UNIVERSITY OF SINDH JOURNAL OF ANIMAL SCIENCES
DOI: https://doi.org/10.57038/usjas.v7i1.6219
Uni. Sindh. J. Anim. Sci., vol. 7(1); 01-09, 2023
Email: editors.usjas@usindh.edu.pk
ISSN (P): 2521-8328
ISSN (E): 2523-6067
Published by University of Sindh, Jamshoro.

BIOTOPIC FEATURES CHANGE THE SIZE OF *CARABUS ODORATUS* SHIL

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ARTICLE INFORMATION

Article History:
Received: 31st December 2022
Accepted: 28th March 2023
Published online: 31st March 2023

***Author's contribution*:**
AS designed the study, TA analyses the data, RS compiled the results.

Key words:
body size variation, ground beetles, biotope, morphometry, mountains.

ABSTRACT

Body size variation attracts attention of many researchers in different fields because of its importance in organisms functioning. We sampled ground beetles of mountain species *Carabus odoratus* in different biotopes of Barguzinskiy Ridge (northeast part of Baikal Lake; N 54° 20'; E 109° 30'; Russia). Nine biotopes at different elevation were under the study. We measured sampled beetles for six morphometric traits (elytra, pronotum, head lengths and width). In total 984 specimens were measured individually. Length parameters varied to greater extent in *C. odoratus*. Elytra length and pronotum and head length as well were significantly shorter in beetles dwelling in aspen, fir, tundra, heath and park birch if compared with ones in forestry habitats. Wherein width parameters were, roughly speaking, similar in beetles of all studied biotopes. Undoubtedly observed effect of biotope impact on beetles' size variation was connected with differing environmental factors at the certain elevations.

1. INTRODUCTION

The habitat of an organism is the most important component that assures reproductive fitness, secure species interaction, and group living of different species. The survival and existence of a species need a habitat with defined qualities that satisfy the organism's requirements. Natural habitats are continuously altered due to different environmental factors impact. Understanding patterns of variations in species richness and corresponding processes is helpful in planning biological conservation. (Ballard et al., 2013; Zellweger et al., 2017). While studying species diversity in relation to habitat often ecologists focus on the related space partition and resource sharing by the species in correlation with species density, population size, body size, and phylogeny (Taylor & Gotelli, 1994). And variation in body size is becoming increasingly important.

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It is correlated with many aspects of life history such as generation time, reproduction rate and dispersal, and it is associated with ecological interactions and resource requirements. And habitat features affect directly or indirectly body size variation in animals, particularly in such little creatures as insects. The latter depends extremely on environmental factors. This concerns especially ground dwelling species in tundra or mountains ridges. During winter, snow cover was the key predictor of soil microclimate (Oppe et al., 2022). It was discovered that topography and moisture explained little variation in the measured temperatures. But local vegetation and topography can alter environmental conditions above, near, and below the soil surface (Lenoir et al., 2013; Aalto et al., 2018; Bramer et al., 2018).

Shading from standing vegetation dominated by shrubs can reduce soil temperatures and soil temperature fluctuations during the growing season (Klene et al., 2001; Kade et al., 2006; Blok et al., 2010; Myers-Smith & Hik, 2013, Aguirre et al., 2021).

Cooling of soils has also been observed under insulating mats of bryophytes (Blok et al., 2011; van der Wal & Brooker, 2004) or lichens (Cannone & Guglielmin, 2009; Mallen-Cooper et al., 2021; van Zuijlen et al., 2020). Furthermore, soils are commonly colder in depressions or shady locations within topographically heterogeneous landscapes (Aalto et al., 2018; Opedal et al., 2015), and particularly where high soil moisture induces evaporational cooling (Aalto et al., 2013). During winter and early spring, insulation from snow cover, which accumulates in dense shrub vegetation or lee positions (Sturm et al., 2001), leads to soils that are warmer than aboveground layers (Aalto et al., 2018; Kade et al., 2006). This effect can even outweigh summer cooling and results in a net annual warming of soils under tall shrub canopies (Kropp et al., 2021). However, tall shrubs can also reduce snow insulation of soils in spring, as dark branches penetrating the snow increase the radiative heat input and accelerate snow melt (Wilcox et al., 2019). Through these effects on soil temperature, vegetation and topography can influence soil microbial community composition, nutrient cycling and ecosystem fluxes (Cahoon et al., 2012; Lafleur &Humphreys, 2018; Sturm et al., 2001). In addition, microclimatic variation above and below the soil surface across tundra vegetation types can affect abundance of organisms from higher trophic levels such as arthropods (Høye et al., 2021).

