landscape and Dunajské Luhy Protected Landscape Area).

RESULTS AND DISCUSSION

During the research, we confirmed the occurrence of 1319 individuals from the Carabidae family, belonging to 29 species. The total average value of EV per individual is 221 mm^3. The highest average EV value per individual (223 mm^3) was recorded in the Dunajské Luhy nature reserve (study areas four, five, six). The lowest average value of EV per individual (217 mm^3) was confirmed in Agrarian landscape (study areas one, two, three). The above-mentioned results confirm that in natural forests (Danube floodplains), which were not adjacent to agricultural areas, there were larger individuals of ground beetles that inhabit habitats providing the necessary food optimum for them. Forests that were adjacent to agricultural crops (Agrarian landscape) are disturbed by the influence of anthropogenic activity, there were smaller individuals of ground beetles that did not have a food optimum in these forest habitats (Table I).

A similar result was also confirmed in their research by Jelaska & Durbes (2013), Langraf et al. (2017, 2018), where they confirmed the predominance of macropterous species with lower average EV values in anthropogenically disturbed habitats. Conversely, in habitats with low anthropogenic intervention, they found a predominance of apterous species with a higher average EV value.

Using the redundancy analysis (SD= 2.2 on the first ordination axis), we determined the connection of species from the Carabidae family to land use (Agrarian landscape and Dunajské Luhy Protected Landscape Area). The values of the explained cumulative variability of species data were 32.9 % on the first ordination axis and 47.3 % on the second ordination axis. Due to the influence of land use, the variability on the 1st ordination axis increased to 69.5 % and on the second cumulative axis there was an increase to 99 %. The Monte Carlo permutation test (iteration 499) confirmed the significant influence of Agrarian landscape (p= 0.016) and Dunajské Luhy Protected Landscape Area (p= 0.0092) on the spatial dispersion of ground beetles.

On the ordination graph (Fig. 1), we show the arrangement of species in two clusters. The first cluster consists of species preferring forest stands in the conditions of the Dunajské Luhy Protected Landscape Area. The second cluster is represented by species correlated with forest biotopes in Agrarian landscape conditions. We recorded a greater number of macropterous species in the forest stands of Agrarian landscape, which points to an increased negative impact on forest habitats due to the cultivation of crops in their neighbourhood. Macropterous species inhabit habitats that are disturbed by cyclical changes or anthropic activity, they do not have enough food in the habitat and have to fly for it.

