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Original Paper

Morphometric variation of *Abax parallelepipedus* (Piller & Mitterpacher, 1783), (Coleoptera: Carabidae) in rural – urban areas

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In the 2015–2017 period, we evaluated the morphometric variation of traits and Ellipsoid biovolume (EV) in 478 individuals (226 ♂, 252 ♀) of *Abax parallelepipedus* (Piller and Mitterpacher, 1783) in forest habitats and riparian stands. We confirmed, lower average of EV values in the rural compared to the urban areas (Kruskal-Wallis test – $p = 0.037$). The Friedman test showed a shortening of the morphometric features length ($p = 0.030$), height ($p = 0.016$), width ($p = 0.011$) and EV ($p = 0.01$) in the urban-rural direction. Spatial modeling of dispersion confirmed a significant change between 2016–2017. These changes may be affected by the food supply.

Keywords: ground beetles, morphometrics, population variability, Slovakia

1 Introduction

Studies of morphometric features changed due to environmental factors necessary to improve species populations' dynamics and structure. The interpretation of Community and species-specific responses require to be linked to the landscape characteristics of the urban and rural gradient to be applied in terms of disruptive features (Niemelä and Kotze, 2009; Oboňa et al., 2017; Oboňa et al., 2019; Demková et al., 2018). The high adaptive capacity of *Abax parallelepipedus* has allowed the species to spread to more of Europe, making it dominant for geophilic carabids of the forestry assemblages (Huidu, 2011, 2012). Two factors influence the change in body size along urban and rural gradients. The first is the expansion of urban areas and the related impact of urbanization on wildlife. The second is the integrity of body size as a sign that affects many life situations, e.g., ontogenesis, sexual selection, fertility, predatory type size, quality and availability of resources, competition (Angilletta and Dunham, 2003; Dial et al., 2008). Carabidae is a family of Coleoptera often used to study changes in the environment. The advantage is a good knowledge of ecological demands concerning species inhabiting different habitats; some are stenovalent. This family is sensitive to various toxic substances (e. g., herbicides, insecticides), changes in soil pH and soil moisture (Heydeman, 1955; Bezděk, 2001; Ivanič Porhajášová et al., 2018a, 2018b, Oboňa and Stašiov, 2018). The influence of urban, suburban, and rural areas on body size was analyzed by Sukhodolskaya (2013); Sukhodolskaya and Saveliev (2014, 2016). Studies have shown morphometric variations in the urban-suburban-rural gradient. The authors detected greater body length in *Carabus cancellatus*, *Poecilus cupreus* and *Pterostichus melanarius* occurring in rural areas. The suburban environment did not significantly affect body length changes in the above species. In the earlier studies (Gordienko and Sukhodolskaya, 2011; Sukhodolskaya,

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2011; Sukhodolskaya and Saveliev, 2012) pointed out a reduction in elytron length, pronotum width, and head width in *Carabus cancellatus* inhabiting the urban environment. However, the width of the elytron increased. Several authors (Wheller, 1996; Naidenko and Grechkanev, 2002; Timofeeva and Savosin, 2009) confirmed a reduction of body length in the direction of the species' urbanization gradient *Carabus nemoralis*, *C. aeruginosus*, and *Pterostichus oblongopunctatus*. According to Rueffler et al. (2006), the asymmetry of morphometric features is one indicator of selection in the population. Brygadyrenko and Reshetniak (2014) dealt with the asymmetry of morphometric features in Harpalus affinis sampled from the forest, field, and steppe ecosystems. They noticed a significant negative asymmetry of some characters: body length, head length, elytra length, eye distance, head width, prothorax width between anterior and posterior angles, elytra width between humeral angles, and maximum elytra width in females, indicating their shortening.

The first to use the term Ellipsoid biovolume (EV) to determine the body size (volume) of Carabidae family were Braun et al. (2004). The EV is calculated from the morphometric features of individuals (length, thickness, and width). The Carabidae family is suitable for calculating EV due to their morphology characterization by a relatively large ellipsoid body size (Barndt et al., 1991; Turín, 2000). In the study of ground beetles (Carabidae) during the restoration of the pine forest, Szyszko (1983) formulated and confirmed the hypothesis that "the decrease of environmental disturbance allows a larger than average body size." Šustek (1987) pointed out the declining body size of Carabidae in anthropically intensively disturbed areas. According to Niemelä et al. (2002), urbanization causes a decrease in the biodiversity of Carabidae species and, in the most cases, increases the number of small species towards the city center.