Among arthropods ground beetles were studied sufficiently. Their body size varied in geographical and anthropogenic impact gradients (Sukhodolskaya, Eremeeva, 2013; Sukhodolskaya, 2014; Sukhodolskaya, Ananina, 2015). Modeling procedures also confirmed habitats vegetation cover effect on beetle's size variation (Sukhodolskaya, Saveliev, 2016; 2017). The aim of this paper was to reveal whether biotope vegetation affected body size in one of the dominating species in mountain ridge *C. odoratus*. Our hypotheses were: (i) body size in beetles inhabiting open biotopes would be smaller than in the forested ones; (ii) in high elevation biotopes beetles body size would be smaller; (iii) in high elevated biotopes sexual size dimorphism (SSD, the difference between males and females) would be larger than at low altitudes.

2. MATERIALS AND METHODS

Studied area

The studies were carried out on the territory of the Barguzinsky State Reserve, located on the western macroslope of the ridge of the same name (North-Eastern Baikal region). The profile of 30 km passes in the valley of the Davsha river, from the shore of Lake Baikal to watershed Tarkulik and Davsha river (a spur of the Barguzinsky Range). According to the landscape features of the study area, the following high-altitude sections were distinguished: the coast of lake Baikal, 454-517 m above sea level; lowland (lower part of the mountain-forest belt) - 518-720 m; midland (upper part of the mountain-forest belt), 721-1300 m; highland (subalpine belt of vegetation), 1301-1700 m. Nine entomological stationary sites are located in biotopes of Barguzinsky Range, Fig. 1.

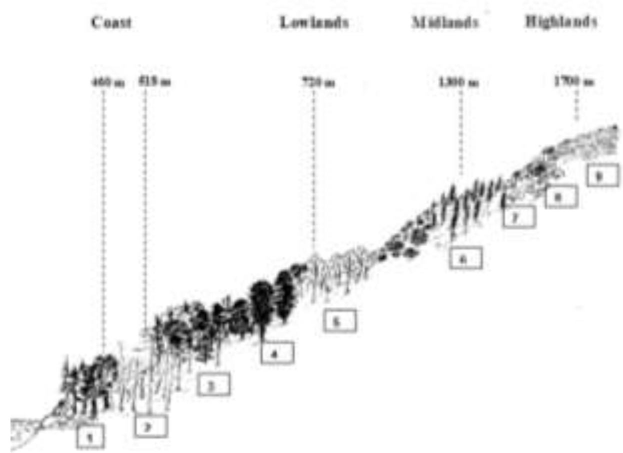

Figure 1. Location of biotopes on the altitudinal profile.

1 – bilberry cedar (54.21104 N, 109.30123 E);
2 – blueberry larch forest (54.21108 N, 109.39291 E);
3 – cowberry pine forest (54.23585 N, 109.41062 E);
4 – aspen cedar (54.2931N, 109.5431E);
5 – bergenia aspen (54.23065N, 109.43546 E);
6 – green moss fir forest (54.21172 N, 108.47101 E),
7 – sparse birch forest (54.20382 N, 109.48358 E),
8 – bilberry tundra (54.20322 N, 109.49595 E),
9 – lichen mountain heath (109.49595 N).

We used pitfall traps for beetles sampling - glass jars with volume of 0.5 liters, 70 mm in diameter and with 4% formalin as a fixative. Pitfall traps were placed in a straight line at 5 m interval (Barber, 1931). The captured insects were selected every decade from the third decade of May to the second decade of September in 2004 – 2017 (Ananina, 2010).

We selected undamaged specimens for habitat analysis, but without fixing the selection time (year, month, decade). In total 2200 specimens of ground beetles were selected and measured individually for six traits: elytra length and width, pronotum length and width, head length and distance between eyes, Fig. 2.

