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Short communication

Body volume in ground beetles (Carabidae) reflects biotope disturbance

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Abstract
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Changes in body size of living organisms can indicate changes in environmental quality. The family Carabidae is frequently used as an indicator of environmental status. We collected ground beetles in 9 Slovakian localities (in the Veporské vrchy Mts and the Juhoslovenská kotlina Basin) of various levels of disturbance, and evaluated the volume of individuals. The lowest average body volumes of individual were found for an intensively grazed pasture (locality 5) and a nitrophilous waterside vegetation (locality 6) (1,298 mm^3–4,648 mm^3) with predominantly macropterous species. We have confirmed the significantly higher average biovolume value of individual Carabidae in less disturbed habitats: a *Picea abies* plantation (locality 1), a Carpathian oak-hornbeam forest (locality 4) and a Carpathian turkey oak forest (locality 7) (from 9,837 mm^3 to 13,038 mm^3), where apterous and brachypterous species dominated.

Keywords
biovolume, Carabidae, indicator, Slovakia

Introduction

Environmental quality, resource availability, and interspecific interactions all influence metabolic activity, generation time, reproductive rate, and also the body size of organisms (West et al., 1997). Depending on body size, we can also predict if an organism is a potential predator or prey (Peters, 1983). Changes in the body size and an individual species distribution across a certain space are parameters that indicate the degree of environmental burden (McGeoch, 1998). Relationships between the species structure of animal communities and the body size were also studied in connection with their use as bioindicators in a long-term anthropogenic intervention (Brown, 1995). The family Carabidae is suitable for such calculations because the ecological characteristics of the species are well known (Lövei and Sunderland, 1996) and these can be used for bioindication. Rouabah et al. (2015) analyzed the influence of vegetation structure on the diversity, and spatial distribution of ground beetles in correlation with their body size. They confirmed that big-bodied species achieve high population densities in forests, while small species prefer species-rich meadow vegetation. Šustek (1987) found that average body size of the ground beetles decreased in areas under intensive anthropogenic disturbance. Lövei and Magura (2006) reported that average body size in predatory carabids decreased close

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to an industrial area, but not in slightly polluted areas. Szyszko (1983) found that the average size of ground beetles increased with decreasing disturbance in Polish pine forests, and concluded that "the decrease of environmental disturbance allows a larger than average body size". Magura et al. (2006) analyzed differences in the ground beetle body size distribution influenced by urbanization along a forest-urban park urbanisation gradient. They confirmed the presence of individuals of various species with larger body size in rural rather than in urban or suburban areas. Braun et al. (2004) claimed that the average species size increased with decreasing environmental pollution at a former chemical factory site in Germany. They used the term biovolume, calculated from morphometric parameters of individuals (body length, thickness and width) to characterise ground beetle body size (volume). The family Carabidae is suitable for such calculations because of their relatively large body size. Majzlan and Frantzová (1994) compared biovolume values of male vs. female carabids. In most cases, females were bigger than males (although not confirmed statistically). Only 3 ground beetles species (*Panagaeus crux-major*, *Pterostichus diligens* and *Harpalus schaubergerianus*) have larger males than females. The biggest differences between the sexes exist in the genus *Carabus*. In their study, Majzlan and Frantzová confirmed that the species is of bigger volume display major value differences of biovolume between the sexes. Majzlan and Baťalík (1997) also confirmed this fact. Teiji et al. (2000) have analyzed 15 beetle species of the genus *Carabus*. The average female was bigger than the average male, except for the *Carabus uenoi*.

Marcoptery or brachyptery within ground beetles are related to ecosystem stability, mostly *via* habitat structure and vegetation type (Sonomi et al., 2014). Larger average body size is related to the occurrence of apterous and brachypterous ground beetles (Majzlan and Frantzová, 1994). On the contrary, the smaller average body size indicates the presence of macropterous species in the biotope. Brachypterous and apterous ground beetles are unable to fly, so their dispersal power is lower, and they colonise new biotopes with more difficulties. Macropterous forms of ground beetles can more easily occupy new biotopes, and consequently, sudden and substantial changes in biotopes influence apterous and brachypterous species more profoundly. Species living in stable ecosystems lose their flight ability, but species living in cyclical changeable ecosystems still retain their flight ability (Porhajášová and Šustek, 2011). The predominance of apterous and brachpterous species indicates a higher degree of environmental stability, and the presence of macropterous species indicates less stable environmental conditions.