Similarly, Weller and Ganzhorn (2006) state a decrease in body size of *Carabus nemoralis* due to urbanization towards the city center. Magura et al. (2006) also examined differences in the Carabidae species' body size in rural, urban, and suburban areas. In the urban environment, authors noticed several species with larger body size than in urban and suburban areas. Lövei and Magura (2006) found that the body size of carnivorous Carabidae decreased near the industrial area. In less polluted environments, a change in body size was not observed.

This study was focused on the analysis of variables of morphometric features (length, height and width) species *Abax parallelepipedus*, during the years 2015–2017. The (EV) in the studied 2 forest localities and 2 waterside vegetationin (4 localities) the southern part of central Slovakia was also evaluated.

2 Material and methods

The research took place from 2015 to 2017, from April to November, in 4 localities and 3 types of biotopes, according to Ružičková et al. (1996). The study areas are located in the southern part of Central Slovakia (geomorphological units Stolické vrchy Mts. and Juhoslovenská kotlina basin). Location data and habitat characteristics of localities are summarized in Table 1.

Material from pitfall traps at regular biweekly intervals was collected. We used pitfall traps (750 ml) (Novák et al., 1969). Five pitfall traps were arranged in 1 line per each locality and 10 m away from each other. As a preservation, 4% NaCl was used. The species of *Abax parallelepipedus* were determined according to Hůrka (1996).

2.1 Computation of the Carabidae Ellipsoid biovolume (EV)

The morphometric variables were measured for each individual using a digital microscope (0.1 mm accuracy):

a) the length – dorsal length between the upper lip (labium) and the terminal part of elytra,
b) the width – dorsal length between the maximum width of the elytra,

Table 1 Location data and habitat characteristics of analyzed localities

Geomorphological unit	Study area		C. a.	m a.s.l.	biotope	G.C.
Stolické vrchy Mts.	1	Lichovo	Utekáč	518	Culture of *Picea abies*	48 °36´27˝ N 19° 48´ 23˝ E
	2	Farkaška	Utekáč	446	nitrophilous waterside vegetation	48° 36´ 34˝ N 19° 47´ 52˝ E
Juhoslovenská kotlina basin	3	pri Ľadove	Lučenec	258	Carpathian turkey oak forest	48° 19´ 08˝ N 19° 37´ 48˝ E
	4	Ľadovo	Lučenec	207	nitrophilous waterside vegetation	48° 20´ 12˝ N 19° 37´ 06˝ E

C. a. – Cadastral area; m a.s.l. – metres above sea level; G.C. – geographic coordinates

c) the height – the maximum dorsoventrally thickness of the left side of the body.

Each parameter was measured three times to minimize error, and the final value is their arithmetic average. For each specimen, the Elipsoid biovolume was calculated from morphometric data according to Braun et al. (2004):

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

where: L – individual length; H – individual height; W – individual width

2.2 Database quality

The data of the obtained research was saved and performed using a Microsoft SQL Server 2017 database (Express Edition). It consisted of frequency tables for collections, measured morphometric features, and EV. The database also consisted the code tables for localities and their variables (habitat, locality name, cadastral area, altitude, coordinates of localities), species, and bioindication characteristics. Matrices for statistical calculations were programmed using Microsoft SQL Server Management (SSMS, 2017).

2.3 Statistical analyses

The spatial modeling was performed by multivariate analysis using Canoco program 5 (Ter Braak and Šmilauer, 2012), with which we look for dependencies Ellipsoid biovolume of *Abax parallelepipedus*. Based on the lengths of the gradient (using Detrended Correspondence Analysis – DCA), we used the unimodal method of Canonical Correspondence Analysis – CCA analysis to evaluate the material.

The analysis in the statistical program Statistica Cz. Ver. 7.0 (StatSoft, Inc., 2004) was focused on Shapiro-Wilk W-test, which determines the normality of data distribution. Based on the violation of the normality data distribution (p-value = 0.00) we used a nonparametric Kruskal-Wallis test (ANOVA), and Friedman test (ANOVA) were used to test the differences in EV, length, height, and width of the body between areas (rural, urban landscape). Using the regression model (Polynomial regression), we expressed the relationship (correlation) between EV's average value per individual to the years of harvest for urban and rural areas.