Object

The ground beetle *Carabus odoratus barguzinicus* Shil., 1996 served as a model species for morphometric measurements. The habitat of *C. odoratus barguzinicus* is limited to the Barguzin Ridge. *C. odoratus* is a dominant species (17.3% from total ground beetle's assemblages), it belongs to the group of walking epigeobionts, the class of zoophages, brachiopteric, with a two-year breeding cycle. It is represented in all plots of the altitudinal belt series (Ananina, 2015). Fig. 2.

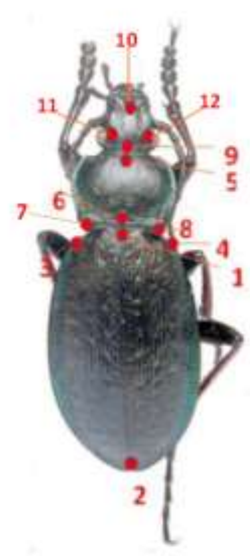

Figure 2. Scheme of measurement of *C. odoratus* traits, numbers indicate the terminal ends of the measurements (red color).

Legend: 1-2 – length of elytra (distance along the seam from the middle of the edge to the top); 3-4 – the width of the elytra (the distance between the shoulder angles of the left and right elytra); 5-6 – length of pronotum (distance along the midline from base to apex); 7-8 – width of the pronotum (width of the base); 9-10 – head length (distance from neck to upper lip); 11-12 – the distance between the eyes.

Morphometric analysis

Morphometric measurements were carried out under an MBS-9 binocular microscope at a magnification of 1x8.In the study area, the length of *C. odoratus* varies from 12.8 mm to 24.8 mm. Visually the largest individuals were found in the aspen cedar forest of the low-mountain vegetation belt, in the vicinity of the thermal spring in the valley river Big. The smallest specimens of ground beetles were found in the subalpine belt in the valley of Davshe river, in the lichen tundra. The sex of the beetles was distinguished by the width of the segments on the front legs; in males, the segments are more expanded. After determining the sex with an eyepiece micrometer, 6 morphometric features of the body organs were measured in each beetle: the length and width of the elytra, pronotum (pronotum), and head, fig.2.

Statistical analysis

All statistical analyzes of morphometric data were carried out using the R system (R Development Team…2021). First, we formed a data set, coding each individual for the biotope where it was selected. Next, we used linear models to reveal the effects of biotope on trait variability. For example, a model that estimated elytra length variability was written using the R syntax: **** Elytra. Length~fSex/(fHabitat), where fSex is a factor representing sex, etc. Analysis of Variance (ANOVA) of models was used to test the significance of effects. We assessed the interaction effects of environmental factors on each trait, confidence intervals (using Student's t-tests) and residual statistics (errors). The results were presented as estimated effects, and their confidence intervals were used to present the results in the form of figures. Interaction effects were compared to baseline (reference) (95% confidence level and normal approximation used). Apart from the confidence intervals for the main gender effects, some other variables were also shown.

3. RESULTS AND DISCUSSION

At the figures below all parameters are given compared with the baseline. Usually, it is taken at the discretion of the researcher. We took beetles parameters in bilberry cedar forest on the coast. Elytra length was significantly smaller in males than in females in all studied biotopes (sexual size dimorphism). But the response to habitat type did not differ in both sexes (Fig. 3, 4).

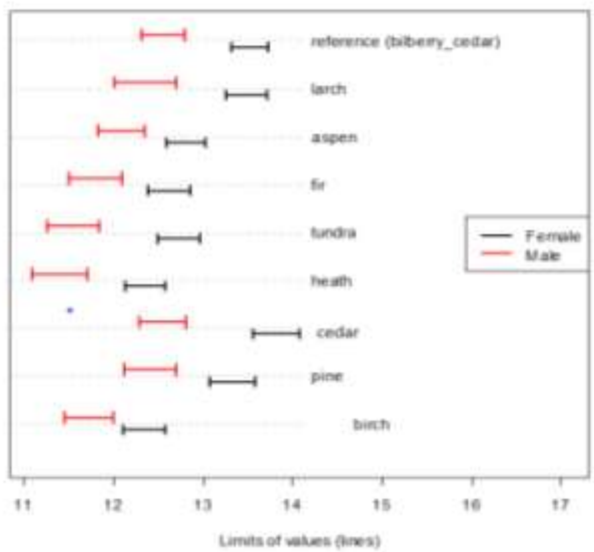

Figure 3. Elytra length variation in different habitats in *C. odoratus.* Herein and after 95% confidence intervals are given