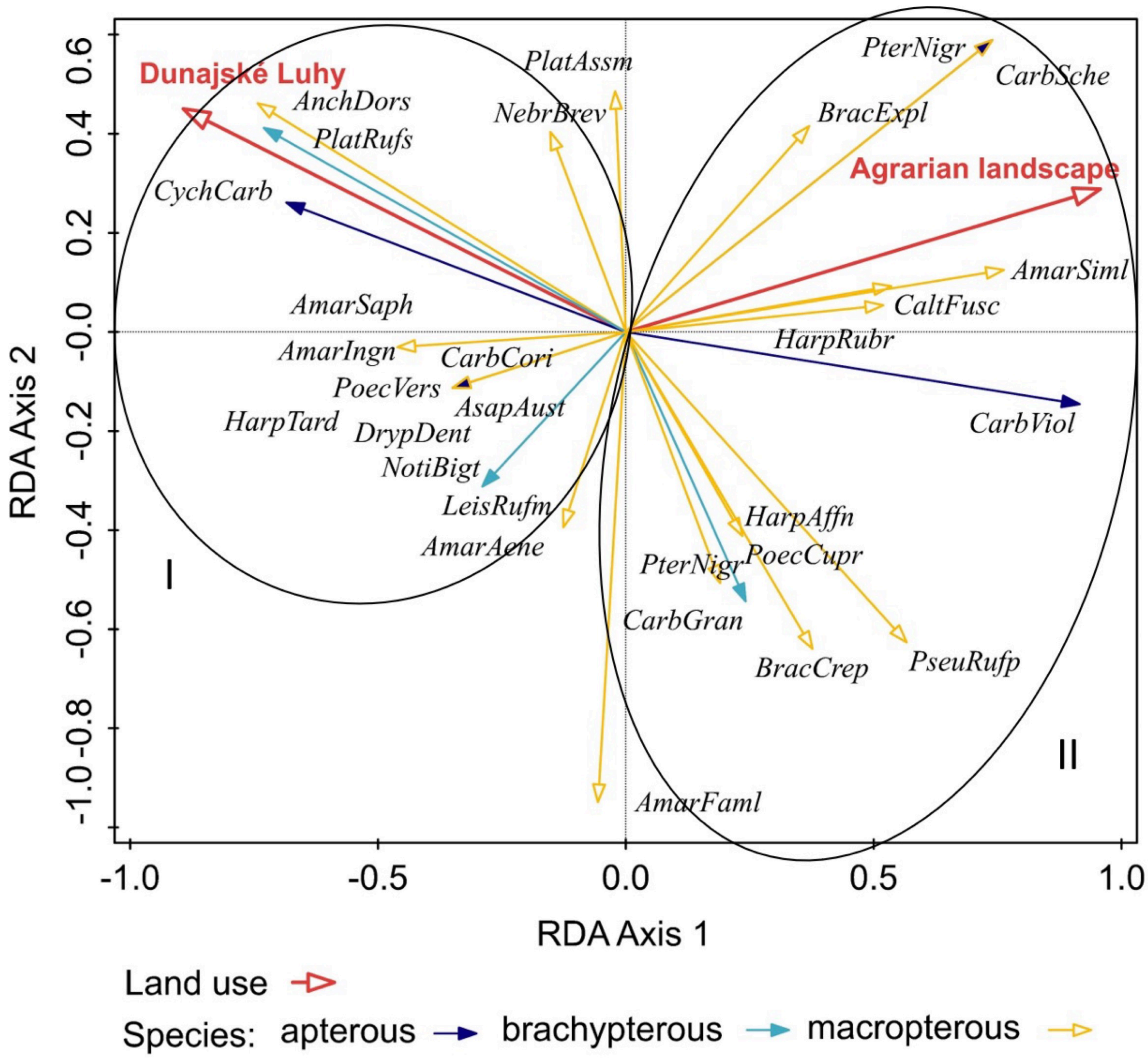

Fig. 1

Spatial dispersion of ground beetles with the binding of species to the preferred area of land use (Agrarian landscape, Dunajské Luhy)

The link between flight ability and habitat stability was also confirmed in studies by Gobbi et al. (2007), Shibuya et al. (2014), Rusch et al. (2013). In the papers, they investigated the variability of flight ability and body size in the biotopes based on the strength of anthropogenic intervention. They confirmed that the type of flight ability is directly related to the stability of the ecosystem. Apterous and brachypterous species of ground beetles were found in stable habitats, on the contrary, macropterous species were found in habitats disturbed by anthropogenic activity.

Using a heatmap, we found out the grouping of the similarity of the study areas and the preference of species to individual study areas. From the results, we highlight the similarity between study areas six and four (Willow-poplar floodplain forest) belonging to the Dunajské Luhy Protected Landscape Area. Another similarity is between study areas two and three (Willow-poplar floodplain forest and Regenerated poplar forest) belonging to Agrarian landscape. Study area one (Willow-poplar floodplain forest) belonging to the Agrarian landscape and study area five (Regenerated poplar forest) belonging to the Dunajské Luhy Protected Landscape Area were measured separately. Based on the EV species, we can see that the largest individuals occurred in study area five (with low anthropogenic interference) and the smallest individuals in study area two (with high anthropogenic interference) (Fig. 2).