The aim of this paper is to evaluate the body size changes (biovolume) of ground beetles influenced by various intensities of anthropogenic activities in nine biotopes of Slovakia, in the Veporské vrchy Mountains and the Juhoslovenská kotlina Basin. We focused on evaluating the following hypotheses: (i) there is no difference in the average value Bv for males and females, (i) the average body size value (Bv) of ground beetles decreases from less disturbed anthropogenic biotopes to more disturbed ones.

Materials and methods

The study areas are located in the southern part of Slovakia in the geomorphological units of the Veporské vrchy Mountains and the Juhoslovenská kotlina Basin (Table 1).

Ground beetles were collected from April to October 2015, in 9 localities representing 7 types of biotopes, classified according to Ružičková et al. (1996). We used pitfall traps (750 ml) and Möricke traps (1,500 ml) which are yellow and attract insects (Novák et al., 1969). The traps were arranged in 5 lines in each biotope. The distance between the individual traps was 10 m from each other and there were 10 traps per a line. As a killing agent, we used 4% saline solution. The traps were checked and emptied at regular two-week intervals. The collected material was sorted in the laboratory, and carabids were identified to species using the nomenclature and keys according to Hůrka (1996). We measured the following morphometric characters on each individual according to Braun et al. (2004): (i) body length in mm, as the dorsal length between the upper lip (labrum) and the terminal part of elytra, (ii) the body width (mm) as the length between the edges at the maximum width of the elytra, and (iii) body thickness (mm) as the maximum dorsoventral thickness on the left side of the body. To minimize the measuring error, each parameter was measured three times, and the arithmetic average was used. On the grounds of measured morphometric features, the volume of each individual or biovolume (Bv) was calculated as:

$$Bv = (h + š/2)^2 \,.\, D \,.\, \pi, \qquad (1)$$

where h is individual thickness, š is individual width, D is individual length, (Majzlan and Frantzová 1995). Flight ability was assigned as in Hůrka (1996).

The resulting Bv values are given in mm^3. The results indicate the average Bv value of the subject on the habitat. The data analysis sample represents the Bv (mm^3) values of individuals captured into the pitfall traps and Möricke traps at each habitat.

We used the Statistica Cz. Ver. 7.0 (StatSoft, Inc., 2004) program for statistical analysis of morphometric signs and biovolume. The analysis was focused on:

- the morphometry and biovolume were analyzed by descriptive statistics
- testing normality of data distribution
- testing deviations to average values by gender for selected species

Table 1. Location data of the study localities and their biotope characteristics

Locality	Municipality	Altitude (m asl)	Biotope	Geographic coordinates
Veporské vrchy Mts				
Lichovo	Utekáč	518	*Picea abies* plantation forest	48°36′27″N 19°48′23″E
Lichovo	Utekáč	556	Pasture	48°36′30″N 19°48′35″E
Farkaška	Utekáč	446	Nitrophilous waterside vegetation	48°36′34″S 19°47′52″N
Juhoslovenská kotlina Basin				
Kúpna hora	Poltár	300	Carpathian oak-hornbeam forest	48°26′09″N 19°49′27″E
Prievranka	Poltár	272	Pasture	48°25′52″N 19°49′08″E
Pažiť	Poltár	218	Nitrophilous waterside vegetation	48°25′41″N 19°46′35″E
Pri Ľadove	Lučenec	258	Carpathian turkey oak forest	48°19′08″N 19°37′48″E
Zajačie brehy	Lučenec	208	Fallow field	48°19′017″N 19°39′05″E
Ľadovo	Lučenec	207	Nitrophilous waterside vegetation	48°20′12″N 19°37′06″E

We used the Lilliefors test, Shapiro-Wilk´s W test for testing normality in Bv distribution and morphometric parameters, respectively. We analyzed biotopic influence on Bv for both sexes by one-way ANOVA. Testing differences in Bv between sexes was made by a non-parametric Kruskal-Wallis test.

Results

We collected 1,873 individuals (882 males, 991 females) belonging to 44 species (see Appendix). The highest abundance was found in the habitat Culture of *Picea abies* (466 individuals collected), while the lowest (95 adults) in pasture. Nitrophilous waterside vegetation was the most species-rich habitat (21 species) and the lowest number of species was collected in Carpathian oak-hornbeam forest (11 species).