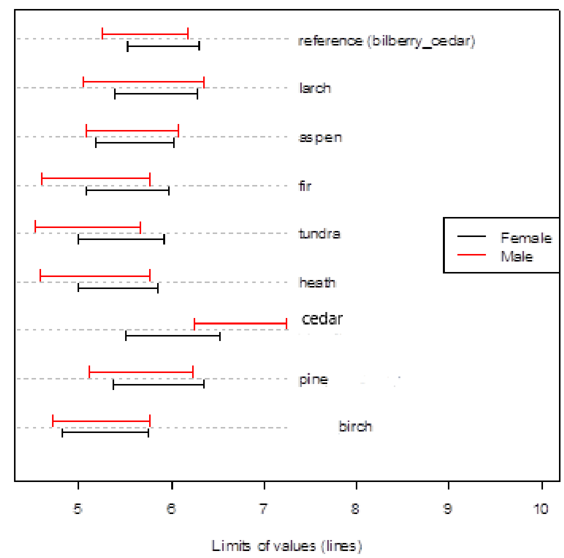

Figure 5. Elytra width variation in different habitats in *C. odoratus.*

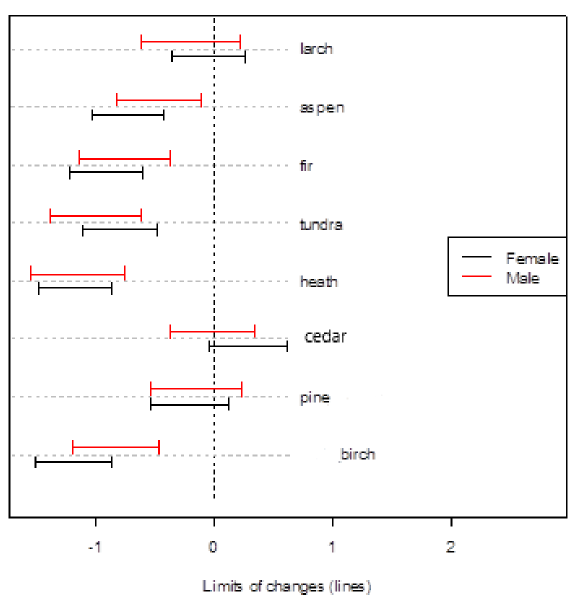

Figure 4. Comparative visualization of elytra length variation in different habitats in *C. odoratus*. Vertical dotted line denotes beetle's elytra length value in bilberry cedar.

Elytra width values did not differ among males and females in studied biotopes (Fig. 5). And that trait reacted to biotopes characters similarly in all studied cases (excluding males in cedar) (Fig (6).

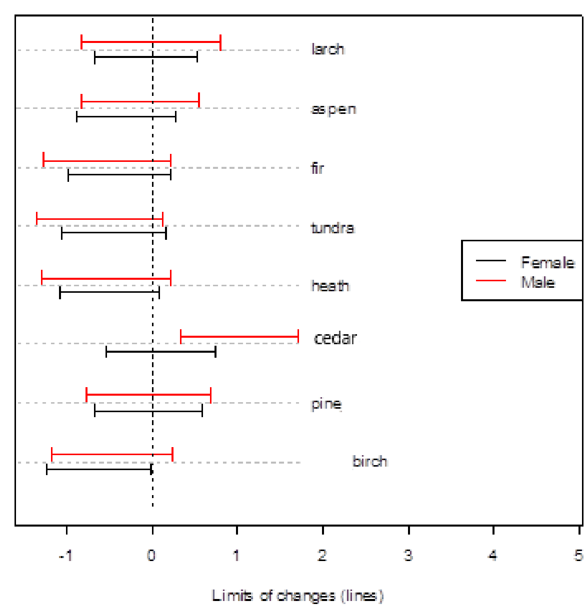

Figure 6. Comparative visualization of elytra width variation in different habitats in *C. odoratus*. Vertical dotted line denotes beetle's elytra width value in bilberry cedar.

Pronotum length variation was similar with elytra length one: there were significant shifts toward smaller ones in beetles dwelling in aspen, fir, tundra, heath and birch (Fig. 7, 8).

