IMPACT OF LATITUDE ON SEXUAL SIZE DIMORPHISM IN GROUND BEETLE POECILUS CUPREUS L

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ABSTRACT

Sexual dimorphism is a common phenomenon in insects, and it may be expressed in various traits including body size and body shape. Sexual selection is the main factor shaping such differences between males and females in insects, even if they depend also on food availability during larval stages. Body size can differ geographically between particular populations of one animal species, both with latitude and altitude, and it was undoubtedly shown for ground beetles. The latter are considered excellentbioindicators and model organisms for evolutionary studies. We have investigated ground beetle Pocilus cupreus body size variation practically throughout its entire range and have found that the curve of its body size variation was saw-tooth in latitude gradient and in longitude as well. Using that base set we estimates sexual size dimorphism (SSD) variation in geographical gradients.We have measured more than 8000 specimen of males and females in ground beetle Poecilus cupreus L. sampled in 14 large regions of Eurasia. Sexual Size Dimorphism changed drastically in latitude gradient not showing any trend to decrease or to increase. We conclude that several dominating factors affected SSD presentation in species studied, among which climatic factors at the sites where beetles have been sampled.

KEYWORDS

Sexual Size Dimorphism, Ground Beetles, Latitude Gradient, Body Size Variation, Sexual Selection, Environmental Factors, Climate Change.

1. INTRODUCTION

The patterns and causes of body size variation in geographical gradients are fundamental themes in studies on life-history evolution [1]. Their importance is high because climate changes and trends in space may be highly relevant for predictions of changes over time [2]. Body of publications in this theme grows but the diversity of ecogeographic body size clines remains not fully understood, particularly in ectotherms [3, 4].

The most known are latitudinal and altitudinal clines in body size [5]. Temperature is often assumed to be the principal determinant of ecogeographic body size clines, because temperature covaries consistently with latitude and altitude, and it strongly affects vital processes in the organisms [6]. Yet, a number of recent studies have found that water availability (precipitation, humidity), and particularly seasonality (within-year variation in temperature or precipitation), often explain a higher proportion of body size variation than does mean temperature [7, 8]. For each of these factors, multiple mechanistic hypotheses have been proposed (see below). However, rigorous testing of such hypotheses is often impeded by collinearity between climatic variables [9] which is particularly common within limited geographic areas.

No less significant in studies of body size is the phenomenon of differences observed between females and males, the so-called sexual-size dimorphism (SSD). A lot of research has been done to elucidate the evolutionary processes that underlie sexual dimorphism patterns betweenanimals [10]. The direction and extent of the sexual differences in body shape and size in many insect species are greatly influencedby sexual dimorphism and particular developmental processes [11]. Beetles (Coleoptera) are cosmopolitan in distribution andexhibit great sexual dimorphism among different species.The evolutionary foundation for the study of sex differences is provided by Darwin's sexual selection theory, whichincludes intrasexual competition for mates and discriminative mating partner choice (intersexual choice). Although nichedifferentiation between sexes through ecological character displacement can cause sexual dimorphism, its development hastraditionally been attributed mostly to differences in the strength of sexual selection acting on males and females [12].Competition and selection dynamics not only result in the evolution of sex variations in trait size or degree of elaboration,but they also make these traits more sensitive to social and ecological pressures.

2. MATERIAL AND METHODS

2.1. Sampling Regions

The material was obtained under scientific cooperation agreements from researchers from fifteen regions of Russia and abroad. Ground beetles were caught using the standard Barber trap method. The sample from each region included beetles caught in a range of sites that differed in the degree of anthropogenic impact and vegetation: cities, suburbs, agrocenoses, and natural biotopes. The number of individuals from each raft was at least 35 individuals (Table 1).

Table 1. Description of sampling localities of *P. cupreus*

	Region	Latitude, °N	Longitude, °E	Number of Sites	Type of Habitats	Sample Size
1	Switzerland	47,0016° N	8,0013° E	1	rape	148
2	Germany	51,0916° N	9,0013° E	4	rape	569
3	Bulgary	42.3243° N	25.0232° E	3	rape	698
4	Romania	44.2518° N	26.3703° E	9	rape	1174
5	Krasnodar Territory	44.3833° N	38.9667° E	1	rape	154
6	Kostroma Oblast	57,4606° N	40,5559° E	1	meadow	100
7	Stavropol Territory	48,46° N	35,04° E	1	meadow	71
8	Chechen Republic	43,1719° N	45,4534° E	1	arable	187
9	Republic of Tatarstan	55,4731° N	49,0720° E	9	barley, pea, spring wheat, rye, vetch & oat, alfalfa, carrot, lawn	2643
10	Sverdlovsk Oblast	55,1719° N	68,4534° E	1	meadow	200
11	Kemerovo Oblast	55,2520° N	86,70° E	1	meadow, lawn	67
12	Novosibirsk Oblast	55,27° N	79,33° E	2	meadow	548
13	Slovakia	45,02° N	41,55° E	1	meadows, pasture	146
14	Ukraine	48,77° N	35,08° E	3	arable lands	145

