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INTRASPECIFIC BODY SIZE VARIATION IN GROUND BEETLES (COLEOPTERA, CARABIDAE) IN URBAN – SUBURBAN – RURAL – NATURAL GRADIENT

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This study aims to analyse how body size of Ground Beetles (Coleoptera, Carabidae) is controlled by environmental factors. Beetles were sampled in different regions of Russia. Sampling plots included urban, suburban, rural and natural habitats. We have measured elytron length of more than 25000 specimen. The study was conducted on intraspecific level and six species of carabids were investigated. We used Linear Models to estimate the contribution of different environmental factors (region, anthropogenic disturbance, type of habitat vegetation) into the elytron length variation in the studied species of carabids. The response of different species to the anthropogenic press was not identical. Species which shared the same ecological niche showed different directs of elytron length alteration. For example, *Carabus cancellatus* Ill. size decreased in urban habitats, *Carabus granulatus* L. size remained unchanged but in *Carabus aeruginosus* F.-W. we registered sexual dimorphism in contribution of "urban" factor into the elytron length variation. Suburban habitats didn't contribute significantly into the size variation but in rural habitats elytron length of species studied were larger.

Key words: body size variation, morphometry, Carabidae, urban –suburban – rural - natural gradient.

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INTRODUCTION

Studies of intraspecific variation in the presence of different environmental features are essential to improving the knowledge of species population dynamics and structure. Community and species specific responses need to be related to characteristics of the urbanised landscape, i.e. the urban–rural gradient needs to be operationalised in terms of specific disturbance features (Niemela & Kotze 2009). The question how animal body size changes along urban–rural gradients has received much attention among specialists in different branches of biology. This is determined by two factors. The first is the expanding urban areas and increased awareness of urbanization impacts on wildlife. The second is the integrity of body size as the trait which affects many life-history traits in insects, e.g. ontogenesis, biomechanical constraints, sexual selection, fecundity, size-specific predation, resource quality and availability, overcrowding, competition, manoeuvrability in flying insects etc. (Berven & Gill 1983, Juliano 1985, Wheeler 1996, Angilletta & Dunham 2003, Dial et al. 2008). Changes in morphological characteristics

of organisms have been used successfully as indicators of habitat quality and disturbance (Lagisz 2008). This article is devoted to intraspecific size variation in Ground Beetles. They are a well-studied group, frequently discussed in research papers concerning the effects of environmental changes, such as land management, fragmentation and pollution (Rainio & Niemela 2003, Avgin & Luff 2010).

Ground beetles (Coleoptera: Carabidae) are frequently used to indicate habitat alteration since they are affected by anthropogenic activities such as urbanization, crop and forest management, overgrazing by domestic livestock, tourist flow in natural landscapes and soil pollution. Moreover, carabids are well known both taxonomically and ecologically. They are extremely sensitive to several abiotic and biotic factors, respond quickly to habitat alteration and can be easily and cost-effectively collected by using classic pitfall traps. For these reasons this group of ground-dwelling arthropods are increasingly being used in ecological studies in order to evaluate the environmental impacts of man in terrestrial ecosystems. Whilst disturbance effects on community composition are well documented for many taxa in a variety of disturbed habitats, there are complex effects on population dynamics, and traits affecting fitness. This suggests that changes in species composition of communities are inadequate for assessing the ecological impacts of disturbance. There is clearly a need for the development of other indicators for assessing the ecological impacts of disturbance (Venn 2007).

In this paper we examine how different environmental factors contribute to elytron length variation (the indicator of body size) in Ground Beetles with especial attention to the anthropogenic effect and on the intraspecific level.

MATERIAL AND METHODS

Collection sites and insect sampling. Wild specimens of carabids were sampled in 1996 - 2006 in different provinces of Tatarstan Republic (Russia) (53 sites). Material from other regions of Russia were kindly presented to us from our colleagues from Kemerovo, Udmurtia, Mariy El, Stavropol Universities, Visim and Preduralie Reserves and Institute of Animals Ecology and Systematic (Novosibirsk).