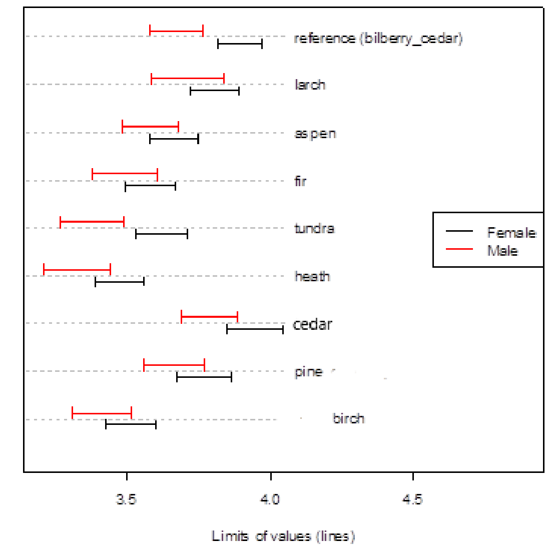

Figure 7. Pronotum length variation in different habitats in *C. odoratus.*

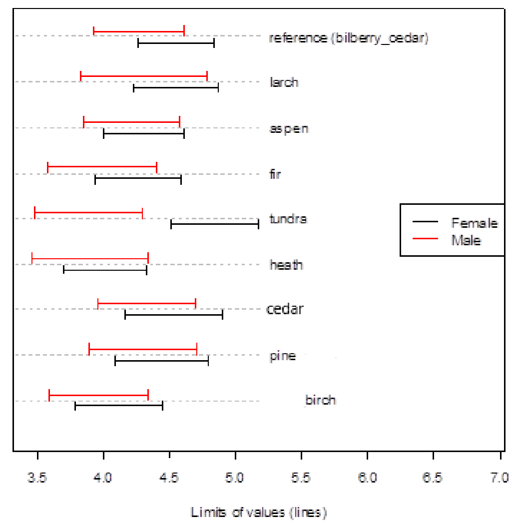

Figure 9. Pronotum width variation in different habitats in *C. odoratus.*

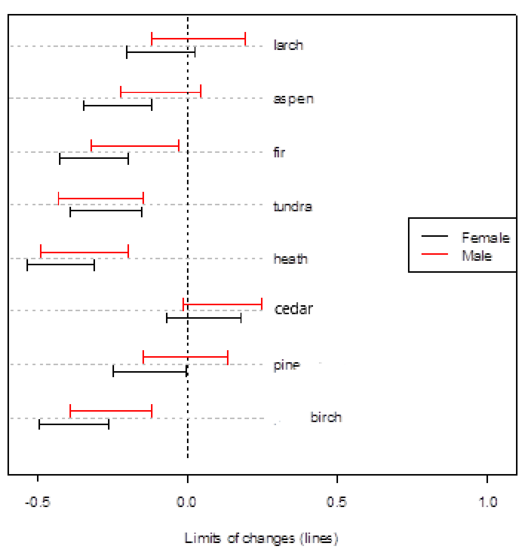

Figure 8. Comparative visualization of pronotum length variation in different habitats in *C. odoratus*. Vertical dotted line denotes beetles pronotum length value in bilberry cedar.

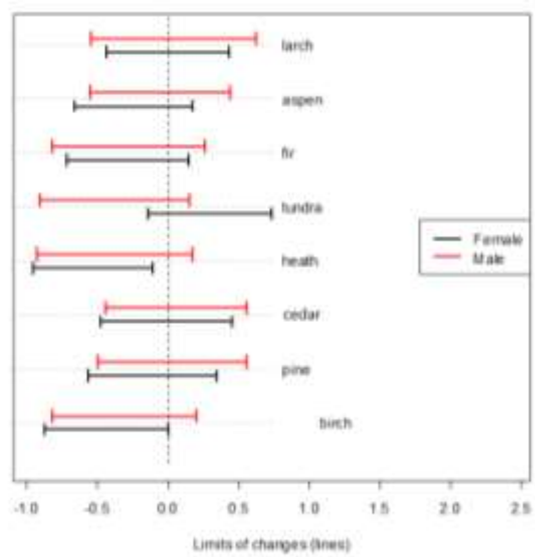

Figure 10. Comparative visualization of pronotum width variation in different habitats in *C. odoratus*. Vertical dotted line denotes beetles pronotum width value in bilberry cedar.