All Bv values were normally distributed. The lowest average Bv value of individuals was recorded in the pasture (locality 5), and the highest in the biotope of Carpathian oak-hornbeam forest (locality 4) (Table 2). The average values were close to the median values for the biotopes of *Picea abies* plantation (locality 1), pasture (locality 2), Carpathian turkey oak forest (locality 7), fallow field (locality 8) and nitrophilous waterside vegetation (locality 9).

The parametric ANOVA indicated significant (p = 0.00) difference in the average Bv values among the localities (Fig. 1). The biotopes with the lowest average Bv values were also the ones with presence of small macropterous species. On the other hand, biotopes with a higher average Bv value had mostly apterous and brachypterous species.

Biotopes pasture (locality 2) and nitrophilous waterside vegetation (locality 9) show an approximately even number of apterous, brachypterous and macropterous species. In the forested biotopes and nitrophilous waterside vegetation (locality 3), apterous species prevailed, which may indicate greater ecological stability. We found more macropterous species in the biotopes with intensive agricultural land use.

During the evaluation, we were also comparing the Bv values of males and females of species with at least 35 individuals of each sex: *Abax parallelepipedus*, *Carabus coriaceus*, *C. glabratus*, *C. hortensis*, *C. violaceus* and *Harpalus affinis* (Table 3).

Non-normality was detected for females of *Carabus glabratus*, *C. hortensis* and for males *Carabus coriaceus*, *C. hortensis*, and *Harpalus affinis*. Statistically significantly different Bv values were reported for *Abax parallelepipedus Carabus coriaceus*, *C. glabratus* and *C. violaceus* but not for *Carabus hortensis* (p = 0.12) and *Harpalus affinis* (p = 0.54).

Discussion

Through our research, we evaluated the anthropogenic (developed agriculture) impact on carabid beetles. By Bv and flight abilities, we achieved a more comprehensive bioindication evaluation of 9 localities, representing 6 types of biotopes. The species were divided on the basis of flight ability according to Hůrka (1996),

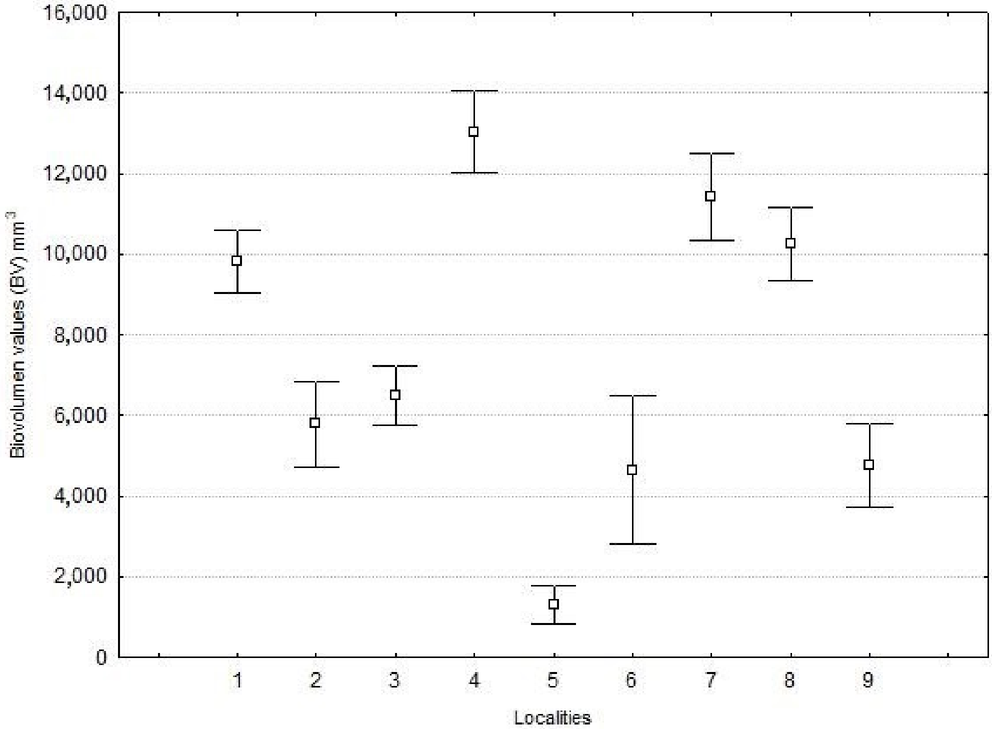

Fig. 1. Ground beetle biovolume analysis in nine study localities in central Slovakia. Data are arithmetical means; vertical lines indicate a 95% confidence interval.