2.2. Study Organism

P. cupreus is a widespread Palaearctic species 8.5-13.5 mm in length. The humeral tooth of the elytra is indistinct. The head is densely dotted. The elytra are somewhat wider than the base of the pronotum. The upper surface is copper-red, bronze, green, black, blue, etc.; sometimes the femora, rarely the legs, are red. The coloration is very diverse, sometimes two-colored, the legs are always black. This is a meadowfield species with a high population in agrocenoses. It is of great importance as an entomophage. It finds favorable conditions for living in urban areas also and has a wide range of requirements for the habitat.

2.3. Study Design

Individuals were photographed 5-6 specimen at a time and the parameters were measured on a self-written program in Python 2.7 using the numpy and openCV libraries. The program is necessary to achieve greater measurement accuracy, automate the process and reduce subjectivity. They are measured according to six dimensional traits (Fig. 1.). A total of 6,909 insect specimens were measured, with the last column indicating the number of specimens measured in each region (Table 1). The data are collected in Excel tables for subsequent statistical analysis.

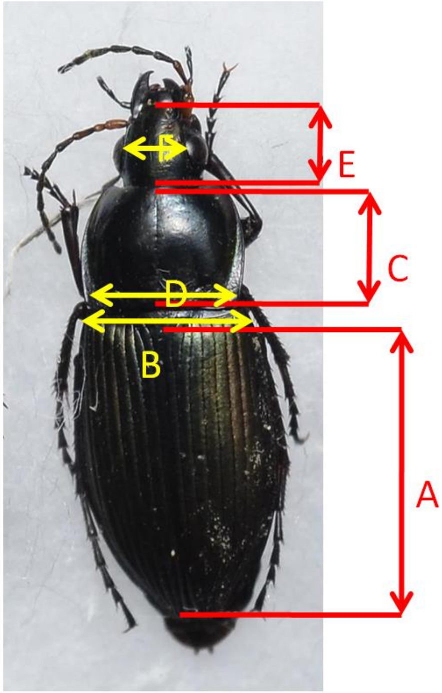

Figure 1. The scheme of beetles measurements. A –elytra length, B – elytra width, C – pronotum length, D – pronotum weight, E – hat length, F – distance between eyes.

2.4. Statistical Analysus

Statistical processing was carried out in the Excel program. Methods of onedimensional statistical analysis were used. The mean, standard deviation, error of the mean, and the variation coefficient were calculated. The variation coefficient is calculated using the formula standard deviation/mean*100. Graphs were constructed based on the data obtained, and the results were entered into a table. SSD was calculated according the formula: mean trait in females/mean trait in males -1. Thus, if calculated value of SSD was positive, females in the sample studies were larger than males. And vice versa: when SSD value was negative, then we thought that the conditions of that region were unfavorable, or some microevolutionary changes were taking place in that region, since negative SSD values (when females are smaller than males) are not typical for ground beetles

3. Results and Discussion

The SSD values changed significantly in the latitudinal gradient (Fig. 2): they became more or less stable closer to the northern latitudes - this is the northern boundary of the range of the studied species. In the south, the SSD values changed abruptly when moving from one region to another, acquiring negative values in the Krasnodar Territory and in Ukraine. The latter phenomenon (when females are smaller than males) is not typical for ground beetles in general. This fact supports the opinion that such environmental conditions developed there. Considering that *P. cupreus* is a field species, this may well be explained by some agricultural practices that were used in the places of capture. However, this is not the only explanation. SSD studies have shown that its value can be determined by a number of factors: mean summer temperature, summer precipitation, seasonality, and reproductive mode/lineage identity on female size, male size, and SSD. For example the investigators found a moderate effect of reproductive mode and precipitation and a strong but complex effect of seasonality [13]. The latter differed drastically between the lineages, being also modulated by precipitation and especially by temperature. Female size and SSD varied stronger than male size, and virtually all the effects were strongly female-biased. That study operated with lizards.

