diversity

MDPI

Article

Change of Ellipsoid Biovolume (EV) of Ground Beetles (Coleoptera, Carabidae) along an Urban–Suburban–Rural Gradient of Central Slovakia

Vladimír Langraf [1,*], Stanislav David [2], Ramona Babosová [1], Kornélia Petrovičová [3] and Janka Schlarmannová [1,*]

[1] Department of Zoology and Anthropology, Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Tr. A. Hlinku 1, 94901 Nitra, Slovakia; rbabosova@ukf.sk

[2] Department of Ecology and Environmental Sciences, Faculty of Natural Sciences, Constantine the Philosopher University in Nitra, Tr. A. Hlinku 1, 94901 Nitra, Slovakia; sdavid@ukf.sk

[3] Department of Environment and Zoology, Faculty of Agrobiology and Food Resources Slovak, University of Agriculture in Nitra, Tr. A. Hlinku 2, 94901 Nitra, Slovakia; kornelia.petrovicova@gmail.com

* Correspondence: langrafvladimir@gmail.com (V.L.); jschlarmannova@ukf.sk (J.S.)

Received: 29 November 2020; Accepted: 11 December 2020; Published: 14 December 2020

check for updates

Abstract: Changes in the structure of ground beetle communities indicate environmental stability or instability influenced by, e.g., urbanization, agriculture, and forestry. It can affect flight capability and ellipsoid biovolume (EV) of ground beetles. Therefore, we analyzed ground beetles in various habitats. In the course of the period from 2015 to 2017, we recorded in pitfall traps 2379 individuals (1030 males and 1349 females) belonging to 52 species at six localities (two rural, two suburban, two urban). We observed the decrease in the average EV value and morphometric characters (length, height, and width of the body) of ground beetles in the direction of the rural–suburban–urban gradient. Our results also suggest a decrease in EV of apterous and brachypterous species and an increase in macropterous species in the urban and suburban landscapes near agricultural fields. The increasing EV of apterous and brachypterous species and the decreasing of macropterous species was observed in rural landscape conditions with not continuous cover forestry and partial forest management. The creation of habitat fragments in urbanized conditions is key to maintaining the average EV in apterous and brachypterous species in urban and suburban landscapes.

Keywords: bioindication; carabid beetles; anthropogenic intervention; flight ability; Europe

---

1. Introduction

The epigenous invertebrate groups are influenced by changes in habitat conditions, e.g., spiders or beetles very quickly react to the changed requirements by modification in the structure of their assemblages [1,2]. The spatial distribution of ground beetles is important for assessing the potential impacts of environmental change [3]. The dynamics and structure of species populations are also affected by morphometric changes caused by environmental factors. Specific reactions of species communities and body size in the population are related to the characteristics of the urban landscape and changes in the environment [4–8]. Morphometric variability in the population indicates a degree of adaptation, which may be different [9].

Of the Coleopterans, the ground beetles are most often used to monitor changes in the environment. The advantage comes from a good knowledge of the ecological requirements of species inhabiting different types of habitats. In many cases, ground beetles are sensitive to various environmental disturbances, such as toxic substances (pesticides), changes in soil pH and moisture [10,11], urbanization [12], and habitat types [13]. The first to use the term ellipsoid biovolume to determine the body size (volume) of ground beetles was Braun et al. [14] in 2004. It was calculated using the morphometric features of the individual (length, height, width). Ground beetles are suitable for ellipsoid biovolume (EV) calculation due to their morphometric parameters and relatively large ellipsoid-shaped body size. The advantage of using EV is the rapid evaluation of body size in the environmental changes due to anthropogenic activities [15].

Urbanization is one of the major anthropogenic activities affecting the environment, ecosystems, and biodiversity worldwide [16]. Changes in average body size of ground beetles across urban–rural gradients have been analyzed in several studies [17–23]. The results point to the presence of species with larger body size in rural areas compared to urban and suburban areas. On the other hand, the urban landscape causes a shortening of body length, with the suburban landscape not affecting the changes in body length. The studies pointed to morphometric variations in the urban–suburban–rural gradient. Declining body size of ground beetles in areas with intense human disturbance was shown in studies [24,25]. The authors state that urbanization, in most cases, leads to a decrease in the species diversity of ground beetles and an increase in the number of smaller species towards the center of the settlement. Merckx et al. [26] demonstrate that the urban heat-island effect and urban habitat fragmentation are associated with contrasting community-level shifts in body size that critically depend on the association between body size and dispersal. Simultaneously, body size determines the structure and dynamics of ecological networks; such shifts may affect urban ecosystem function. The decrease in the body size of the ground beetles near the industrial area was confirmed in studies [27,28]. Based on the results of the research, Braun et al. [14] pointed out the increase in the average size of species with a decrease in land pollution caused by the closure of an industrial site. Porhajašová and Šustek [29] recorded no changes in body size in a less polluted environment. The authors state that the variation in body size is the result of morphometric adaptation to the environment.

Flight capability of ground beetles is also related to the body size, as a manifestation of vagility. Ground beetles living in stable ecosystems have lost their flight ability, and this persists only in species from ecosystems exposed to cyclical changes. The predominance of apterous (membranous wings missing) and brachypterous (shortened membranous wings) species indicates that the environment is stable. Increased incidence of macropterous species indicates a less stable ecosystem [30–34]. Apterous and brachypterous species are known to have a lower dispersing ability, in contrast to the macropterous (winged) species [35]. Therefore, a stable environment can be identified by a larger number of brachypterous and apterous species [36]. A trend pointing to a decrease in apterous species of ground beetles with increasing habitat disturbance and, conversely, an increase in the number of macropterous species has been recorded [37]. The predominance of macropterous species in isolated forests with higher anthropogenic intervention and a higher number of apterous and brachypterous species in continuous forests with lower anthropogenic intervention has been confirmed in previous studies [38,39]. Flightless apterous species are sensitive to the fragmentation of forest stands and occur preferentially in continuous natural forests. It is expected that during the successful development of the forest, the average body size as well as the number of apterous species will increase. On the contrary, the macropterous species show high dispersion in the settlement of anthropogenically disturbed habitats [40].

An agricultural landscape is a cultural type of landscape where the course of material and energy processes is altered and influenced by humans. Depending on the intensity of management, the biodiversity of ecosystems is declining on agricultural land. Ground beetles are well adapted to the cultivation regime of agricultural soils [41,42]. Different tillage methods and intensities are found to influence the species composition of ground beetle communities. For this reason, the bioindication potential of ground beetles is used to detect different intensities of land use [43].