Fig.1. Sampling localities of studied Carabid Beetles.

Table 1. Sampling localities and number of specimen of carabids used in the morphological analysis

	Region	Latitude, °N	Longitude, °E	Number of sites	Sample size
1	Stavropol region	45°02’	41°55’	6	76
2	Kemerovo region	54°56’	87°14’	14	1954
3	Novosibirsk region	55°27’	79°33’	3	360
4	Tatarstan Republic	55°47’	49°06’	53	10722
5	Mari El Republic	56°42’	47 52’	14	67
6	Udmurtia Republic	57°17’	52°45’	16	396
7	Cis_Ural	57° 01’	57°9’	21	58
8	Sverdlovsk region	58°42’	61°20’	6	458

The localization of these regions is shown in Table 1 and Fig. 1.

Study organisms

Six species of carabids were in analysis – *Carabus granulatus* (Linnaeus, 1758), *Carabus cancellatus* (Illiger, 1798), *Carabus aeruginosus* (Fischer von Waldheim, 1823), *Pterostichus melanarius* (Illiger, 1798), *Pterostichus niger* (Schaller, 1793) and *Poecilus cupreus* (Linnaeus, 1758). All of them, except *C. aeruginosus*, are widespread and prolific beetles, generalists, zoophagous. They are distributed all over Eurasian continent, from subtropical belt in the south (Italy, Spain) till Fennoscandia in the north (Kryzhanovskij et al. 1995, Philippov 2008, http://www.faunaeur.org/distribution_table.php). The first three species mentioned have been introduced to North America (Erwin 2007, Hartley et al. 2007). *C. aeruginosus* is distributed only in Central, East and North Russia (Savosin 2008, Obydov 2011).

Morphometric analysis

All measurements were made with a Leitz RS stereoscopic dissecting microscope at a magnification of 10 diameters, using a calibrated ocular grid with a scale interval of 0.1 mm. For each of specimens six variables were measured, including: elytra length and width, pronotum length and width, head length and distance between eyes (Fig. 2). In this paper we presented results only in elytra length variation.

Statistical analysis

All dimensions (in millimeters) were $\log_{10}$ transformed to ensure normality. All statistical analyses of the morphometric data were performed using R programs (R Development Core Team 2011).

Linear models were used to reveal how different environmental factors affected morphometric traits. The models like those gave the possibility to identify the influence of each factor in its range (Faraway 2005, McCulloch et al. 2008, Bingham & Fry 2010).

Thus, in our case we estimated the contribution of area, anthropogenic disturbance, type of habitat into the traits variation in every species of Ground Beetles. In other words, these variables were considered independent. The contribution of other factors was considered to be random and was summarized as the error of the model. All variables were modeled as categorical using treatment contrasts. As the base (reference) level we used: for regional aspect – Tatarstan as the center of the area, for anthropogenic disturbance – natural cenosises (minimal anthropogenic affect), for habitat type –the most favourable habitat unique for certain species where it usually dominated. The contributions of area (signed as “region” in tables and “@” in figures in the main text), anthropogenic disturbance (“anthropogen” and “%”), habitat type (habitat” and “$”) were considered to be additive and independent. The influence of the

Fig.2. 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.

listed factors was considered to be different in males and females, besides the effect of sex was taken into account too. In other word the model included sex and its interaction with every listed factor. For example, the model which estimated the variation of elytra length was recorded as follows (using the R syntax): ****

Elytra.Length~fSex/(fRegion+fAnthropogen+f Habitat+fIsolation)

where fSex – the factor, representing sex, fRegion- factor, representing the area etc. Variance analysis (ANOVA) of models was used for factors significance test. We estimated the contribution of all variables and their interactions for every trait and pointed confidence intervals (using Student criteria) and residual statistics (errors). Received values and their confident intervals were used to present results in figures and tables: interactions were compared with corresponding base levels (the 95% confident level was used for the normal approximation). Besides the confidence intervals for the additive effects of sex and certain variables were displayed.

