

SPATIAL VARIATION IN MORPHOMETRIC TRAITS OF *CARABUS GRANULATUS* L., 1758 (COLEOPTERA: CARABIDAE) AT A SMALL SCALE

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ABSTRACT

This study examines the small-scale spatial variability of morphometric traits in the carabid beetle *Carabus granulatus* L., 1758 across diverse habitats in Kaluga Province, Russia. A total of 5,039 specimens were collected from seven distinct vegetation types to assess the impact of environmental conditions and anthropogenic pressure on morphological variation. Linear discrimination analysis revealed statistically significant, though subtle, differences in morphology among habitats, most notably in pronotum length and elytral dimensions. Beetles from urban and suburban areas tended to be larger and more robust, whereas individuals from natural floodplain habitats were generally smaller. These findings enhance our understanding of ecological influences on intraspecific morphological diversity and support the use of morphometric traits as indicators in environmental biomonitoring.

1. INTRODUCTION

Studying the patterns of organism response to various ecological factors helps in developing biomonitoring models and, furthermore, hint on the phylogenetic ways of the taxa. It is known that animals respond to changes in their environment with dynamic adaptive and microevolutionary transformations of various structures (Newman, 1995; Staton et al., 2001; Hauser et al., 2003), that can change independently or co-dependent, building complex relationships, where local environment can affect their expression (Peiman, Robinson, 2017). Distinct species' traits may be considered as a component of biodiversity, determining how organisms respond to disturbances and changing environmental conditions, with impacts at a population level and beyond (Lavorel, Garnier, 2002), so choosing certain traits for the study determines the ecological data to be received.

Body size is considered a key characteristic of organisms. It varies depending on environmental conditions and can be affected by selection. In insects, body size correlates with many aspects of life history traits, i.e., reproduction rate; dispersal ability; duration of ontogeny; competition, number, and size of offspring largely determining the type of interactions between the insects and environment (Stearns, 1992). Existing data indicate that the sizes and, consequently, the shapes of individual beetle organs differ in habitats with varying vegetation and levels of anthropogenic pressure. Similar studies have been conducted on the species of ground beetle *P. cupreus*. The authors showed that in agrocenoses, the size of this beetle decreases, and both the conditions of the agrocenosis and the type of vegetation significantly influence the shape of the beetles (Sukhodolskaya et al., 2017). The aim of this study was to reveal if carabid beetle *Carabus granulatus* L., 1758 individuals from the different populations have distinctive traits' values,

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which traits have the most impact and how they change under certain conditions.

2. MATERIALS AND METHODS

Carabus granulatus is a transpalearctic hygrophilous eurytopic species with a one-year life cycle. It's a spring-breeder species without larval diapause, but with obligatory diapause for adult individuals (Turin et al., 2003). Both the adults and larvae are predators. The material was sampled in the Kaluga province (Russian Federation) on 10 sites, represented by 7 habitats classified by vegetation type: birch forest (bir), swamp (sw), linden forest (lin), spruce forest (spr), willow thicket (wil), black alder forest (baf), and gray alder forest (gaf).

Localities were classified by the level of anthropogenic pressure – urban, suburban, natural habitat – as well as by the landscape type: floodplain, plateau and urban ecosystem.

The following morphological traits of the beetles were measured: length (I) and width (II) of the elytra, length (III) and width (IV) of the pronotum, length of the head (V), and distance between the eyes (VI). A total of 5039 specimens were measured.

Research Technique

After sampling the beetles and determining their species and sex, all individuals were photographed, and their parameters were measured using a custom program by Python 2.7 with the libraries numpy and OpenCV. (Mukhametnabiev, 2018). The scheme for measuring the beetles is presented in Figure 1. Linear discriminant analysis was performed by Statistica 10 software.

3. RESULTS AND DISCUSSION

Discriminant analysis by habitat type

Different populations of *C. granulatus* are weak (Wilks' Lambda = 0.79), but significantly ($p < 0.001$) discriminated by habitat type, indicating that beetles in different habitats possess unique specific metric characteristics, although these differences are weak and hard to distinguish. Classification function coefficients show the greatest contribution for the length of the pronotum, as well as the length and width of the elytra. Squared Mahalanobis distances (Table 1.) are small, but reliable, and vary from 0.16 to 1.41. Greatest distances are noted for pairs «gray alder forest»-«birch forest» and «gray alder forest»-«swamp». According to the factor structure matrix and the plot (Figure. 2.), beetles from the gray alder forest have shorter and wider pronotum as well as longer and

narrower elytra than ones from the swamp and birch forest. Also, beetles from the swamp habitats have wider distance between eyes.



Figure 1. Illustration of measurements: 1-2 – elytra length, 3-4 – elytra width, 5-6 – pronotum length, 7-8 – pronotum width, 9-10 – head length, 11 – 12 – distance between the eyes.