In this paper, we evaluate the changes in body size EV and flight capability of ground beetles along the rural–suburban–urban gradient of Central Slovakia. Partial research results analyzing the same problem have been published in short communications [44,45]. The results of studies suggest that increasing average EV value occurs in habitats with ongoing ecological succession, and decreasing average EV occurs in habitats with anthropogenic activity (interventions in waterside vegetation). We formulated the following hypotheses: (1) ellipsoid biovolume (EV) decreases in the rural–suburban–urban gradient direction only in apterous and brachypterous species; (2) a larger number of apterous and brachypterous species occurs in less frequently disturbed biotopes (rural landscape with continuous cover forestry and partial forest management); and (3) macropterous species predominate in unstable biotopes (urban and suburban landscapes with agricultural soils) compared to continuous cover forestry (rural landscape).

2. Materials and Methods

Ground beetle research took place from 2015 to 2017, during the April–November in six localities and four types of biotopes (meadow, pasture, fallow field, nitrophilous waterside vegetation). Wheat, barley, sunflower, maize, and rape were grown in the contact area of localities 3, 4, 5, and 6. Material from pitfall traps was collected at regular biweekly intervals. We used pitfall traps (750 mL) located in the middle of the habitat [46]. Five pitfall traps were arranged in one line per each locality and were 10 m away from each other. Altogether there were 30 pitfall traps in six localities. We used 4% saline as a preservative. We identified the collected material and the determined the nomenclature, and flight ability was edited according to Hůrka [47].

2.1. Study Area

The study areas were located in the southern part of Central Slovakia (geomorphological units Stolické vrchy and Juhoslovenská kotlina basin) (Table 1). We selected six study localities. Localities 1 and 2 represented a rural landscape. The locality 1 (Lichovo) was a meadow biotope with the predominance of species *Arrhenatherum elatius*, *Alopecurus pratensis*, *Trisetum flavescens*, and *Festuca rubra*. The 20-year-old locality, with an area of 1 hectare (ha) was mowed twice a year. No fields occurred in the vicinity of the habitat. The second rural locality (Farkaška) was a nitrophilous waterside vegetation biotope characterized by *Carduus* in the undergrowth of *Salix* and *Tilia*. This five-year-old biotope was without modification of the riparian vegetation and fields in the vicinity of the habitat. The other two localities featured a subrural landscape. Locality 3 (Prievanka) was a pasture biotope with the predominance of *Trifolium repens*, *Carex hirta*, *Cynosurus cristatus*, and *Festuca pratensis*. In the vicinity of the 20-year-old grazed pasture with an area of 0.7 ha, wheat and corn fields were grown. Locality 4 (Pažiť) was a nitrophilous waterside vegetation biotope represented by *Galium* in the undergrowth of *Salix* and *Tilia*. This 10-year-old suburban habitat was without the modification of riparian vegetation. Near the analyzed habitat, we observed wheat and rape fields. The last two localities accounted for an urban landscape. Locality 5 (Zajačie zbehy) represented the fallow field biotope with a predominance of species *Arrhenatherion elatioris* and *Festuca pratensis*. This five-year-old biotope with an area of 0.3 ha was without vegetation modification. Wheat, barley, sunflower, maize, and rape fields were located near the habitat. Locality 6 (L'adovo) was a nitrophilous waterside vegetation biotope characterized by *Gallium* in the underground of *Salix* and *Tilia*. This 10-year-old biotope was also without vegetation modification. Wheat, barley, sunflower, maize, and rape fields were located around the habitat. The urban landscape is characterized by a developed and high density of human structures such as houses, commercial buildings, roads, bridges, and railways. It includes the city as well as the surrounding areas. The suburban landscape is represented by smaller urban areas surrounding cities, made up of suburbs, mostly family houses, shops, and services. The rural landscape is less densely populated, ranging from rural parts of the town to extremely remote rural areas.

Table 1. Locality data of the study localities.

Geomorphological Unit	Study Area	C. a.	m a.s.l.	Landscape	Biotope	G.C.
Stolické vrchy	1 Lichovo	Utekáč	556	rural	meadow	48°36′30″ N 19°48′35″ E
	2 Farkaška	Utekáč	446	rural	nitrophilous waterside vegetation	48°36′34″ N 19°47′52″ E
Juhoslovenská kotlina basin	3 Prievranka	Poltár	272	suburban	pasture	48°25′49″ N 19°48′39″ E
	4 Pažiť	Poltár	218	suburban	nitrophilous waterside vegetation	48°25′41″ N 19°46′35″ E
	5 Zajačie brehy	Lučenec	208	urban	fallow field	48°19′017″ N 19°39′05″ E
	6 Ľadovo	Lučenec	207	urban	nitrophilous waterside vegetation	48°20′12″ N 19°37′06″ E

Notes: C. a.—cadastral area; m a.s.l.—meters above sea level; G.C.—geographic coordinates.

2.2. *Computation of the Carabidae Ellipsoid Biovolume*

The morphometric signs were measured for each individual using a Bresser LCD digital microscope (0.1 mm accuracy): (i) the length–dorsal length between the upper lip (labium) and the terminal part of elytra, (ii) the width–dorsal length between the maximum width of the elytra, and (iii) the height–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. According to Braun et al. [14], EV was calculated for each specimen from our measured morphometric signs:

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

where L = individual length, H = individual height, W = individual width.

2.3. *Statistical Analyses*

Multivariate analysis (redundancy analysis (RDA)) was used to determine the dependencies between objects (EV of species, flight ability of species) and EV of years 2015–2017. We tested the statistical significance of EV during the years 2015–2017 with the Monte Carlo permutation test in the Canoco program5 [48]. The analysis in the statistical program Statistica Cz. Ver. 7.0 [49] was focused on the 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 the nonparametric Kruskal–Wallis test (ANOVA), and the Friedman test (ANOVA) was used to test the differences in EV, length, height, and width of the body based on flight ability between areas (rural, suburban, urban landscape).

3. Results

In the course of three years of research, we recorded 2379 individuals of Carabidae (1030 males and 1349 females) belonging to 52 species, with an average EV value of an individual at $\bar{x}$ = 399.94 mm^3. The highest EV values we recorded were in the rural landscape with continuous cover forestry and partial forest management (localities 1 and 2). The highest proportion in the rural landscape was of the apterous species 41%; macropterous species accounted for 33% and brachypterous species 26% (Table 2). In contrast, the lowest EV we identified was in the suburban landscape with agricultural fields (localities 3 and 4). Dominant representation in the suburban landscape was in macropterous species 74%, and brachypterous species accounted for 16% and apterous species 10%. The highest average EV value was recorded in apterous species and the lowest in the macropterous species.

Table 2. List of species of study sites and ellipsoid biovolume (EV) values (mm^3).

