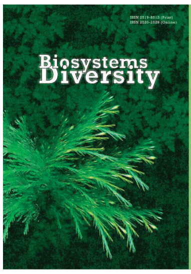

Biosystems Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers., 2019, 27(1), 21–25
doi: 10.15421/011903

Morphological variability of *Bembidion aspericolle* (Coleoptera, Carabidae) populations in conditions of anthropogenic impact

V. O. Komlyk, V. V. Brygadyrenko

Oles Honchar Dnipro National University, Dnipro, Ukraine

Article info

Received 04.02.2019
Received in revised form 12.03.2019
Accepted 16.03.2019

Oles Honchar Dnipro National University, Gagarin ave., 72, Dnipro, 49010, Ukraine. Tel.: +38-066-21-21-708. E-mail: slynko@ua.fm, brigad@ua.fm

Komlyk, V. O., & Brygadyrenko, V. V. (2019). Morphological variability of Bembidion aspericolle (Coleoptera, Carabidae) populations in conditions of anthropogenic impact. Biosystems Diversity, 27(1), 21–25. doi:10.15421/011903

Bembidion (*Talanes*) *aspericolle* (Germar, 1829) is a Western Palearctic species which lives on the shores of the Atlantic Ocean, the Mediterranean, Black and Caspian Seas and saline inland habitats from Central Europe to Central Asia. Anthropogenic impact is one of the most important environmental factors affecting the morphological variability of ground beetles. The objective of our research is assessment of the morphological variability of this species in three ecosystems differing by intensity of anthropogenic impact. 13 linear characteristics, one angular characteristic, density of pores on the prothorax and elytra, contrast of spots on the beetles' elytra were measured, and 6 morphometric indices were calculated. The mean value of body length in females is more than in males in the studied populations. In the ecosystem with high anthropogenic pressure, female body length is shorter by 3.7% and elytra length is shorter by 6.0% than in females in the ecosystem with low anthropogenic impact. Differences between populations in the body length of males are not significant. In the ecosystem with high anthropogenic transformation, sexual dimorphism is observed only on head and prothorax width. The ratio of maximum width of elytra to maximum prothorax width decreases significantly with increasing anthropogenic load. The impact of anthropogenic factors on the ecosystem produces significant changes in elytra length and head width of *B. aspericolle* and in four of the six morphometric indices. It is reasonable to use these morphometric characteristics of *B. aspericolle* adults in bioindication. The complex of anthropogenic factors does not have a significant impact on the value of anterior and posterior angles of prothorax, density of prothorax and elytra puncturing and contrast of the light spots at the top of the elytra. The sex of the specimen influences all linear characteristics. The absence of significant differences in morphometric indices between males and females shows that the body proportions of the beetles remain unchanged and only linear dimensions vary. Research on the morphological variability of *B. aspericolle* is important for understanding microevolutionary processes in populations of beetles under anthropogenically induced changes in the environment.

Keywords: population variability; sexual dimorphism; morphometrics; riparian beetles.

Introduction

Selye (1976) defined stress as a set of reactions of an organism which are caused by any strong, super-strong and extreme effects and are accompanied by restructuring of the organism adaptive systems. There are three stages of response of an organism (Selye, 1982) to the stress effect, the so-called «Selye triad»: 1) stage of alarm – there is a mobilization of adaptive processes in the organism; 2) stage of resistance – increased resistance of the organism to stress is established; 3) stage of exhaustion – if the stress effect is too strong and prolonged, the adaptation mechanisms of the organism may be exhausted and resistance will decrease. The duration and characteristics of the course of each stage depend on many factors: the type of organism, its physiological state and also on the strength of the stress factor impact. The work of the hypothalamic-pituitary-adrenocortical system provides formation of stress reactions in vertebrates (Eremina & Gruntenko, 2017). For a long time, the absence of the hypothalamic-pituitary-adrenocortical system in insects was taken as proof of the absence of a stress reaction characteristic of warm-blooded animals. However the presence of stress reactions in insects, in which various hormones take part, was later proved (Rauschenbach et al., 2003). Invertebrate animals are convenient objects for studying the basic mechanisms of stress reactions (Mirth et al., 2014; Zakharenko et al., 2014). There are many publications on the mechanisms of stress reactions at the larval stage (state of diapause, delay of metamorphosis, mutations) (Sukhanova et al., 1997) and imago stage (Rauschenbach et al., 2000; Hanna et al., 2015).