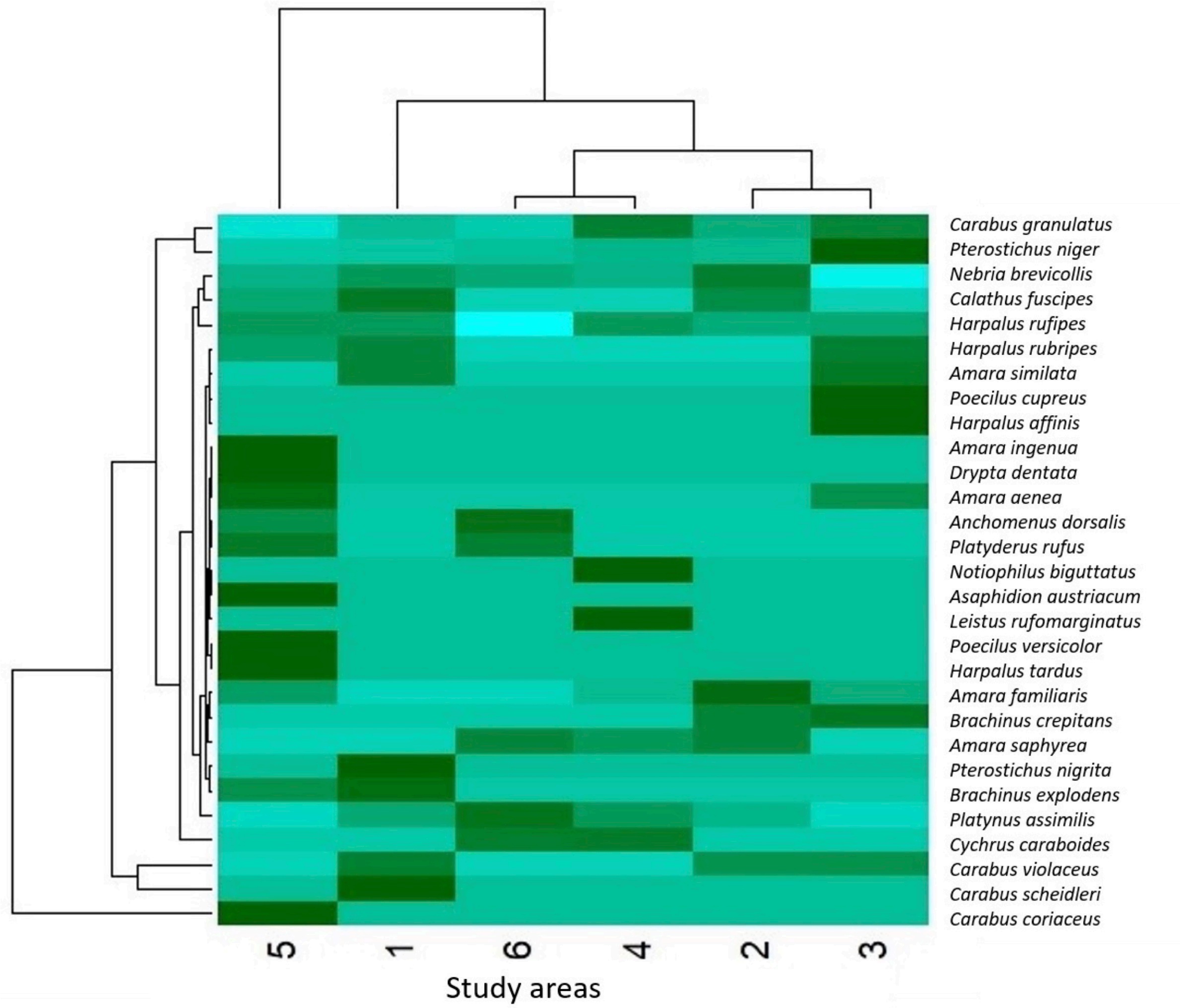

Fig. 2.

Heatmap of study areas (1-6) with the binding of ground beetles to them (method of clustering is Bray Curtis Similarity Index).