Species	F.A.	Study Localities					
		1	2	3	4	5	6
		EV/N	EV/N	EV/N	EV/N	EV/N	EV/N
Abax ovalis (Duftschmid, 1812)	B	201/1	180/1	0/0	0/0	0/0	122/1
Abax parallelepipedus (Piller&Mitterpacher, 1783)	B	22,062/56	36,089/87	358/1	10,203/30	0/0	16,424/54
Abax parallelus (Duftschmid, 1812)	B	2921/20	9412/53	0/0	444/3	0/0	10,691/63
Agonum viduum (Panzer, 1797)	M	0/0	0/0	0/0	0/0	0/0	35/1
Amara aenea (DeGeer, 1774)	M	0/0	0/0	54/3	0/0	54/2	0/0
Amara aulica (Panzer, 1797)	M	0/0	75/1	0/0	0/0	82/1	0/0
Amara erratica (Duftschmid, 1812)	M	231/8	0/0	0/0	0/0	0/0	0/0
Amara familiaris (Duftschmid, 1812)	M	0/0	0/0	146/6	0/0	0/0	38/1
Amara saphyrea (Dejean, 1828)	M	0/0	0/0	0/0	0/0	0/0	83/2
Amara similata (Gyllenhal,1810)	M	0/0	0/0	39/1	0/0	0/0	38/1
Anchomenus dorsalis (Pontoppidan, 1763)	M	0/0	0/0	39/3	11/1	23/2	129/10
Brachinus crepitans (Linnaeus, 1758)	M	0/0	0/0	61/6	13/1	39/2	0/0
Brachinus explodens (Duftschmid, 1812)	M	0/0	0/0	0/0	7/1	0/0	0/0
Calathus fuscipes (Goeze, 1777)	M	588/7	0/0	970/12	0/0	0/0	0/0
Calathus melanocephalus (Linnaeus, 1758)	B	0/0	0/0	35/2	0/0	0/0	0/0
Callistus lunatus (Fabricius, 1775)	M	0/0	0/0	0/0	0/0	61/3	0/0
Carabus cancellatus (Illiger, 1798)	A	18,136/28	21,114/36	0/0	0/0	0/0	0/0
Carabus convexus (Fabricius, 1775)	A	1158/4	2638/9	0/0	0/0	0/0	0/0
Carabus coriaceus (Linnaeus, 1758)	A	0/0	71,076/26	0/0	1962/2	0/0	3546/2
Carabus glabratus (Paykull, 1790)	A	5932/6	10,291/10	0/0	0/0	1029/1	0/0
Carabus granulatus (Linnaeus, 1758)	B	324/1	11,150/29	0/0	0/0	0/0	3507/9
Carabus hortensis (Linnaeus, 1758)	A	1629/2	16,718/20	0/0	0/0	0/0	1654/2
Carabus intricatus (Linnaeus, 1761)	A	0/0	3601/4	0/0	0/0	0/0	6055/6
Carabus nemoralis (O.F. Müller, 1764)	A	21,450/36	2128/4	0/0	0/0	641/1	0/0
Carabus scheidleri (Panzer, 1799)	A	66,284/57	0/0	0/0	2558/3	17,9812/205	943/1
Carabus ullrichi (Germar, 1824)	A	7885/5	40,111/39	0/0	0/0	43,632/41	0/0
Carabus violaceus (Linnaeus, 1758)	A	140,249/134	8854/8	1618/2	0/0	46,841/58	7030/9
Cylindera germanica (Linnaeus, 1758)	M	0/0	0/0	399/9	0/0	737/17	0/0
Cychrus caraboides (Linnaeus, 1758)	A	0/0	317/1	0/0	0/0	0/0	0/0
Cymindis humeralis (Fourcroy, 1785)	B	0/0	0/0	0/0	0/0	19/1	39/2
Drypta dentata (Rossi, 1790)	M	0/0	0/0	95/3	0/0	68/3	0/0
Elaphrus aureus (P. Müller, 1821)	M	0/0	0/0	0/0	57/3	0/0	95/5

Table 2. *Cont.*

Species	F.A.	Study Localities					
		1	2	3	4	5	6
		EV/N	EV/N	EV/N	EV/N	EV/N	EV/N
Harpalus affinis (Schrank, 1781)	M	0/0	0/0	17,051/350	0/0	412/10	0/0
Harpalus froelichi (Sturm, 1818)	M	0/0	0/0	0/0	374/7	0/0	0/0
Harpalus rubripes (Duftschmid, 1812)	M	1072/25	0/0	237/5	114/3	551/15	0/0
Lebia chlorocephala (Hoffm. a kol., 1803)	M	0/0	0/0	55/3	0/0	0/0	0/0
Leistus rufomarginatus (Duftschmid, 1812)	M	0/0	0/0	0/0	0/0	0/0	186/6
Molops piceus (Panzer, 1793)	B	736/9	268/3	0/0	0/0	0/0	0/0
Nebria brevicollis (Fabricius, 1792)	M	426/5	216/3	0/0	1439/17	32/1	8838/101
Notiophilus biguttatus (Fabricius, 1799)	B	0/0	0/0	0/0	7/1	0/0	0/0
Ophonus azureus (Fabricius, 1775)	B	0/0	0/0	0/0	0/0	67/3	0/0
Ophonus nitidulus (Stephens, 1828)	M	0/0	100/2	0/0	0/0	0/0	0/0
Platynus assimilis (Paykull, 1790)	M	0/0	630/9	0/0	4332/74	0/0	7185/116
Poecilus cupreus (Linnaeus, 1758)	M	835/11	69/1	3161/36	0/0	7593/36	0/0
Poecilus versicolor (Sturm, 1824)	M	0/0	0/0	125/2	0/0	0/0	0/0
Pseudoophonus rufipes (DeGeer, 1774)	M	0/0	0/0	7533/58	4235/34	5025/39	577/4
Pterostichus melanarius (Illiger, 1798)	B	0/0	3102/17	0/0	2172/13	399/2	746/4
Pterostichus melas (Creutzer, 1799)	B	159/1	0/0	0/0	0/0	0/0	0/0
Pterostichus niger (Schaller, 1783)	M	0/0	0/0	0/0	2812/11	965/3	4098/15
Pterostichus nigrita (Paykull, 1790)	M	0/0	0/0	0/0	198/2	0/0	0/0
Pterostichus oblongopunctatus (Fabricius, 1787)	M	0/0	615/9	0/0	486/7	954/13	103/1
Zabrus tenebrioides (Goeze, 1777)	M	0/0	0/0	187/1	0/0	0/0	0/0
$\sum$ EV(mm^3)/N/$\bar{x}$	-	292,278/416/702.59	238,754/372/641.81	36,251/503/72.07	31,423/213/147.53	289,037/459/629.71	72,162/416/173.47

Notes: F.A.—flight ability of the carabids: apterous (A), brachypterous (B), macropterous (M); N—number of individuals, EV—ellipsoid biovolume (mm^3).