Author of the original photo: Komarov P. <https://www.zin.ru/animalia/coleoptera/rus/cargraek.htm>

Table 1. Squared Mahalanobis distances with dependent variable “habitat”, p -value<0,001.

biotope	bir	sw	lin	spr	gaf	wil	baf
bir	0.00						
sw	1.03	0.00					
lin	1.04	0.95	0.00				
spr	0.18	1.11	0.99	0.00			
gaf	1.32	1.41	0.08	1.17	0.00		
wil	0.58	0.89	0.13	0.52	0.31	0.00	
baf	0.80	0.89	0.18	0.86	0.34	0.16	0.00

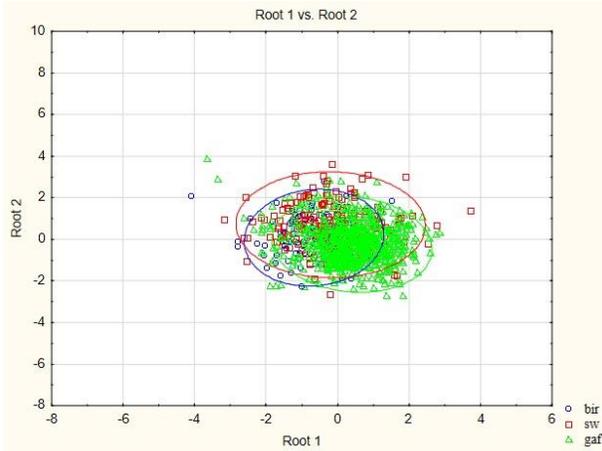


Figure 2. Scatter plot of the discriminant analysis. Discriminate scores for populations from different biotopes (Root1, Root2) are shown on the axes. Bir: birch forest, sw – swamp, gaf – gray alder forest.

Landscape

Summary results of the discriminant analysis by landscape type show slightly higher degree of discrimination (Wilks' Lambda = 0.68) than by habitat, $p < 0.001$. Squared Mahalanobis distances are quite low (Table 2.), but in general higher than those for habitat type discrimination, vary from 0.79 to 2.24. Greatest distances are between plateau and urban landscape, lowest – between floodplain and urbans. Classification function coefficients show the greatest influence of the pronotum length, coefficients for elytra length and width have relatively high values as well. According to the factor structure matrix and the plot (Figure. 3), Carabids from the plateau have longer and wider pronotum and greater distance between eyes. Beetles from urban landscape have longer and wider elytra, beetles from floodplain: short and narrow elytra.

Table 2. Squared Mahalanobis distances with dependent variable “landscape”, p -value <0.001 .

landscape	floodplain	plateau	urban
floodplain	0.00		
plateau	1.40	0.00	
urban	0.79	2.24	0.00

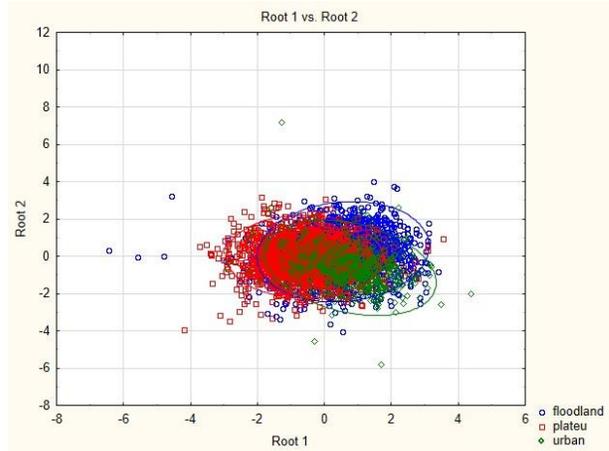


Figure 3. Scatter plot of the discriminant analysis. Discriminate scores for populations from different landscape types (Root1, Root2) are shown on the axes.

Anthropogenic pressure

Summary results of the discriminant analysis by anthropogenic pressure levels show very low degree of discrimination (Wilks' Lambda: 0.92), but still reliable ($p < 0.001$). Squared Mahalanobis distances respectively are very low (Table 3.), but reliable ($p < 0.001$), vary from 0.27 to 0.42. The highest value belongs to the pair urban-suburban, the lowest – for suburban and natural habitats. Classification function coefficients show similar level of contribution from the traits: the most for the pronotum length, less for elytra length and width.

Table 3. Squared Mahalanobis distances with dependent variable “anthropogenic pressure”, p -value <0.001 .

Anthropogenic pressure	Urban	Suburban	Natural habitat
Urban	0.00		
Suburban	0.42	0.00	
Natural habitat	0.36	0.27	0.00

Carabids from the urban ecosystems have longer elytra as well as wider elytra and pronotum in comparison with those from suburban and natural habitats. Beetles from suburban habitats have relatively longer and narrower pronotum and elytra as well as greater distance between eyes.