Ground beetles quickly respond to changes in the environment with the variability of morphometric features, which makes them suitable as bioindicators of environmental changes. The value of ground beetles as environmental bioindicators using morphometric variability was also pointed out by Sukhodolskaya & Eremeeva (2013), Brygadyrenko & Komlyk (2015), Teofilova et al. (2022).

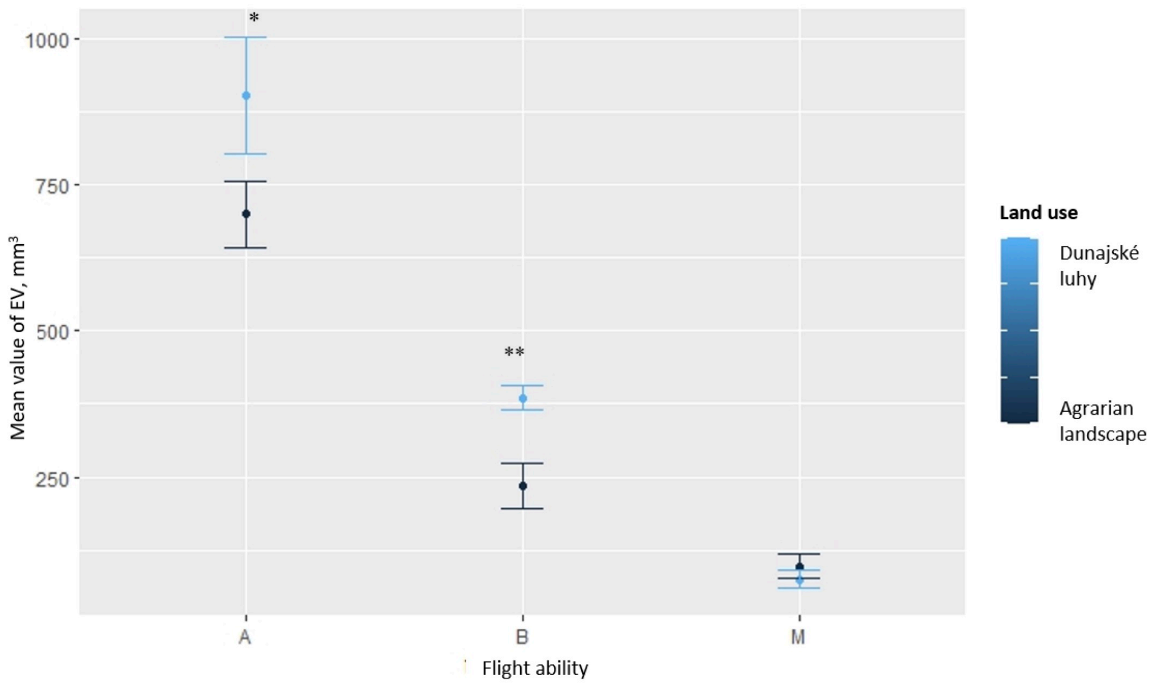

Fig. 3.

The difference in average values of EV based on the flight ability of ground beetles in the conditions of use of the land Agrarian landscape and Dunajské luhy.

Dunajské luhy A: mean 904±100 SD; B: mean 385±20 SD; M: mean 74±15 SD; Agrarian landscape A: mean 700±56 SD; B: mean 235±39 SD; M: mean 97±21 SD.