Multivariate analysis of the ground beetles from the study localities during the years 2015–2017, based on flight ability and EV, was determined by redundancy analysis (RDA, SD = 3.60 on the first ordination axis). The values of the explained cumulative variability of species data were 34.2% on the first ordination axis and 52.1% on the second ordination axis. Using the Monte Carlo permutation test, we identified a statistically significant effect of EV for the years 2015 (p-value = 0.0174), 2016 (p-value = 0.0168), and 2017 (p-value = 0.0201) for the species composition of the ground beetles locations under examination. The selected variables were not mutually correlated with the maximum value of the inflation factor = 3.2184.

The ordination graph (biplot) contains species ordered into four clusters based on EV and flight ability (Figure 1). The first cluster (I) mostly included the apterous species (10 species); brachypterous species were represented by six species and macropterous by four species. The species in the first cluster prefer the conditions of the rural landscape, with continuous cover forestry.

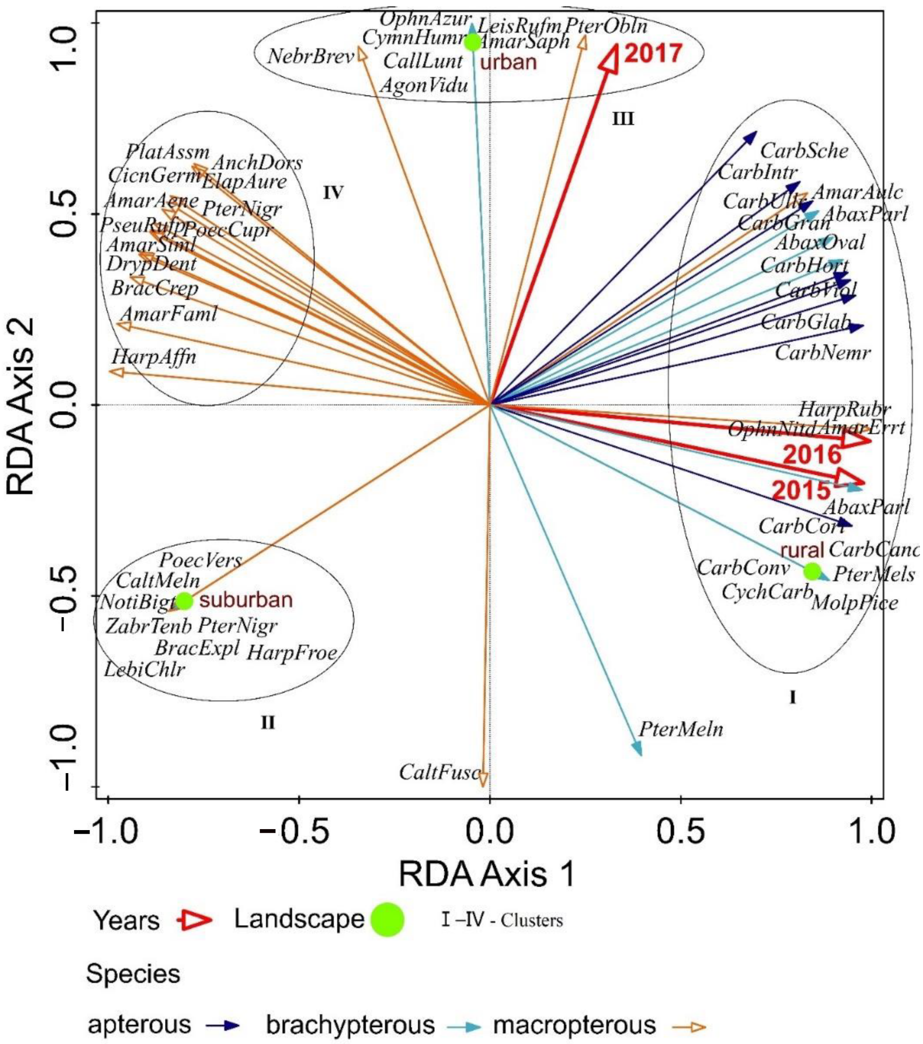

Figure 1. Redundancy analysis (RDA) of species based on EV and flight ability, during the years 2015–2017.

The second cluster (II) was characterized by species correlating with the developed agricultural suburban landscape. Macropterous species were represented by six species and brachypterous by two species.

The third cluster (III) consisted of species with links to an urban landscape with the agricultural fields. Macropterous species were dominant (six species), and two species represented brachypterous.

The fourth cluster (IV) was located between suburban and urban landscapes because of the higher representation of individuals in both areas. This cluster consisted of only macropterous species: *Amara aenea*, *Anchomenus dorsalis*, *Harpalus affinis*, and *Pseudoophonus rufipes*.

The species *Calathus fuscipes* was not assigned to clusters. This ground beetle prefers arable land; therefore, it is closer to cluster II. Another brachypterous species, *Pterostichus melanarius*, correlated closer to cluster I, indicating a less frequently disturbed environment.

EV vectors during 2015 and 2016 were not significantly remote, indicating small changes in EV in those years. On the other hand, the EV vector for 2017 is remote from 2015 and 2016, which indicates greater differences in EV between 2017 and 2015, 2016.

We confirm the statistically significant difference (p-value = 0.00, F = 2934, df = 2) of EV based on flight ability. The mean EV value decreased as follows: apterous—967 mm^3, brachypterous—282 mm^3, and macropterous—71 mm^3 (Figure 2).