Pronotum width (like elytra width) did not demonstrate any differences between different habitats (Fig. 9, 10).

Head length demonstrated the most striking variation (Fig. 11, 12). It was significantly smaller in fir and heather beetles, but nearly equal to bilberry beetles in tundra and in cedar the beetles had even longer head.

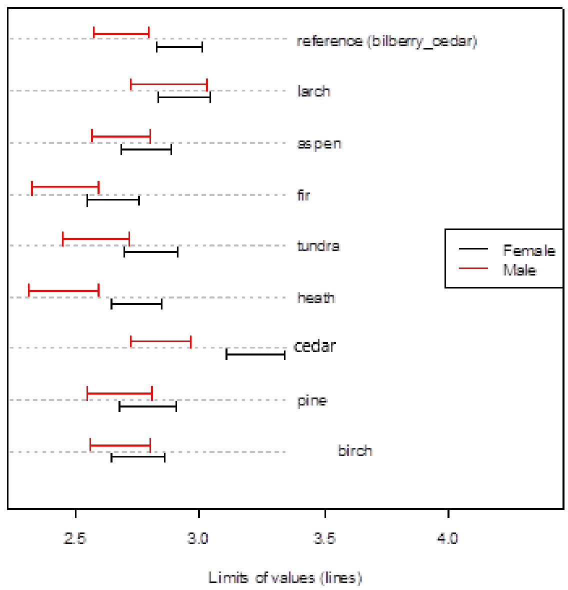

Figure 11. Head length variation in different habitats in *C. odoratus.*

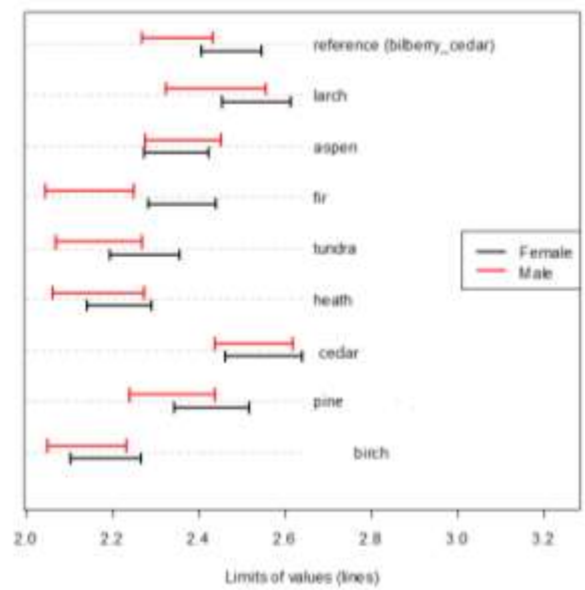

Figure 13. Between-eyes distance variation in different habitats in *C. odoratus.*

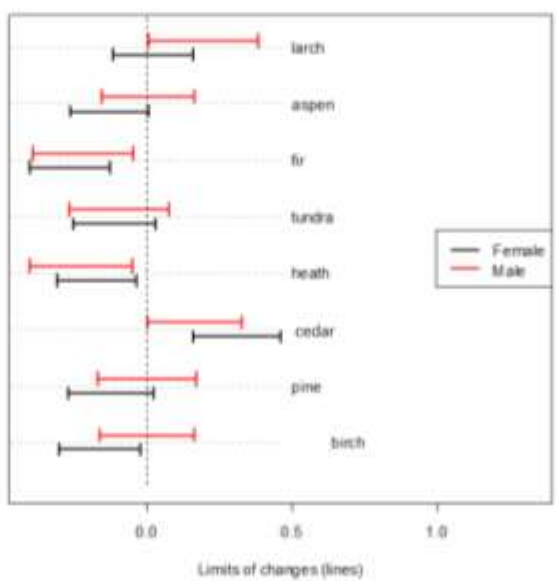

Figure 12. Comparative visualization of head length variation in different habitats in *C. odoratus*. Vertical dotted line denotes beetles head length value in bilberry cedar.