Table 2. Biovolume (mm^3) of ground beetles in studied localities

Locality	N valid	Average biovolume	Median biovolume	SD
Veporské vrchy Mts				
Lichovo	466	9,477	9,708	5,187
Lichovo	95	5,861	5,453	5,363
Farkaška	191	6,881	5,279	5,871
Juhoslovenská kotlina Basin				
Kúpna hora	303	13,254	10,405	9,298
Prievranka	236	1,302	591	3,672
Pažiť	107	4,497	1,042	8,794
Pri Ľadove	245	11,463	10,02	8,604
Zajačie brehy	130	10,244	10,771	28,381
Ľadovo	100	4,534	4,102	4,958

and we supplemented the distribution theory. Our results confirmed earlier findings (Majzlan and Frantzová,1994; Porhajášová and Šustek, 2011) according to which biovolume and habitat disturbance are related. More disturbed habitats have species that are smaller and/or macropterous, while lower disturbance allows the increased presence of larger species also often brachypterous or apterous. Porhajášová and Šustek (2011) and Sono et al. (2014) pointed to the prevalence of macropterous species in habitats with an intense anthropogenic interference. Similar trends were found at 39 localities around Bratislava (Šustek, 1987), and along an urbanisation gradient near Debrecen, Hungary (Lövei and Magura, 2006). Apparently, the same trend was detectable during a recovery from heavy industrial pollution (Braun et al., 2004).

Table 3. Biovolume mm^3 of selected Carabidae common species for males and females

Species	Sex	N valid	Average biovolume	Median biovolume	SD
Abax parallelepipedus	♀	74	4,676.38	4,565.00	901
	♂	66	4,070.98	4,052.50	831
Carabus coriaceus	♀	38	37,496.00	38,157.00	6,019
	♂	67	26,760.43	26,856.00	4,854
Carabus glabratus	♀	56	13,535.39	13,689.50	1,543
	♂	49	10,881.37	10,795.00	1,041
Carabus hortensis	♀	284	11,317.08	11,304.00	31,572
	♂	211	8,428.79	8,308.00	1,242
Carabus violaceus	♀	78	14,783.91	15,013.50	2,461
	♂	91	10,594.78	10,616.00	1,757
Harpalus affinis	♀	75	635.32	635.00	136
	♂	119	549.77	540.00	91

Conclusion

We confirmed the lowest average Bv value presented mostly by macropterous species in the biotopes of pasture (locality 5) and nitrophilous waterside vegetation (locality 6). These localities are used as long-term agricultural land. We confirmed the highest average Bv value (mostly apterous and brachypterous species) in the biotopes which are anthropogenically least affected. We confirmed the highest average Bv value in the fallow field biotope (locality 8) because of a higher presence of apterous individuals; but most of them were macropterous species.

The family Carabidae is a suitable tool for the indication of the biotopes´ distortion level and its ecological stability. The assessment of ecological stability is considered to be a basis for the evaluation of the current status, serving for future options for the land use. Moreover, it is a very important part of landscape planning documents in Slovakia (e.g. Development the Territorial System of Ecological Stability). Bioindication evaluation by biovolume can be used as one of the assessment approaches of environmental quality and intensity of anthropogenic impact on landscape. We have statistically confirmed that the Bv average value correlates to intensity of anthropogenic influenced on habitats.