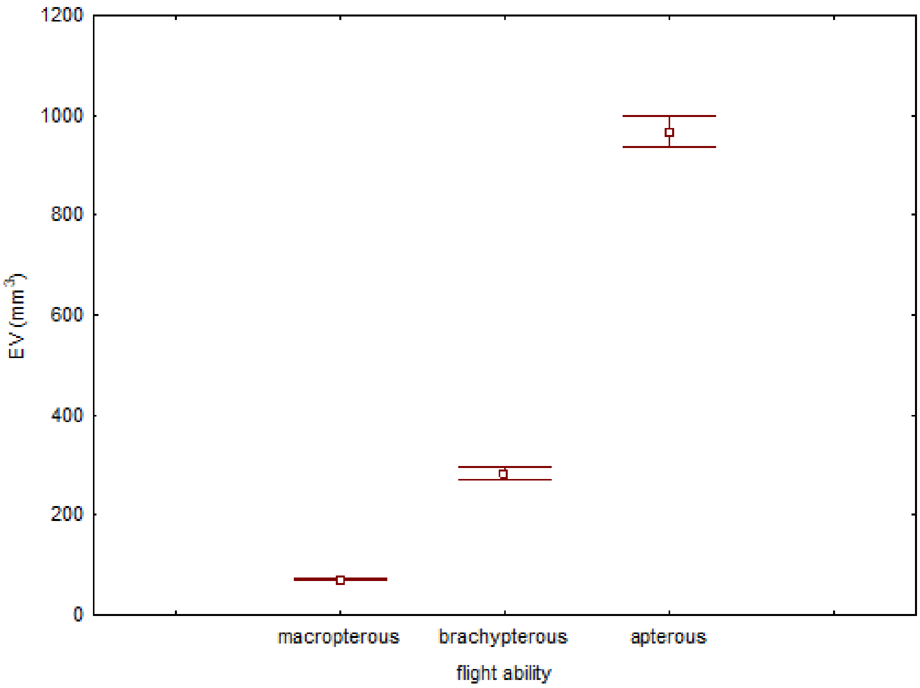

Figure 2. Mean EV values (±95% CI) based on flight ability of carabids.

We confirm the statistically significant difference (p-value = 0.00, F = 5,234, df = 4) in the EV (Figure 3A), the height of the body (p-value = 0.00, F = 6,217, df = 4) (Figure 3B), length of the body (p-value = 0.00, F = 10,83, df = 4) (Figure 3C) and width of the body (p-value = 0.00, F = 8,94, df = 4) (Figure 3D) based on flight ability between areas (rural, suburban, urban landscape). The results show a decrease in EV, length, height, and width of the body in macropterous species in the direction of the urban–suburban–rural gradient. The opposite trend (increase) was confirmed for apterous and brachypterous species in the urban–suburban–rural direction. The length of the body of apterous species was increased in the urban–suburban landscape and decreased in the rural landscape. Apterous and brachypterous species had predominance in the rural landscape with continuous cover forestry. In these species, we observed a larger average EV value and morphometric characters (length, height, and width of the body) prevailed, compared to the suburban and urban landscapes with the agricultural fields.

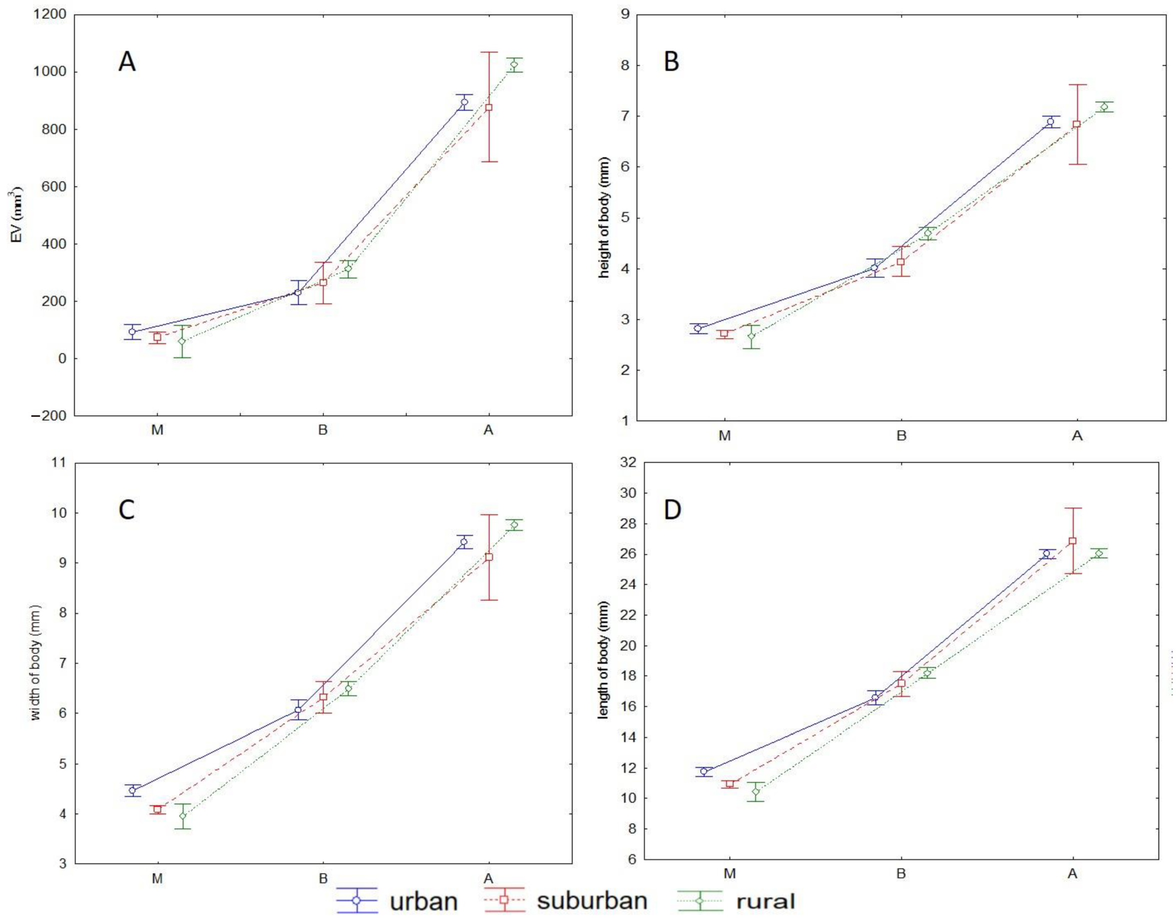

Figure 3. Average EV values (**A**), height of the body (**B**), length of the body (**C**), width of the body (**D**) of carabid species with different flight ability. Notes: M = macropterous, B = brachypterous, A = apterous. Vertical lines denote ±95% CI.