3 Results and discussion

During three years of research (2015–2017), we collected 478 individuals (226 ♂, 252 ♀) belonging to the species *Abax parallelepipedus* at the examined localities 1 (62 ♂, 75 ♀), 2 (32 ♂, 55 ♀) (rural areas), and localities 3 (66 ♂, 49 ♀), 4 (66 ♂, 73 ♀) (urban areas). The total EV value was

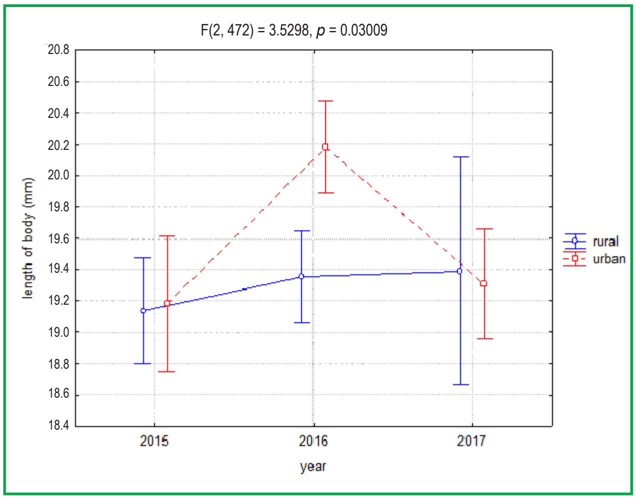

Figure 1 Analysis of variance (Friedman test (ANOVA)) of the length of body average

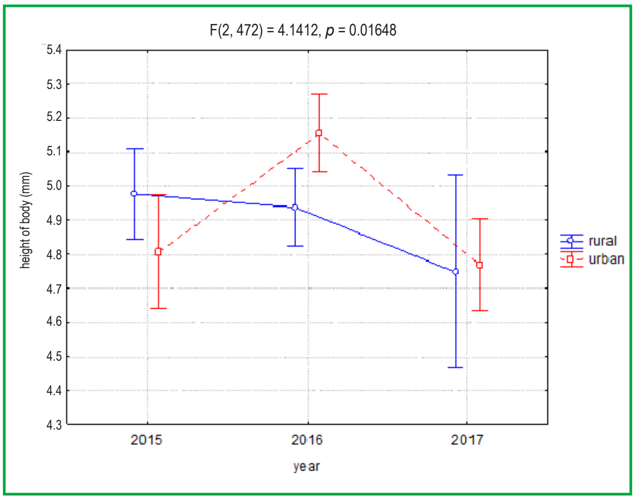

Figure 2 Analysis of variance (Friedman test (ANOVA)) of the height of body average

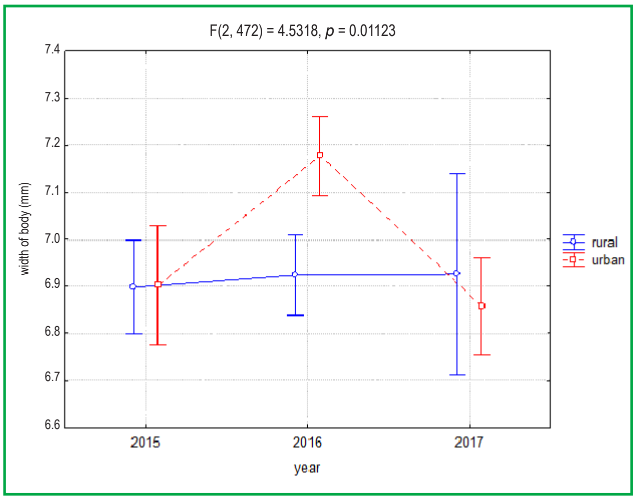

Figure 3 Analysis of variance (Friedman test (ANOVA)) of the width of body average

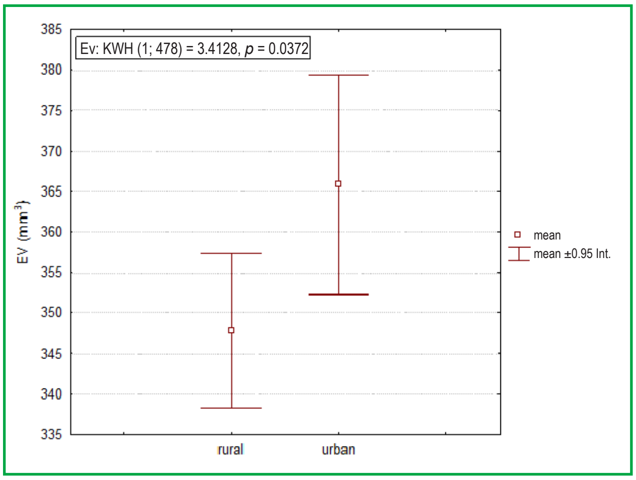

Figure 4 Analysis of variance (Kruskal-Wallis test (ANOVA)) of mean EV values of species *Abax parallelepipedus*