RESULTS

As the example of *variation of studied morphometric traits* in studied species we present Fig. 3. It illustrates the contribution of different environmental factors into the only one trait (elytron length) in the only one species – *C. cancellatus.* Elytron length in this species significantly decreased only under the factors "Udmurtia", "Urban" and "Barley" but became longer under the influence of some vegetation, i. e. "Pine", "Shrubs" and "Vetch&Oat"/ Factor "Rural" affected males only.

Similar statistical analyses were done in all six carabid species studied. So we could form the similar figures for all species and then could clip out the information concerning the anthropogenic affect only and unite it into the general figure. Results are presented in Fig. 4.

Factor "Urban" contributed negatively into elytron length variation only in two studied species – *C. cancellatus* and *P. melanarius.* In *C. aeruginosus* in urban habitats males elytra length increased but females – decreased. And in *C. granulatus* and *P. niger* this trait didn't change significantly.

Factor "Suburban" statistically significantly decreased males elytra length in *C. granulatus* and females in *P. melanarius* but in *C. aeruginosus* males this trait increased in suburban habitats. Factor "Suburban" didn't contribute significantly into elytron length variation in *C. cancellatus* and *P. niger.*

Factor "Rural" increased elytron length in *C. cancellatus* males and in both sexes in *P. cupreus.*

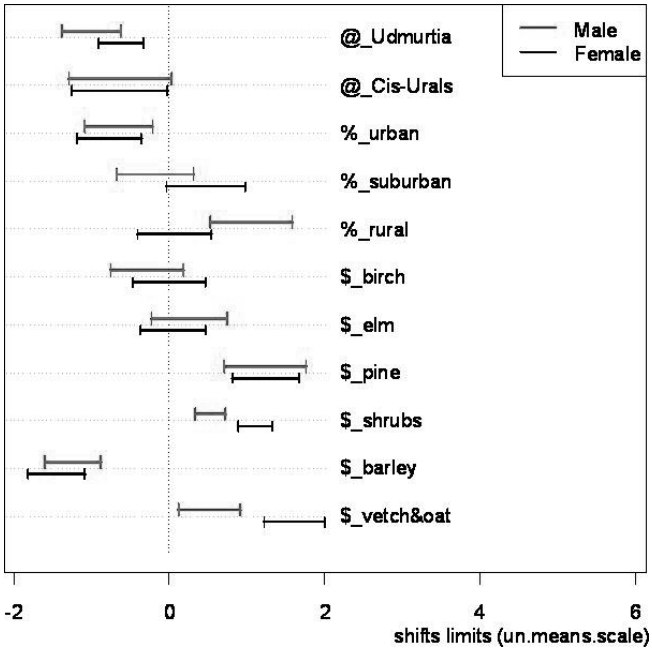

Fig.3. Contribution of environmental factors into elytron length variation in *C. cancellatus* (signed as "@" – the contribution of area, "%"-anthropogenic disturbance, "$" – type of vegetation; the vertical dotted line denotes the basic means of *C. cancellatus* elytron length, i. e. in Tatarstan, natural habitat, lime forest).