4. Discussion

Ground beetles living in anthropogenic environments have a wider environmental tolerance than species of natural habitats [50]. They achieve high local density due to anthropogenic activities such as urbanization [12], forestry [13], or agriculture [51]. Sukhodolskaya [15] states that as a result of urbanization the body size of ground beetles changed. It is reflected in a reduction of average body size along a rural–suburban–urban gradient. Braun et al. [14] pointed out that the average body size value per individual increases in the direction of decreasing anthropogenic activity. The authors found that the average body size increased due to the decrease in environmental pollution by industrial areas. Decreasing body size of ground beetles in areas with intense human disturbance was also identified in further studies [24,25]. These state that urbanization and expansion of the industrial area lead to a biodiversity reduction and distribution of macropterous species. Several works [27–31] also reported the predominance of apterous and brachypterous species in less frequently disturbed ecosystems. Macropterous species are predominant in ecosystems exposed to cyclical changes, which indicate instability. The average EV value of apterous and brachypterous species decreased in the direction of the rural–suburban–urban gradient. We did not confirm this decrease in macropterous species. On the contrary, we found an increase in the average EV value of the urban landscape compared to the rural landscape. We observed the increase in body weight of macropterous species in an urban landscape. This may be influenced by the fact that urban landscape (forests, parks, meadows) are more heterogeneous than natural habitats and offer a higher food supply. The change in body size due to morphometric adaptation to the environment was confirmed by [29]. For morphometric characteristics—length, height, and width of the body—we also found a significant difference based on flight ability between rural, suburban, and urban landscapes. In the rural landscape, we recorded a higher average value of morphometric characteristics (length, height, and width) in apterous and brachypterous species. The increase in body length in rural conditions due to environmental factors (the locality in the geographic range, level of anthropogenic influence, and degree of biotope openness) has been reported in several studies [17–21]. Fragmentation of habitats in the urban landscape changes the structure of the ground beetle community composition in the remaining fragments. This leads to a shortening of morphometric features in the urban landscape when compared to rural [22,23]. Differences in body size between rural and urban landscapes can also be affected by different temperatures. In the urban landscape, the temperature is higher, which can affect the life cycles of ground beetles and, as a result, the reduction in body size. The effect of temperature and heat islands on body reduction in an urban landscape was confirmed by Merckx et al. [26]. An increase in temperature of urban heat islands leads to a rise in beetle metabolism, which causes a decrease in their body size [52].

The less frequently disturbed environment can be identified based on the predominance of apterous and brachypterous species. The rural landscape is characterized by cover forestry and with a predominance of apterous and brachypterous species [36]. During forest development, the number of apterous species increases [53]. These species are characterized by lower dispersing ability, and their presence indicates a less frequent disruption of the habitat [35]. On the contrary, the macropterous species show high dispersion in the settlement of anthropogenically disturbed habitats [53]. Studies [38,39] confirm a decrease in apterous and brachypterous species with increasing habitat disturbance and an increase in the number of macropterous species. We also found the predominance of apterous (41%) and brachypterous (26%) species, indicating a less frequently disturbed environment in rural landscape conditions with continuous cover forestry and partial forest management. On the contrary, we observed a higher proportion of macropterous species in less stable ecosystems in the suburban (74%) and urban (58%) landscape, with developed agriculture (wheat, barley, sunflower, maize, and rape grown in the vicinity). Similarly, Rainio and Niemalä [37] state that macropterous species increase with increasing environmental disturbance. The high dispersion of macropterous species in the settlement of anthropogenically disturbed habitats was confirmed by [54]. Apterous species are sensitive to forest fragmentation and prefer continuous forest stands [40]. This fact is consistent with our results. Differences in the representation of species between rural, suburban, and urban landscape may be influenced by the agricultural fields around the urban and suburban landscape. Ground beetles are well adapted to the cultivation regime of agricultural fields, and their species composition is influenced by different tillage methods and intensities [41,42]. From our results, we found that species binding to arable land (IV) were between clusters II (suburban) and cluster III (urban). Similarly, determination of the typical arable land species, *Clivina fossor*, *Calathus fuscipes*, *Amara aenea*, *Anchomenus dorsalis*, *Harpalus affinis*, *Harpalus distinguendus*, and *Pseudoophonus rufipes*, was pointed out by other studies [43,55,56].

5. Conclusions

We confirmed the decrease of the average EV value per individual in the direction of the rural–suburban–urban gradient in apterous and brachypterous species. Interestingly, this trend does not apply to macropterous species. Their average body size (EV) is larger in an urban landscape. For macropterous species, we did not confirm the rule that the average body size decreases due to anthropogenic activity. The highest average EV values per individual were in the rural landscape. This area is characterized by continuous cover forestry and a correlation to apterous and brachypterous species indicating more stable ecosystems. The lowest average EV values per individual were recorded in the suburban and urban landscapes, characterized by developed agriculture. We also recorded in this area the species *Amara aenea*, *Anchomenus dorsalis*, *Harpalus affinis*, *Pseudoophonus rufipes*, and *Calathus fuscipes* binding to arable land. Based on these factors, ground beetles are suitable as environmental bioindicators and an assessment of the degree of disturbance activity. Urban management should aim to minimize the intensity of urbanization-related environmental filters, to enable apterous and brachypterous species to survive in habitat fragments under urbanized conditions. Ground beetles may be used for landscape planning documents (e.g., development of environmental systems), which is what the study will examine in the future.