Studies in ground beetles SSD variation are scarce. So, it was shown, that SSD in them also varied. In different species its value fluctuated between 0.02 and 0.12, and according to various characteristics those values varied even more [14]. Moreover, intra-specific variation of SSD values was great. Latitudinal variability of SSD in six species of ground beetles was studied and the authors concluded that despite SSD occurred in some analyzed latitudes and mainly at the margins of area, modeling results did not confirm opinion than SSD systematically changes in latitude gradient [15, 16]. Moreover, sometimes SSD varied according to the type of biotope [17].

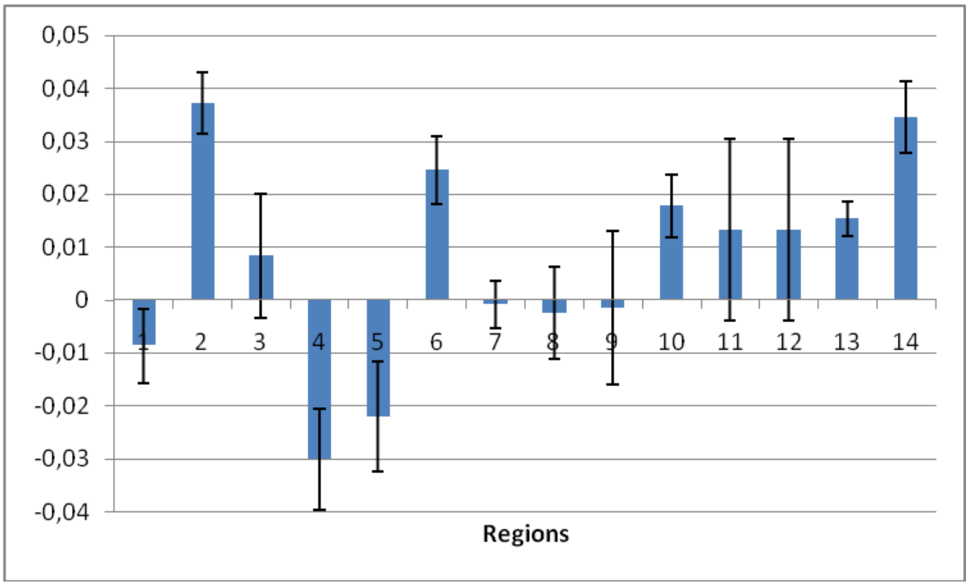

Figure 1. Variation of SSD in *P. cupreus* in different points. 1) Bulgaria 2) Chechen Republic 3) Romania 4) Krasnodar Province 5) Ukraine 6) Stavropole Province 7) Switzerland 8) Slovakia 9) Germany 10) Kostroma Oblast 11) Kemerovo Oblast 12) Novosibirsk Oblast 13) Tatarstan Republic 14) Sverdlovsk Oblast

4. CONCLUSIONS

Despite the relevance of the topic, the problem of SSD is far from being resolved. To solve it, it is necessary to comply with a lot of conditions, both when collecting material and when choosing an object and research methods. Similar to the conditions for conducting experiments to assess the variation of animal sizes in environmental gradients, when studying SSD, it is necessary to keep in mind that the object must be massive, well studied in biological and ecological terms, and a unified measurement method must be used. In our study, the SSD value changed in the same saw-tooth pattern as shown in earlier studies on size variability in this species of ground beetles. However, the approximation showed a weak trend toward an increase in the SSD value toward the north. At the same time, in ground beetles of other genera, the SSD values either did not change in the latitudinal gradient or were tied to the population size in a given region. This suggests that the expression of SSD may be genus-specific, which should be taken into account in further studies.

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REFERENCES

[1] Arendt, J., & Fairbairn, D. J. (2012). Reproductive allometry does not explain the temperaturesize rule in water striders (*Aquarius remigis*) *Evolutionary Ecology*, Vol. 26, pp745–757. https://doi.org/10.1007/s10682-011-9524-4

[2] Teplitsky, C., & Millien, V. (2014). Climate warming and Bergmann's rule through time: is there any evidence? *Evolutionary Applications*, Vol. 7, pp156–168. https://doi.org/10.1111/eva.12129

[3] Hjernquist, M. B., Söderman, F., Jönsson, K. I., Herczeg, G., Laurila, A., &Merilä, J. (2012). Seasonality determines patterns of growth and age structure over a geographic gradient in an ectothermic vertebrate *Oecologia*, Vol.170, pp641–649. https://doi.org/10.1007/s00442-012-23384

[4] Rypel, A. L. (2014). Cold-water connection: Bergmann's rule in North American freshwater fishes *The American Naturalist*,Vol.183, pp147–156.https://doi.org/10.1086/674094