The Shapiro-Wilk (SW) test confirmed the normal distribution of data for all morphometric characteristics, the results were as follows: EV (p= 0.0614), body length (p= 0.0814), body width (p= 0.1042) and body height (p= 0.0984). As a result of the intact normality of the data distribution, we used the parametric test multifactorial ANOVA. We confirmed a significant difference between flight ability (apterous, brachypterous and macropterous) and land use (Agrarian landscape and Dunajské Luhy Protected Landscape Area) in the morphometric characteristics of EV (p= 0.0216) (Fig. 3), body length (p= 0.0308) (Fig. 4), body width (p= 0.0002) (Fig. 5) and body

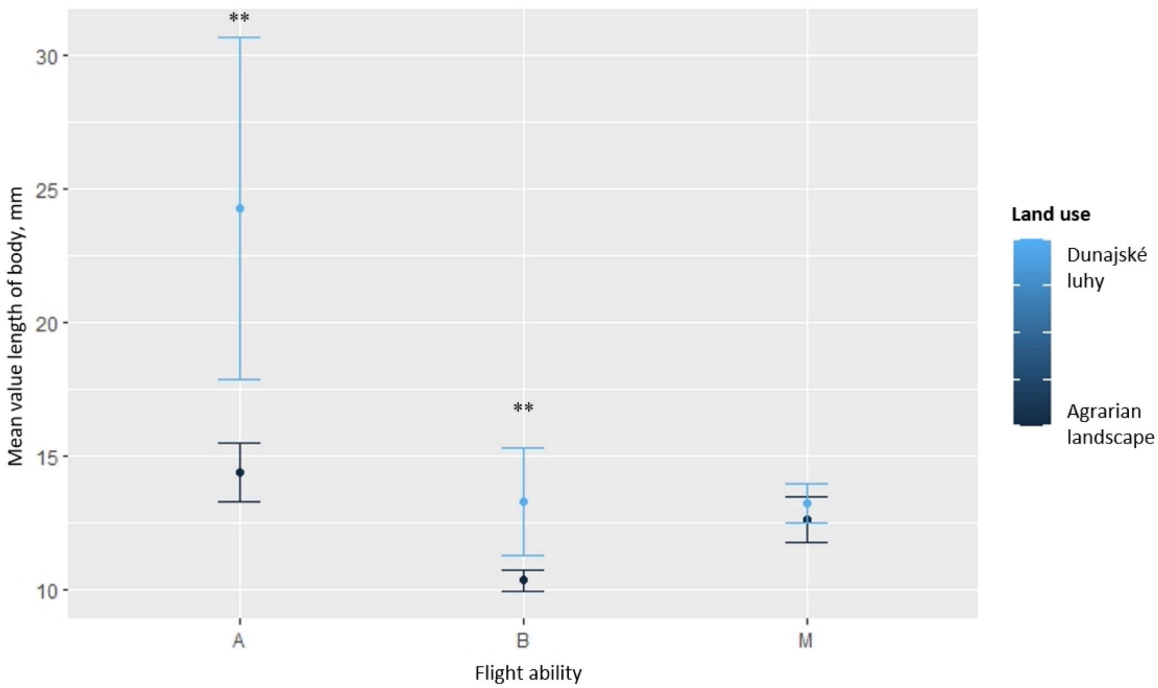

Fig. 4.

The difference in average values of body length based on the flight ability of ground beetles in the conditions of use of the land Agrarian landscape and Dunajské luhy.

Dunajské luhy A: mean 24±6 SD; B: mean 13±2 SD; M: mean 13±1 SD; Agrarian landscape A: mean 14±1 SD; B: mean 10±0.5 SD; M: mean 13±1 SD.