Author Contributions: Conceptualization, V.L. and S.D.; methodology, V.L.; software, V.L.; validation, V.L., S.D., R.B., and K.P.; formal analysis, V.L., R.B., and J.S.; investigation, V.L.; resources, V.L.; data curation, V.L.; writing—original draft preparation, V.L. and S.D.; writing—review and editing, V.L. and R.B.; visualization, V.L.; supervision, S.D.; project administration, V.L.; funding acquisition, V.L. and K.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was made possible by the project VEGA 1/0604/20 Environmental assessment of specific habitats in the Danube Plain.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Krumpálová, Z. Epigeic spiders (Araneae) of one Middle Danube floodplain forest. *Biologia* **2002**, *57*, 161–169.
2. Krumpálová, Z.; Krumpál, M.; Štrbík, I. Classification of epigeic spiders (Araneae) at the western part of the Carpathians (Slovakia). *Biologia* **2009**, *64*, 116–123. [CrossRef]
3. Wang, C.; Liu, Y.; Axmacher, J.C. Habitat-GIS-based models for ground beetles (Coleoptera: Carabidae) distribution in agricultural landscape. In Proceedings of the 17th International Conference on Geoinformatics, Fairfax, VA, USA, 12 August 2009; pp. 1–4.
4. Niemelä, J.; Kotze, D.J. Carabid beetle assemblages along urban to rural gradients: A review. *Landsc. Urban Plan.* **2009**, *92*, 65–71. [CrossRef]
5. Rueffler, C.; Van Dooren, T.J.M.; Leimar, O.; Abrams, P.A. Disruptive selection and then what? *Trends Ecol. Evol.* **2006**, *21*, 238–245. [CrossRef] [PubMed]
6. Brygadyrenko, V.V.; Reshetniak, Y.D. Morphological variability among populations of Harpalus rufipes (Coleoptera, Carabidae): What is more important–The mean values or statistical peculiarities of distribution in the population? *Folia Oecol.* **2014**, *41*, 109–133.
7. Komlyk, V.; Brygadyrenko, V.V. Morphological variability of Bembidion varium (Coleoptera, Carabidae) in gradient of soil salinity. *Folia Oecol.* **2020**, *47*, 23–33. [CrossRef]
8. Grumo, D.D.; Löve, L.G. Body size inequality in ground beetle (Coleoptera: Carabidae) assemblages as a potential method to monitor environmental impacts of transgenic crops. *Period. Biol.* **2016**, *118*, 223–230. [CrossRef]
9. Kawano, K. Comparative quantification of intralocalityal, interlocalityal, and interspecific variability in stag beetles (Coleoptera: Lucanidae) and the questions of phenotypic plasticity and species selection. *Ann. Entomol. Soc. Am.* **2016**, *109*, 555–566. [CrossRef]
10. Ivanič Porhajašová, J.; Babošová, M.; Noskovič, J.; Ondrišík, P. Long-Term Developments and Biodiversity in Carabid and Staphylinid (Coleoptera: Carabidae and Staphylinidae) Fauna during the Application of Organic Fertilizers under Agroecosystem Conditions. *Pol. J. Environ. Stud.* **2018**, *27*, 2229–2235. [CrossRef]
11. Porhajašová, J.I. *Biodiversity and Spatial Structure of Carabidae (Coleoptera) Populations in the Conditions of Different Habitat Types*; Slovenská Poľnohospodárska Univerzita v Nitre: Nitra, Slovakia, 2018; p. 79.
12. Alberti, M.; Marzluf, J.; Hunt, V.M. Urban driven phenotypic changes: Empirical observations and theoretical implications for eco-evolutionary feedback. *Phil. Trans. R. Soc. Lond.* **2017**, *372*, 2–9. [CrossRef]
13. Batáry, P.; Kurucz, K.; Suarez-Rubio, M.; Chamberlain, D.E. Non-linearities in bird responses across urbanization gradients: A meta-analysis. *Glob. Chang. Biol.* **2018**, *24*, 1046–1054. [CrossRef] [PubMed]
14. Braun, S.D.; Jones, T.H.; Perner, J. Shifting average body size during regeneration after pollution–a case study using ground beetle assemblages. *Ecol. Entomol.* **2004**, *29*, 543–554. [CrossRef]
15. Sukhodolskaya, R. Intraspecific Body Size Variation in Ground Beetles (Coleoptera, Carabidae) in Urban–Suburban–Rural–Natural Gradient. *Acta Biol. Univ. Daugavp.* **2013**, *13*, 121–128.
16. Magura, T.; Lövei, L.G. Consequences of Urban Living: Urbanization and Ground Beetles. *Curr. Landsc. Ecol. Rep.* **2020**, *19*, 1–13. [CrossRef]
17. Sukhodolskaya, R.A.; Saveliev, A.A. Effects of Ecological Factors on Size Related Traits in the Ground Beetle Carabus granulatus L. (Coleoptera, Carabidae). *Russ. J. Ecol.* **2014**, *45*, 369–375. [CrossRef]

18. Sukhodolskaya, R.A.; Ananina, T.L. Altitudinal Variation in Population Density, Body Size and Morphometric Structure in *Carabus Odoratus* Shil, 1996 (Coleoptera: Carabidae). *Acta Biol. Univ. Daugavp.* **2015**, *1*, 179–190.
19. Sukhodolskaya, R.A.; Saveliev, A.A. Body Size Variation of Ground Beetles (Coleoptera: Carabidae) in Latitudinal Gradient. *Period. Biol.* **2016**, *118*, 273–280. [CrossRef]
20. Sukhodolskaya, R.A.; Ananina, T.L. Elevation Changes of Morphometric Traits Structure in Pterostichus montanus Motch. (Coleoptera, Carabidae). *Asian J. Biol.* **2017**, *2*, 1–9. [CrossRef]
21. Niemelä, J.; Kotz, J.D.; Venn, S.; Penev, L.; Stoyanov, I.; Spence, J.; Hartley, D.; Oca, E.M. Carabid beetle assemblages (Coleoptera, Carabidae) across urban-rural gradients: An international comparison. *Landsc. Ecol.* **2002**, *17*, 387–401. [CrossRef]
22. Magura, T.; Lövei, G.L.; Tóthmérész, B. Conversion from environmental filtering to randomness as assembly rule of ground beetle assemblages along an urbanization gradient. *Sci. Rep.* **2018**, *8*, 16992. [CrossRef]
23. Löve, L.G.; Magura, T. Body size changes in ground beetle assemblages—Are analysis of Braun et al. (2004)'s data. *Ecol. Entomol.* **2006**, *31*, 411–414. [CrossRef]
24. Weller, B.; Ganzhorn, U.J. Carabid beetle community composition, body size, and fluctuating asymmetry along an urban-rural gradient. *Basic Appl. Ecol.* **2006**, *5*, 193–201. [CrossRef]
25. Magura, T.; Tóthemérész, B.; Lövei, L.G. Body size inequality of carabids along an urbanisation gradient. *Basic Appl. Ecol.* **2006**, *7*, 472–482. [CrossRef]
26. Merckx, T.; Souffreau, C.; Kaiser, A.; Baardsen, F.L.; Backeljau, T.; Bonte, D.; Brans, I.K.; Cours, M.; Dahirel, M.; Debortoli, N.; et al. Body-size shifts in aquatic and terrestrial urban communities. *Nature* **2018**, *558*, 113–116. [CrossRef]
27. Gelashvili, D.B.; Soltzev, L.A.; Yakimov, V.N.; Sukhodolskaya, R.A.; Khabibullina, N.R.; Iudin, D.I.; Snegiryova, M.S. Fractal analysis of the specific structure of Carabidae complexes in urbanized territories. *Povolzhskiy J. Ecol.* **2011**, *4*, 407–420.
28. Turin, H. *De Nederlandse Loopkevers: Verspreiding Enoecologie (Coleoptera: Carabidae)*; KNNV Uitgeverij: Utrecht, The Netherlands, 2000; p. 666.
29. Porhajašová, J.; Šustek, Z. *Spatial Structure of Invertebrate Communities with Emphasis on the Carabidae Family in the Zittau Luh Nature Reserve*; Slovenská poľnohospodárska univerzita v Nitre: Nitra, Slovakia, 2011; p. 77.
30. Shibuya, S.; Zaal, K.; Wataru, T.; Yasuto, K.; Tatsuya, S.; Tamio, Y.; Takahiro, F.; Mohammad, R.M.; Zuhair, S.; Kôhei, K.; et al. Ground beetle community in suburban Satoyama—A case study onwing type and body size under small scale management. *J. Asia Pac. Entomol.* **2014**, *17*, 775–780. [CrossRef]
31. Rouabah, A.; Villerd, J.; Amiaud, B.; Plantureux, S.; Lasserre, F. Response of Carabid beetles diversity and size distribution to the vegetation structure with indifferently managed field margins. *Agric. Ecosyst. Environ.* **2015**, *200*, 21–32. [CrossRef]
32. Rusch, A.; Bommarco, R.; Chiverton, P.; Öberg, S.; Wallin, H.; Wiktelius, S.; Ekbom, B. Response of ground beetle (Coleoptera, Carabidae) communities to changes in agricultural policies in Sweden over two decades. *Agric. Ecosyst. Environ.* **2013**, *176*, 63–69. [CrossRef]
33. Homburg, K.; Schuldt, A.; Drees, C.; Assmannt, T. Broad-scale geographic patterns in body size and hind wing development of western Palaearctic carabid beetles (Coleoptera: Carabidae). *Ecography* **2012**, *35*, 166–177. [CrossRef]
34. Koivula, M.J. Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. *ZooKeys* **2011**, *100*, 287–317. [CrossRef]
35. Den Boer, P.J. Density limits and survival of local populations in 64 carabid species with diff erent powers of dispersal. *J. Evol. Biol.* **1990**, *3*, 19–48. [CrossRef]
36. Gobbi, M.; Rossaro, B.; Vater, A.; De Bernardi, F.; Pelfini, M.; Brandmayr, P. Environmental features infl uencing Carabid beetle (Coleoptera) assemblages along a recently deglaciated area in the Alpine region. *Ecol. Entomol.* **2007**, *32*, 682–689. [CrossRef]
37. Rainio, J.; Niemalä, J. Ground beetles (Coleoptera: Carabidae) as bioindicators. *Biodivers. Conserv.* **2003**, *12*, 487–506. [CrossRef]
38. Jelaska, L.; Durbešič, P. Comparison of the body size and wing form of carabid species (Coleoptera: Carabidae) between isolated and continuous forest habitats. *Ann. Soc. Entomol. Fr.* **2009**, *3*, 327–338. [CrossRef]
39. O'Neill, R.V. Is it time to bury the ecosystem concept? (with full military honours, of course!). *Ecology* **2001**, *82*, 3275–3284.