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Appendix

Table A1. List of the *Carabidae* species from studied localities

Species	Locality									
	1	2	3	4	5	6	7	8	9	Total
Abax ovalis (Duftschmid, 1812)	5	–	1	–	–	–	–	–	–	6
Abax parallelepipedus (Piller & Mitterpacher, 1783)	48	3	17	7	–	19	14	–	38	136
Abax parallelus (Duftschmid, 1812)	14	5	16	7	–	1	5	–	12	60
Agonum viduum (Panzer, 1797)	–	–	–	–	–	–	–	–	1	1
Amara aenea (De Geer, 1774)	–	1	–	–	1	–	–	1	–	3
Amara aulica (Panzer, 1797)	–	–	2	–	–	–	–	–	–	2
Amara familiaris (Duftschmid,1812)	–	–	–	1	–	–	–	–	1	2
Amara saphyrea Dejean, 1828	–	–	–	–	–	–	3	–	2	5
Amara similata (Gyllenhal,1810)	–	–	–	–	–	–	–	–	1	1
Anchomenus dorsalis (Pontoppidan, 1763)	–	–	–	–	3	1	–	2	–	6
Brachinus crepitans (Linnaeus, 1758)	–	–	–	–	2	–	–	2	–	4
Calathus melanocephalus (Linnaeus, 1758)	–	–	–	–	1	–	–	–	–	1
Calosoma Inquisitor (Linnaeus, 1758)	–	–	–	–	–	–	1	–	–	1
Carabus cancellatus Illiger, 1798	3	6	27	–	–	–	–	–	–	36
Carabus convexus Fabr., 1775	4	–	8	–	–	–	1	–	–	13
Carabus coriaceus Linnaeus, 1758	9	–	1	52	2	8	28	1	4	105
Carabus glabratus Paykull, 1790	93	2	7	–	–	–	2	1	–	105
Carabus granulatus Linnaeus, 1758	–	–	24	–	–	–	–	–	7	31
Carabus hortensis Linnaeus, 1758	137	–	8	200	–	–	152	–	–	497
Carabus intricatus Linnaeus, 1761	10	–	2	14	–	–	1	–	5	32
Carabus nemoralis O.F.Müller, 1764	34	17	1	2	–	–	16	–	–	70
Carabus scheidleri Panzer, 1799	–	2	–	–	1	5	–	43	–	51
Carabus ullrichi Germar, 1824	–	–	38	–	–	–	–	24	–	62
Carabus violaceus Linnaeus, 1758	72	22	4	13	5	–	7	41	6	170
Cicindela germanica Linnaeus, 1758	–	–	–	–	7	–	–	8	–	15
Cymindis humeralis (Fourcroy, 1785)	–	–	–	4	–	–	1	–	2	7
Cychrus caraboides (Linnaeus, 1758)	10	–	1	–	–	–	–	–	–	11
Drypta dentata (Rossi, 1790)	–	–	–	–	–	–	–	1	–	1
Elaphrus aureus P. Müller, 1821	–	–	–	–	–	1	–	–	3	4
Harpalus affinis (Schrank, 1781)	–	5	–	–	187	–	–	2	–	194
Harpalus froelichi Sturm, 1818	–	–	–	–	–	7	–	–	–	7
Harpalus rubripes (Duftschmid, 1812)	–	17	–	–	–	–	–	–	–	17
Lebia chlorocephala (Hoffm. a kol., 1803)	–	1	–	–	–	–	–	–	–	1
Molops elatus (Fabr., 1801)	–	–	–	–	–	–	2	–	–	2
Molops piceus (Panzer, 1793)	26	4	1	–	–	–	5	–	–	36
Nebria brevicollis Fabr., 1792	–	2	7	–	–	2	2	–	4	17
Notiophilus biguttatus (Fabr., 1799)	–	–	–	1	–	–	–	–	–	1
Platynus assimilis (Paykull, 1790)	–	–	8	–	–	37	–	–	14	59
Poecilus cupreus (Linnaeus, 1758)	–	3	–	–	7	–	–	4	–	14
Poecilus versicolor (Sturm, 1824)	–	–	–	–	2	–	–	–	–	2
Pseudoophonus rufipes (De Geer, 1774)	–	5	–	–	18	10	–	–	–	33
Pterostichus melanarius (Illiger, 1798)	–	–	6	–	–	11	–	–	–	17
Pterostichus nigrita (Paykull, 1790)	–	–	5	–	–	–	–	–	–	5
Pterostichus oblongopunctatus (Fabr., 1787)	1	–	7	2	–	5	5	–	–	20
Total	466	95	191	303	236	107	245	130	100	1,873
No. of species collected	14	15	21	11	12	12	16	12	14	44