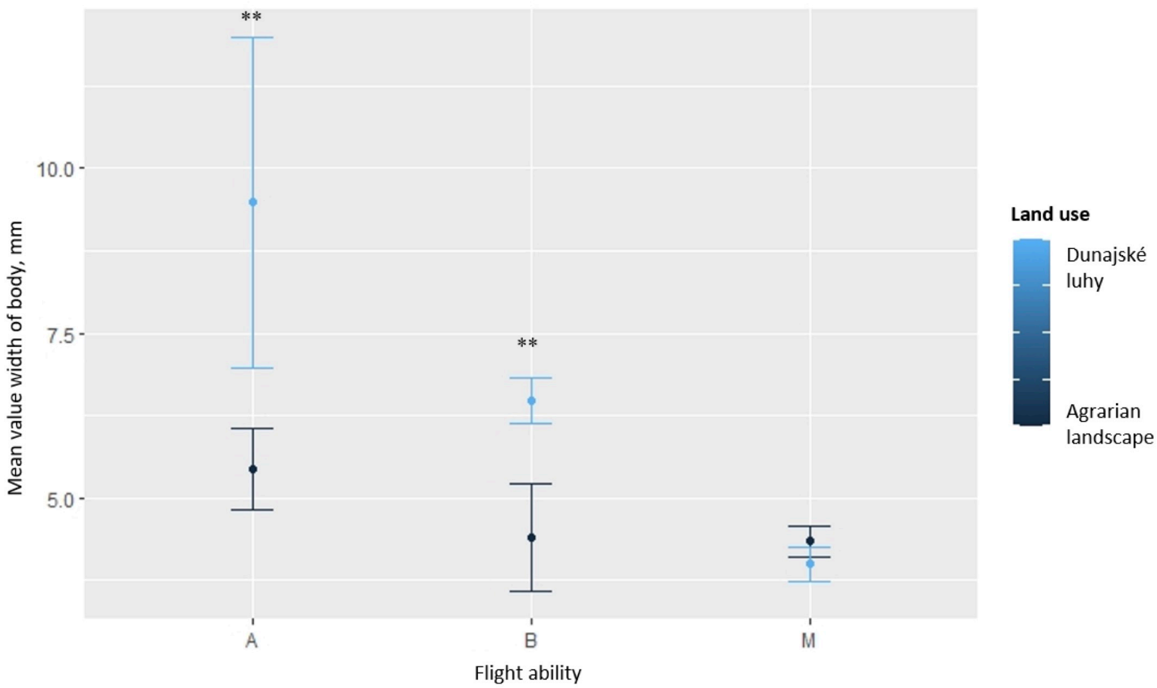

Fig. 5.

The difference in average values of body width based on the flight ability of ground beetles in the conditions of use of the land Agrarian landscape and Dunajské luhy.

Dunajské luhy A: mean 9±2.5 SD; B: mean 6±0.3 SD; M: mean 4±0.3 SD; Agrarian landscape A: mean 5±0.6 SD; B: mean 4±0.8 SD; M: mean 4±0.2 SD.