40. Magura, T.; Ferrante, M.L.; Lövei, G.L. Only habitat specialists become smaller with advancing urbanization. *Glob. Ecol. Biogeogr.* **2020**, *29*, 1978–1987. [CrossRef]
41. Lövei, G.; Sunderland, K. Ecology and Behavior of Ground Beetles (Coleoptera: Carabidae). *Annu. Rev. Entomol.* **1996**, *41*, 231–256. [CrossRef]
42. Vician, V.; Stašiov, S.; Kočík, K.; Hazuchová, L. Impact of different agricultural management on Beetle Communities (Coleoptera, Carabidae) in Podpoľany. In *Selected Problems of the Landscape of Foothills and Mountain Areas*; Benčať, T., Jančura, P., Daniš, D., Eds.; Janka Čižmárová: Poníky, Slovakia, 2008; pp. 93–107.
43. Nietupski, M.; Kosewska, A.; Markuszewski, B.; Sądej, W. Soil management system in hazelnut groves (Corylus sp.) versus the presence of ground beetles (Coleoptera: Carabidae). *J. Plant Prot. Res.* **2015**, *55*, 26–34. [CrossRef]
44. Langraf, V.; Petrovičová, K.; David, S.; Ábelová, M.; Schlarmannová, J. Body volume in ground beetles (Carabidae) reflects biotope disturbance. *Folia Oecol.* **2017**, *44*, 47–53. [CrossRef]
45. Langraf, V.; Petrovičová, K.; David, S.; Kanská, M.; Nozdrovická, J.; Schlarmannová, J. Change Phenotypic Traits in Ground Beetles (Carabidae) Reflects Biotope Disturbance in Central Europe. *J. Entomol. Res. Soc.* **2018**, *20*, 119–129.
46. Novák, K.; Balát, F.; Bartoš, E.; Bouček, Z.; Daniel, M.; Dlabola, J.; Doskočil, J.; Holman, J.; Jagemann, E.; Kunst, M.; et al. *Metódy Sběru a Preparace Hmyzu*; Academia: Praha, Czech Republic, 1969; p. 243.
47. Hůrka, K. *Carabidae of the Czech and Slovak Republics*; Kabourek: Zlín, Czech Republic, 1996; p. 565.
48. Ter Braak, C.J.F.; Šmilauer, P. *Canoco Reference Manual and User's Guide: Software for Ordination, Version 5.0*; Microcomputer Power: Ithaca, NY, USA, 2012; p. 496.
49. Statsoft, Inc. Statistica Cz [Softwarový Systém na Anylýzu Dat], Verze 7. 2004. Available online: www.statsoft.cz (accessed on 9 September 2004).
50. Kotze, D.J.; Brandmayr, P.; Casale, A.; Dauffy-Richard, E.; Dekoninck, W.; Koivula, M.; Brandmayr, T.Z. Forty years of carabid beetle research in Europe-From taxonomy, biology, ecology and population studies to bioindication, habitat assessment and conservation. *ZooKeys* **2011**, *100*, 55–148. [CrossRef] [PubMed]
51. Vician, V.; Stašiov, S.; Kočík, K.; Hazuchová, L. Structure of the Carabids (Coleoptera: Carabidae) Associations on Variously Managed Agricultural Land of Podpoľanie area and their bioindication. *Acta Fac. Ecol.* **2011**, *24*, 123–131.
52. Desender, K.; Small, E.; Gaublomme, E.; Verdyck, P. Rural-urban gradients and the population genetic structure of woodland ground beetles. *Conserv. Genet.* **2005**, *6*, 51–62. [CrossRef]
53. Gaublomme, E.; Hendrickx, F.; Dhuyvetter, H.; Desender, K. The effects of forest patch size and matrix type on changes in carabid beetle assemblages in an urbanized landscape. *Biol. Conserv.* **2008**, *141*, 2585–2596. [CrossRef]
54. Scheffers, B.R.; De Meester, L.; Bridge, T.C.; Hoffmann, A.A.; Pandolfi, J.M.; Corlett, R.T.; Butchart, S.H.; Pearce-Kelly, P.; Kovacs, K.M.; Dudgeon, D.; et al. The broad footprint of climate change from genes to biomes to people. *Science* **2016**, *356*, 71–76. [CrossRef]
55. Vician, V.; Svitok, M.; Michalková, E.; Lukáčik, I.; Stašiov, S. Influence of tree species and soil properties on ground beetle (Coleoptera: Carabidae) communities. *Acta Oecologica* **2018**, *91*, 120–126. [CrossRef]
56. Vician, V.; Stašiov, S.; Kočík, K.; Hazuchová, L. Carabidae (Coleoptera) structure on variously managed agricultural land of Podpoľanie area (in Slovak). *Acta Fac. Ecol.* **2010**, *22*, 133–146.