[5] Blanckenhorn, W. U., & Demont, M. (2004). Bergmann and converse Bergmann latitudinal clines in arthropods: two ends of a continuum? *Integrative and Comparative Biology* V. 44, pp413–424. https://doi.org/10.1093/icb/44.6.413

[6] Angilletta, M. J. (2009). *Thermal adaptation: a theoretical and empirical synthesis*. Oxford:Oxford University press. https://doi.org/10.1093/acpro f:oso/97801 98570 875.001.1

[7] Çağlar, S. S., Karacaoğlu, Ç., Kuyucu, A. C., & Sağlam, İ. K. (2014) Humidity and seasonality drives body size patterns in males of the bush cricket *Isophya rizeensis* Sevgili, 2003 (Orthoptera: Tettigoniidae: Phaneropterinae) *Insect Science* V. 21, pp213–226. https://doi.org/10.1111/17447917.12027

[8] Stillwell, R. C., Morse, G. E., & Fox, C. W. (2007). Geographic variation in body size and sexual size dimorphism of a seed-feeding beetle *The American Naturalist* V. 170, pp358–369. https://doi.org/10.1086/520118

[9] Millien, V., Kathleen, L. S., Olson, L., Smith, F. A., Wilson, A. B., & Yom-Tov, Y. (2006). Ecotypic variation in the context of global climate change: revisiting the rules. *Ecology Letters* Vol. 9, pp853–869. https://doi.org/10.1111/j.1461-0248.2006.00928.x

[10] Benítez, Hugo, Sukhodolskaya, Raisa, Órdenes-Clavería, Rodrigo, Avtaeva, Tamara, Kushalieva, Shapaat, Saveliev, Anatoliy (2020).Measuring the Inter and Intraspecific Sexual Shape Dimorphism and Body Shape Variation in generalist Ground Beetles in Russia *Insects* V.11(6), pp1–13. https://doi.org/10.3390/insects11060361.

[11] Budečević, S, Savković, U, Đorđević, M, Vlajnić, L, Stojković, B. (2021) Sexual Dimorphism and Morphological Modularity in Acanthoscelides obtectus (Say, 1831) (Coleoptera: Chrysomelidae): A Geometric Morphometric Approach *Insects* V.12(4), pp1–12. https://doi.org/10.3390/insects12040350.

[12] Baur, J, Roy, J, Schäfer, M.A, Puniamoorthy, N, Blanckenhorn, W.U, Rohner, P.T. (2020) Intraspecific mating system evolution and its effect on complex male secondary sexual traits: Does male–male competition increase selection on size or shape? *Journal of Evolutionary Biology* V. 33(3), pp297–308. https://doi.org/10.1111/jeb.13565.

[13] Roitberg, Evgeny S., Orlova Valentina F., Bulakhova, Nina A., Kuranova, Valentina N.,| Eplanova, Galina V., Zinenko, Oleksandr I., Arribas, Oscar, Kratochvíl, Lukáš, Ljubisavljević, Katarina, Starikov, Vladimir P., Strijbosch, Henk, Hofmann, Sylvia, Leontyeva, Olga A., Böhme, Wolfgang (2020) Variation in body size and sexual size dimorphism in the most widely ranging lizard: testing the effects of reproductive mode and climate *Ecology and Evolution* V.10, pp4531–4561.

[14] Sukhodolskaya, Raisa, Saveliev,A., Muhammetnabiev T. (2016) Sexual Dimorphism of Insects and Conditions of Its Manifestation *Research Journal of Pharmaceutical, Biological and Chemical Sciences* V. 7(2), pp1992 – 2001.

[15] Sukhodolskaya, Raisa & Saveliev, Anatoliy (2017) Geographical variation of sexual size dimorphism in ground beetle *Pterostichus melanarius* (Coleoptera, Carabidae) *Proceedings of 18 European Carabidologists Meeting*. Rennes, France pp 61.

[16] Sukhodolskaya, Raisa, Saveliev, Anatoliy, Gordienko, Tatiana, Vavilov, Dmitriy (2018) Sexual size dimorphism in Ground Beetles and its modeling in latitude gradient *GSC Biological and Pharmaceutical Sciences* V. 3(1), pp 11-18.

[17] Sukhodolskaya R. A., Avtaeva T. A, Saveliev A. A., Vavilov D. N. 2019. Sexual Size Dimorphism in Ground Beetle *Carabus cumanus* Fischer von Waldheim, 1823 (Coleoptera, Carabidae) and its Variation in Different Traits. *Baltic J. Coleopterol., 19(1): 89 - 100.*

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