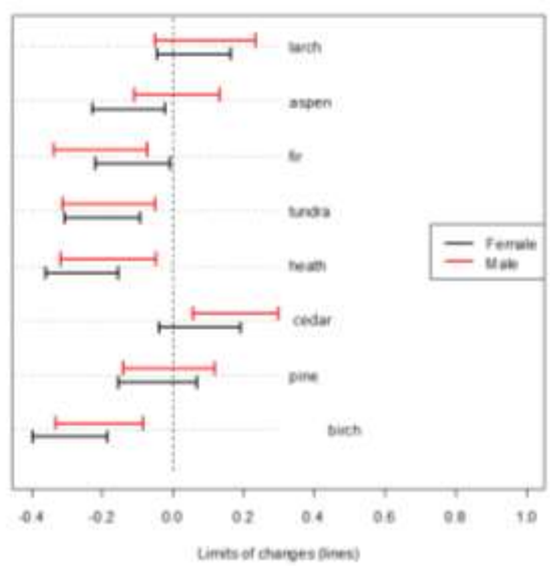

Figure 14. Comparative visualization of between-eyes variation in different habitats in *C. odoratus*. Vertical dotted line denotes beetles between-eyes distance value in bilberry cedar.

Variation in between-eye distance was analogous to elytra and pronotum length variation: it was significantly shorter in fir, tundra, heath and birch (Fig. 13, 14).

The responses of males and females (deviation from base line at the Fig. Fig. 4, 6, 8, 10, 12, 14) were similar in all analyzed traits. So, we did not record sexual size dimorphism in the biotopes situated at high altitudes.

Ground beetles are mainly predators and it seems that vegetation at the habiting biotope affects their presence or some traits in a very low degree. But it is not profoundly true. Ground beetle *Carabus granulatus* size decreased significantly when habiting in linden forest if compared with elm and oak ones and meadows as well (Sukhodolskaya, 2014). But modeling environmental factors impact on *Carabus aeruginosus* body size variation showed that biotopes characters did not affect beetles' size unlike the region of sampling and anthropogenic impact (Sukhodolskaya & Eremeeva, 2013). In rural habitats, sown with agricultural crops, the only males body size decreased leading to the pronounced sexual size dimorphism in rural populations of *Poecilus cupreus* (Sukhodolskaya & Saveliev, 2016).

In our study as we expected biotope characters affected beetles size variation. In forested biotopes (cedar, larch, pine) beetles' elytra and pronotum length were significantly longer than in open ones (tundra, heath, park birch). In this relation two aspects seemed to be expected too. For the first, open habitats in our investigation were situated practically always in high mountains. Climatic factors are specific there and the latter do not promote beetles size increase. In relation to studied species – *C. odoratus* – it was comprehensively shown when investigating beetles size variation in altitude gradient (Ananina et al. 2020) all traits value monotonically decreased towards high elevations. The length parameters did that in greater extent, than width ones. The data on the size of beetles in forested biotopes in middle mountains also speak in favor of altitude effect. Beetles in middle mountain aspen and fir were significantly smaller than in coastal cedar.

Undoubtedly observed regularities are explained by the features of microclimate at the studied plots. Humidity, temperatures above soil surface and at different depth, precipitation level, snowpack – is incomplete list of factors affecting larva growth and then beetles imagoes size. The first steps in revision of climatic factors impact on beetles' size were done. In *C. odoratus* positive correlation was found between soil temperature at the 5 and 10 cm depth, minimal soil temperatures and beetles' size (Ananina et al., 2020). Humidity and other water-including factors (precipitation, snow cover thickness, snowpack) affected beetles' size in the negative: the higher was the factors value the smaller were beetles. Species-specific characters should be taken into account too. In another dominant species of Barguzin Ridge – *Pterostuchus montanus* – relationships between climatic variables and body size variation were just the opposite (Sukhodolskaya et al., 2022).

4. CONCLUSION

Trait-based investigations are gaining popularity. Along with community related traits (species richness, functional groups etc.) population-related traits are of great importance because precisely they are the points of native selection. Ground beetles body size variation in different habitats of the mountain ridge described in our study highlights relationships between altitude, vegetation cover, microclimatic factors and population dynamics. It will therefore provide important insights into how future vegetation changes could affect population-level processes in the mountain ecosystems.

5. CONFLICT OF INTEREST

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

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