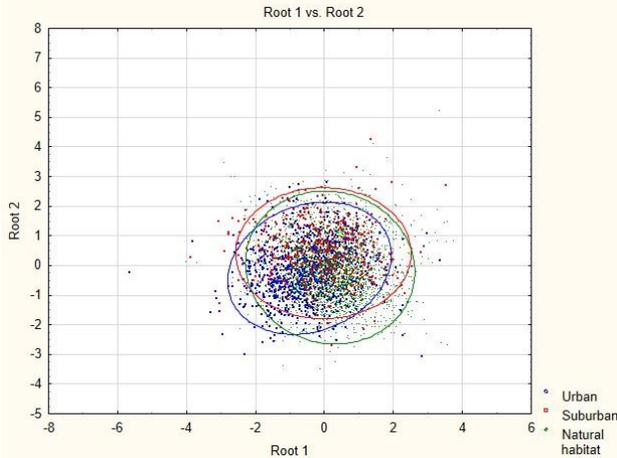


Figure. 4. Scatter plot of the discriminant analysis. Discriminate scores for populations with anthropogenic pressure of different levels (Root1, Root2) are shown on the axes.

Locality

Summary discrimination analysis by localities shows significant and highest discrimination level amongst all dependent variables (Wilks' Lambda: 0.56, $p < 0.001$). Squared Mahalanobis distances vary from 0.02 to 9.98 (Table 4.). Greatest distance belongs to 4 and 10, lowest: for 6 and 8. Localities with the greatest distance, expectedly, have large differences: black alder forest in natural biotope vs urban linden forest biotope. Localities with lowest distance are very similar: natural biotopes in floodplain. Overall, according to Mahalanobis distances, locality, as a factor, has the greatest influence to discriminating different populations of beetles by morphometric traits. Anthropogenic pressure has the lowest influence on morphological traits.

Discussion

Our research confirms that carabid beetles from different habitat types exhibit specific significant differences. However, these differences are low and largely overlap with phenotypic plasticity. Factor structure matrices consistently show that the most important feature for distinguishing beetles from different habitat types is the length of the pronotum, followed to a lesser extent by the length and width of the elytra. Other traits contribute significantly less. In the analysis by habitat type, beetles from swamps show greater differences from others, likely characterize it as extreme, situated at the boundary of the typical epigenetic landscape for *C. granulatus* (Belosludcev, 2023).

Table 4. Squared Mahalanobis distances with dependent variable “locality”. Notes: lower left part: values, upper right: p-values.

Localities	1	2	3	4	5	6	7	8	9	10
1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.46		0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.48	0.02		0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	3.07	3.57	3.43		0.00	0.00	0.00	0.00	0.00	0.00
5	0.26	1.03	1.09	2.78		0.00	0.00	0.00	0.00	0.00
6	1.71	1.25	1.26	5.02	1.59		0.00	0.00	0.00	0.00
7	0.90	0.74	0.71	4.16	1.03	0.23		0.00	0.00	0.00
8	1.56	1.21	1.31	4.70	1.39	0.18	0.37		0.00	0.00
9	3.01	2.22	2.42	8.15	2.92	0.67	1.25	0.52		0.00
10	3.78	3.83	3.88	9.98	3.68	1.37	1.53	1.56	1.28	

Common patterns are observed: beetles from urban/suburban habitats are generally larger and stockier, while those from natural and floodplain habitats are smaller overall. Beetles from suburban areas and plateau habitats are narrower compared to urban ones. This may be explained by two different groups of factors that independently influence the length and width of the beetles. Undoubtedly, based on known data about the biology of *C. granulatus*, floodplain wet habitats characterize a shape that is closest to the normal. At the same time, beetles on plateaus and in suburban areas are influenced by factors that positively affect length, which continue to operate in urban cenoses. The factor positively influencing the width of the beetle is noted to a significant extent only for urban habitats.

Such factors may include humidity levels, soil granulometric composition, and food supply (Martinson, 2013), trampling, toxic effects etc., as well as the degree of isolation that favors gene drift in the population, reducing diversity and shifting the mean values of morphometric traits (Skłodowski, 2019). Factors belonging to the first group may include humidity levels and soil granulometric composition: plateau and suburban habitats typically have a drier microclimate and coarse soil, which is also

characteristic of urban habitats. The second group of factors may include food supply, trampling, toxic effects, and gene drift, which are more pronounced in urban habitats. The fact that locality analysis data show the greatest degree of discrimination confirms that the factors influencing size act together and, at least partially, independently, summing up in habitats that are most different from each other.

4. CONCLUSION

This study highlights the significant influence of environmental factors and anthropogenic pressure on the morphometric traits of *C. granulatus*. The observed variations in body size and shape among different populations underscore the adaptability of this species to diverse habitats. Our findings indicate that urban and suburban environments lead to distinct morphological changes, suggesting a potential impact of habitat alteration on beetle physiology. Furthermore, beetles from floodplain areas exhibited smaller sizes, reflecting the unique ecological pressures of these environments. The differences among various biotopes reveal the complexity of how habitat type influences beetle morphology. This research contributes to the understanding of biodiversity patterns and emphasizes the importance of considering morphometric traits in ecological studies and biomonitoring efforts. Future studies should explore the underlying mechanisms driving these morphological adaptations and their implications for species interactions and ecosystem health.

5. CONFLICT OF INTEREST

All authors have declared that there is no conflict of interest regarding the publication of this article.

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