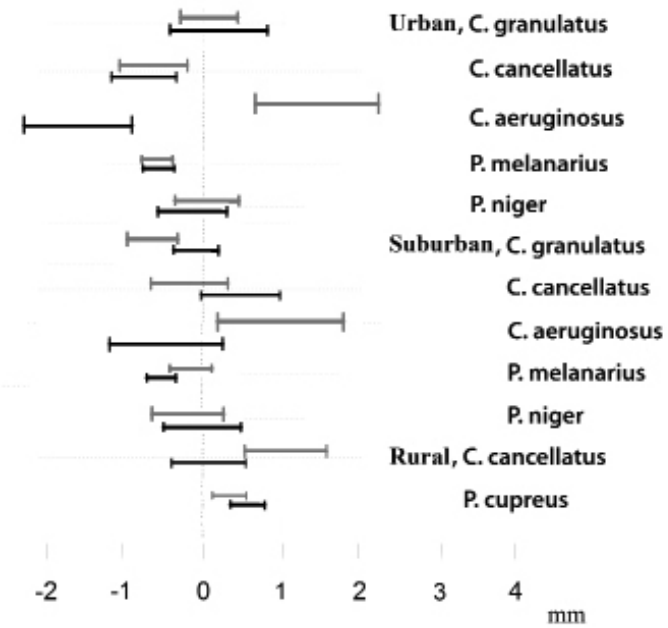

Fig.4. Contribution of anthropogenic disturbance factors into the elytron length changes in different species of carabids; the vertical dotted line denotes the normalized basic means, unique for each species; - females, - males.

DISCUSSION

When choosing the methods researchers usually orient to the main factors that can affect traits variation in certain species. Naturally the range of these factors is very wide. Our study is devoted to Ground Beetles. Thus we have selected four main environmental factors that play role in body size and shape variation in carabids and in this paper we discuss the anthropogenic effect only. The interest of anthropogenic impact on intraspecific body size variation in Ground Beetles appeared in biological papers comparatively recently but the results on this subject are controversy (Braun et al. 2004). There has been shown that body size in *Carabus nemoralis*, *Carabus aeruginosus, Pterostichus oblongopunctatus* decreased in the gradient of urbanization (Naidenko & Grechkanev 2002, Weller & Ganzhorn 2003, Timofeeva & Savosin 2009), but how much factor "urbanization" contributed into the size variation was not clearly estimated. The authors referred that phenomena to stress escalation due to the habitats fragmentation in city centers. But another authors have demonstrated another type of size variation in the species of the same family of the Ground Beetles: *Carabus arvensis and Carabus violaceus* decreased their size in the forest stands disturbed by the hurricane, but *P. niger* – increased (Sklodowski & Gabralinska, 2008).

The current research provides an important step towards synthesizing such a conflicting results. To our mind estimation of urban effect must be done together with the estimation of other factors that can contribute into the size variation, in our case - Ground Beetles, so it is partially depended on the study design. Researcher should focus within species and look at widespread but contiguous populations to account for all sources of variation while minimizing error. Speaking about different morphological gradients in insects M. Shelomi (2012) neatly pointed that "..if you measured a leg instead of a wing, or males instead of females or looked at multiple species together instead of just one, your results would be different."

Our study show that different species response to anthropogenic disturbance can differ. The alteration of different traits in certain species to the certain factor can also vary. In our earlier research there has been shown, that factor "Urban" decreased as elytron length as well as pronotum and head width in *C. cancellatus* but increased elytron width in this species (Sukhodolskaya 2011, Sukhodolskaya & Saveliev 2012). Factors "urban" and "suburban" didn't contribute in any way into the size variation in another Ground Beetle species – *P. niger*, except the fact that in urban habitats males head became wider (Sukhodolskaya 2012). Enlarged head in urban and suburban conditions seemingly referred to the increased searching activity because beetles in urban and in suburban conditions often suffer from the lack of nutrients. Different traits in this species varied in different direction, so the shape of the beetles became different in differing environment. The same has been shown in another carabid beetle – *C. granulatus* (Gordienko & Sukhodolskaya 2011).

CONCLUSION

Actuality of biota monitoring in the urban landscapes is doubtless. But sometimes studies are carried out without proper statistical treatment. Our study showed that morphometric variation in urban – suburban – rural – natural gradient differed in various species of Ground Beetles. Moreover, various traits in the same species reacted in diverse way to the anthropogenic disturbance females being distinct from males. These facts must be taken into attention when new subspecies (or even species) are described. It happens very often that taxonomists present new species having data on the only several traits deviations from "standard type" and does not pay attention to the tremendous amount of variation in nature.

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