The stress response of organisms was formed in the process of evolution and it is an important part of a complex, holistic adaptation mechanism (Sarup et al., 2014; Eremina & Gruntenko, 2017). Insects accumulate (summarize) the effects of factors over time (Hirashima et al., 2000; Moskalev et al., 2015; Zhuravel et al., 2016). Morphological variability is one of the manifestations of such adaptations to changes in environmental conditions. The form and linear dimensions of the insect body are largely related to the adaptation of the organism to the living conditions at the larval and imago stage (Arndt & Putchkov, 1997; Lagisz, 2008). Morphological changes in the populations of the litter invertebrate groups make it possible to assess the state of the environment (Sukhodolskaya & Saveliev, 2014, 2016). Morphological variability is assessed by measuring linear parameters and morphological indices.

Riparian ecosystems are the separation line of land and water and are characterized by the complexity and instability of biotic and abiotic conditions. Here living organisms are under the influence of a large number of factors, the results of which impact on the morphological variability of populations (Tseng & Pari, 2019). Ground beetles (Coleotera, Carabidae) are sensitive to the effects of abiotic and biotic factors, they quickly respond to environmental changes (Brygadyrenko, 2016). Therefore, this group of beetles is often used as bioindicators (Grumo & Lovei, 2016). Earlier we studied the morphological variability of two species of the *Bembidion* genus which are widespread in most riparian ecosystems of Eurasia: *B. varium* (Olivier, 1795) and *B. articulatum* (Panzer, 1796) (Slin'ko et al., 2008; Brygadyrenko & Slynko, 2015). One more species of this genus *B. aspericolle* (Germar, 1829) is considered in this article.

B. aspericolle is a Western Palearctic species (Sigida, 2009), living on the shores of the Atlantic Ocean, the Mediterranean, Black and Caspian Seas, and saline inland habitats from Central Europe to Central Asia (Hurka, 1996). It is distributed in Austria, Croatia, France, Germany, Georgia, Greece, Hungary, Italy, Kyrgyzstan, Kazakhstan, Moldavia, Romania, Russia (south part of the Russian plains; south part of West Siberia), Slovenia, Spain, Tajikistan, Turkmenistan, Ukraine, Uzbekistan (Ratti, 1983; Nitzu, 2003; Makarov & Matalin, 2009; Matalin & Makarov, 2011). It has not yet been found in the Czech Republic and Slovakia (Hurka, 1996). *B. aspericolle* is littoral halophile (Trost, 2003; Müller-Motzfeld, 2007) which is part of saline biocenoses (Trost, 2006; Tilly, 2012; Michailov, 2013). In Ukraine, the species has been recorded in almost all the steppe zone (Putchkov, 2011, 2012). It is found along the shores of salt lakes, estuaries and seas. *B. aspericolle* is a hygrophil which is closely associated with sea club-rush (*Bolboshoenus maritimus* (L.) Palla) (Puchkov & Slynko, 2011). This beetle is a surface-litter stratobiont (Abdurakhmanov et al., 2010; Nakhibasheva et al., 2011). It is mainly found in summer and is a zoophage (Putchkov & Brygadyrenko, 2018). The morphological variability of *B. aspericolle* has not been studied so far. The main objective of this article is assessment of interpopulation and sexual variability of *B. aspericolle* in three ecosystems which differ in the level of anthropogenic impact.