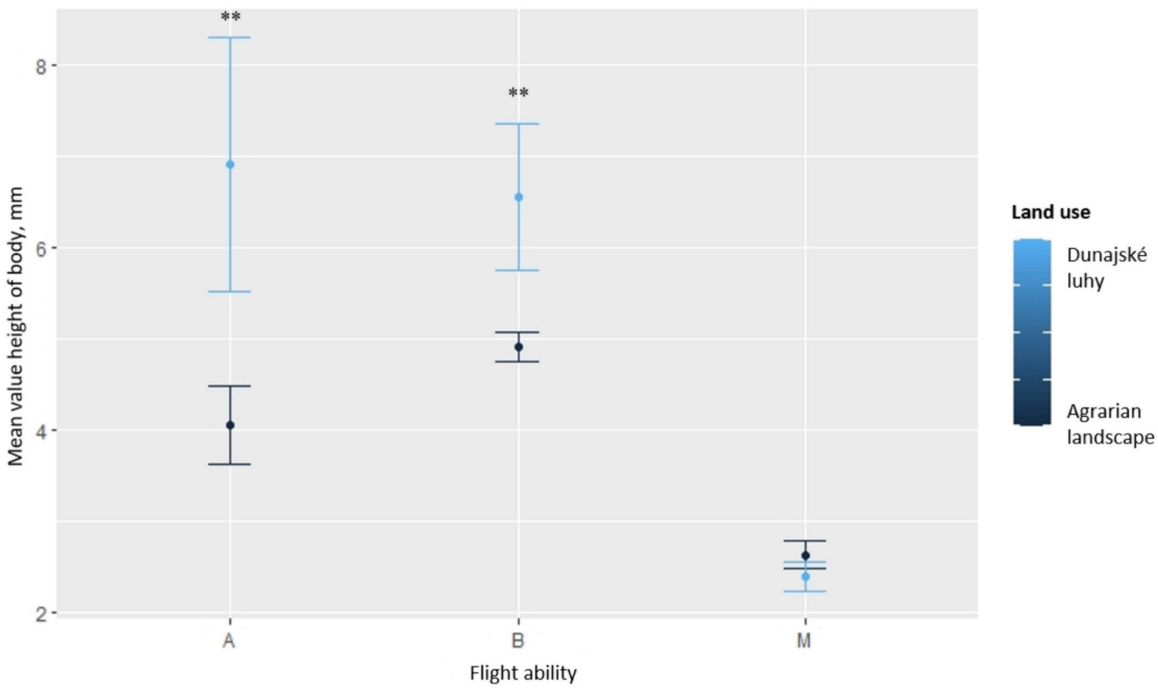

Fig. 6.

The difference in average values of body height based on the flight ability of ground beetles in the conditions of use of the land Agrarian landscape and Dunajské luhy.

Dunajské luhy A: mean 7±1.4 SD; B: mean 7±0.8 SD; M: mean 2±0.2 SD; Agrarian landscape A: mean 4±0.4 SD; B: mean 5±0.2 SD; M: mean 3±0.2 SD.

height (p= 0.0003) (Fig. 6). From the results of the analysis, we found larger individuals of apterous and brachypterous in the Dunajské Luhy Protected Landscape Area. We did not confirm this phenomenon for macropterous species, and the results were similar between the Agrarian landscape and Dunajské Luhy Protected Landscape Area. From the above findings, we can say that in the undisturbed environment of forest biotopes (Dunajské Luhy Protected Landscape Area), there were larger individuals that had their food optimum there. We confirmed smaller individuals in forest biotopes disturbed by anthropogenic activity (Agrarian landscape), where individuals found their optimum food. We did not confirm this fact for macropterous species, which may be due to the fact that these species are small and fly. With a significant increase in body size, their movement between habitats in the form of flying can become worse.

The variability of morphometric characters is influenced by the conditions of the environmental variables of the environment. It also depends on the length of life of the larva and imago, i.e. different types of habitats have an effect on the body size of ground beetles (Kozak et al., 2020). The morphometric variability of the body and its changes in individuals indicate environmental stress caused by anthropogenic activity. Food availability and environmental pollution are related to this (Niemelä et al., 2002).

CONCLUSION

From the results of our study, we confirmed the change in body size in the same types of forest stands (willow-poplar floodplain forest and regenerated poplar forest), located in different environmental conditions. Between the years 2020 and 2022, we conducted research on ground beetles on six study areas located in the conditions of the Dunajská Luhy Protected Landscape Area (important European territory) and agrarian landscape. We collected ground beetles using pitfall traps, with which we caught 1319 individuals belonging to 29 species. Using RDA analysis, we confirmed the connection of apterous and brachypterous species of ground beetles in forest stands in the Dunajské Luhy PLA (an important European territory). These species have a larger EV and inhabit ecosystems that are ecologically stable, without interference or with only low interference from anthropogenic activity. In forest stands located in agrarian landscape conditions, we confirmed the predominance of macropterous species, which have smaller EVs and prefer ecosystems with strong anthropogenic intervention. We also confirmed morphometric variability among the individuals, we confirmed larger individuals belonging to the group of apterous and brachypterous species in the forests of Dunajské Luhy (PLA). On the contrary, we confirmed larger macropterous individuals in forest stands in an agrarian landscape. For the long-term functioning of important European forest biotopes (Danube floodplains) it is important to understand the relationships between ground beetles and biotopes. Ground beetles play a role in the cycle of substances in the soil, thereby contributing to the ecological stability of habitats.

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