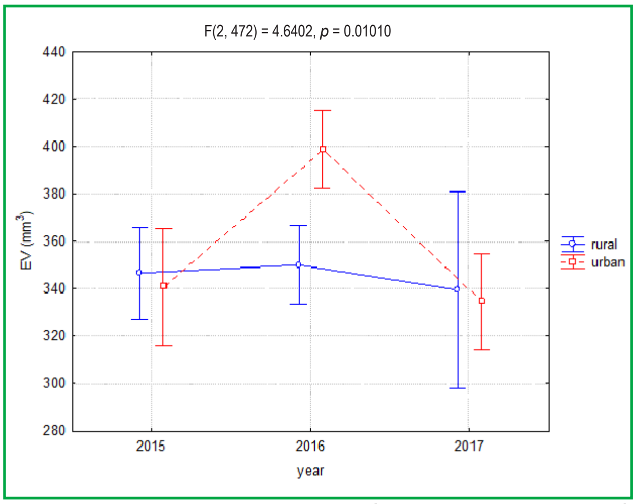

Figure 5 Analysis of variance (Friedman test (ANOVA)) of average EV values of species *Abax parallelepipedus*

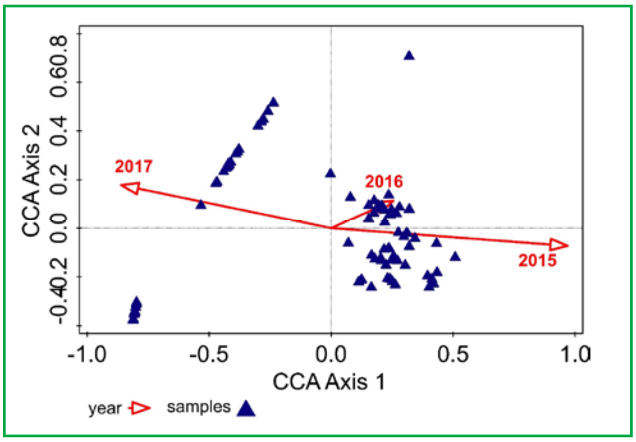

Figure 6 CCA analysis of the dispersion of *Abax parallelepipedus*

170,838.75 mm^3, with an average value per individual $\bar{x}$ = 357.4 mm^3. A violation of the normal distribution of data for all morphometric features (length, thickness, width) and EV (*p*-value = 0.00) in all localities in both sexes of *Abax parallelepipedus* during 2015–2017 was observed.

Based on the violation of the normality data distribution, we used a nonparametric Friedman test (ANOVA) to confirm the statistically significant difference length (*p* = 0.030) (Figure 6), height (*p* = 0.016) (Figure 7), width (*p* = 0.011) (Figure 8) between of urban and rural areas in 2015–2017. Within the height, a slight decrease (shortening) during three years of research we observed.

On the other hand, urban areas had a significant decrease (shortening) for all morphometric features (length, height, width) between 2016–2017, but not between 2015 and 2017. The results showed a shortening of morphometric features in the direction of the urban-rural gradient. Several studies confirmed our findings (Naidenko and Grechkanev, 2002; Weller and Ganzhorn, 2003; Timofeeva and Savosin, 2009; Gordienko and Sukhodolskaya, 2011; Kalivoda et al., 2011; Sukhodolskaya, 2011; 2013 Sukhodolskaya and Saveliev, 2012, 2014, 2016; Vician et al., 2018).

Based on the violation normality of the data distribution, we used a nonparametric Kruskal-Wallis test (ANOVA) to confirm the statistically significant difference (*p*-value = 0.037), in EV's average values in the species *Abax parallelepipedus* between urban and rural areas (Figure 1). Lower EV values for rural areas may be affected by former glass production near these localities, where habitat damage has occurred. Similarly, Braun et al. (2004), Lövei and Magura (2006) observed decreased body size due to industrial production.

Based on the violation of the normality data distribution, we used a nonparametric Friedman test (ANOVA) to confirm the statistically significant difference (*p*-value = 0.01) (Figure 2) difference between the average values of EV urban and rural areas in 2015–2017. In the rural area, we recorded a slight year-on-year decline between 2016 and 2017. On the contrary, in the urban area, were recorded between 2016 and 2017, of up to 70 mm^3. In accordance with our results, many studies (Szyszko, 1983; Šustek, 1987; Niemelä et al., 2002; Magura et al., 2006; Weller and Ganzhorn, 2006) state the body size (EV) reduction in anthropically intensively disturbed areas due to urbanization.

The spatial variability (dispersion) of the species *Abax parallelepipedus* was determined by Canonical Correspondence Analysis (CCA, *SD* = 4.01 on the 1st ordination axis). The explained cumulative variability

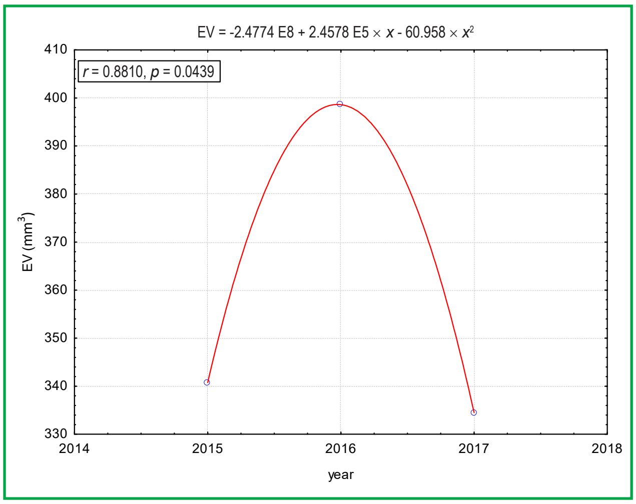

Figure 7 Polynomial regression model of EV values per individual for the years 2015–2017 in urban areas

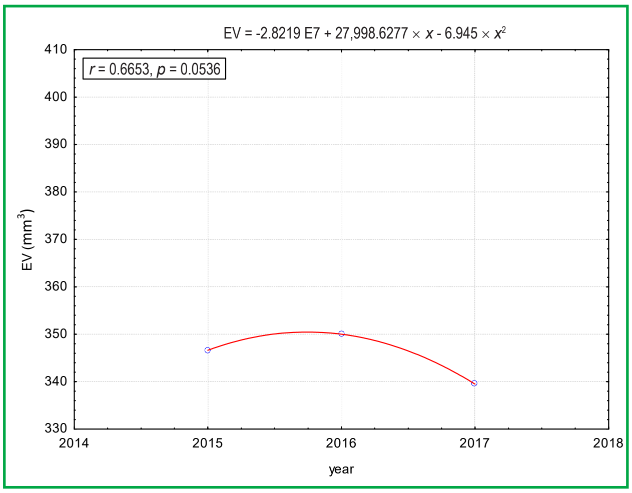

Figure 8 Polynomial regression model of EV values per individual for the years 2015–2017 in rural areas

of species data values was 60% on the 1st ordination axis and 80.2% on the second ordination axis. Cumulative variability of the species set explained by environment variables captured by the 1st ordination axis 63%, and the second axis captures 87.9%. The distance of vectors between the years 2015–2016 was small (Figure 3). On the contrary, in 2016–2017 was the distance large, which indicates a significant change in the dispersion between these years (2016–2017). We assumed that the above facts may be affected by a change in the food supply influenced by climatic conditions (temperature, sum of difficulties).

The correlation coefficient value was very high for the urban ($r = 0.8810$), which indicated a solid relationship. A medium value ($r = 0.6653$) was observed in the rural area, indicating a medium relationship of the measured average EV values per individual to the years of harvest.

The overall suitability of the regression model was statistically significant in areas urban (p-value = 0.04) and rural areas were on threshold (p-value = 0.05).

4 Conclusions

In 2015–2017, we captured 478 individuals (226 ♂, 252 ♀) of the species *Abax parallelepipedus* in the territory of Stolické vrchy Mts. and Juhoslovenská kotlina basin. The research was carried out at 4 localities representing 3 types of habitats. The Kruskal-Wallis test demonstrated a statistically significant difference ($p = 0.037$) in EV values between urban and rural areas. Lower EV values in rural areas may be caused by former glass production. Friedman's test showed a significant difference in morphometric features of length ($p = 0.030$), height ($p = 0.016$), width ($p = 0.011$) and EV ($p = 0.01$) between urban and rural areas. Our results indicated the shortening of morphometric features in the urban-rural direction during years 2016–2017. We also observed the declining body size (EV) in anthropically disturbed areas, during years 2016–2017. Through spatial modeling (CCA) of the dispersion of the species *Abax parallelepipedus*, we found significant changes between years 2016–2017. We assume that the above changes may be affected by a change in the food supply.

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