Material and methods

Specimens of *B. aspericolle* were collected manually using an aspirator and by soil traps. Beetles were killed by freezing during 24 hours in a refrigerating chamber and then laid onto cotton mats. Each beetle was assigned a serial number including the number of the ecosystem it was collected from and its sex (male, female). Photographs of the collected insects were taken using a binocular MBS-10 and digital camera of 5 megapixel resolution. Morphometric measurements were made by digital photos in the TpsDig 2.17 program (F. James Rohlf, State University of New York at Stony Brook, USA, 2004).

The research was carried in three ecosystems in Novomoskovsk district of Dnipropetrovsk region, Ukraine. The ecosystems differed (Table 1) in type of anthropogenic impact, mechanical composition of the soil, salt content in the soil solution. The pH of the aqueous extract from all areas examined was slightly alkaline (from 7.65 to 8.55). Methodology of determination of soil mineralization and pH was reviewed in our previous article (Brygadyrenko & Slynko, 2015).

Table 1
Brief characteristic of ecosystems (Dnipropetrovsk region, Ukraine) where *B. aspericolle* was collected

Degree of anthropogenic impact	Administrative district	Ecosystem coordinates	Mechanical composition of soil	Salt content in soil solution, g/l	pH of soil solution	Dominating plant species (density of herb layer), composition of litter	Prevailing type of anthropogenic impact
Low	Novomoskovsk	48°38′55′′N 35°21′03′′E	loam	4.84	8.55	no grass stand and litter	domestic wastes
Medium	Novomoskovsk	48°38′16′′N 35°18′47′′E	loam	4.50	8.16	no grass stand and litter	domestic wastes, watering of livestock
High	Novomoskovsk	48°36′41′′N 35°19′13′′E	sandy loam	3.63	7.65	no grass stand and litter	domestic wastes, watering of livestock, recreational loading

For investigation of the morphological variability of *B. aspericolle* specimens, 13 linear characteristics, 1 angular characteristic, density of pores on the prothorax, density of pores on the elytra, contrast of the light spots of the left and right elytra were measured. The following linear parameters were evaluated: length of body (Lb), head (Lc), prothorax (Lp), elytra (Le), width of head with eyes (Sc), width of prothorax between front angles (Sp1) and back angles (Sp2), maximum width of prothorax (Spm), maximum width of elytra (Se), distance between setae on the left elytra (L2l), distance between setae on the right elytra (L2r), distance from the base of the left elytra to the first setae (L1l), distance from the base of the right elytra to the first setae (L1r). Linear characteristics were measured with an accuracy of ±1 pixel (0.96 μm) (Brygadyrenko & Fedorchenko, 2008; Brygadyrenko & Korolev, 2015).

The back angles of the prothorax were determined on the left (B1) and right (B2) parts of the body. For the further calculations, their arithmetic mean value was used (B). Accuracy of photographic measurement of angles was equal to ±0.1º. Density of prothorax puncturing (P1) was assessed from photographs by counting the quantity of pores on the area of 150 • 150 pixels. Density of elytra puncturing (P2) was assessed from photographs by counting the quantity of pores on the area of 234 • 234 pixels between the back edge of the scutellar groove and the first groove of the elytra. The contrast of the light spots at the top of the left (Kl) and right elytra (Kr) was determined in a gradient from 1 (clear) to 4 (poorly discernible), and their arithmetic mean value was calculated for each beetle.

Six morphometric indices were calculated: ratio of arithmetic mean value of the width of head, prothorax and elytra to body length ((Sc+Sp+Se)/3Lb), ratio of prothorax length to its maximum width (Lp/Spm), ratio of elytra length to prothorax length (Le/Lp), ratio of maximum width of elytra to maximum prothorax width (Se/Spm), ratio of maximum prothorax width to its width at the back edge (Spm/Sp2), and ratio of elytra length to their width (Le/Se) (Brygadyrenko & Reshetniak, 2014; Brygadyrenko & Slynko, 2015).

The results were processed by standard methods with the calculation of x – mean value, SD – standard deviation. Significance of variations between samples was assessed by one-way ANOVA. For multiple comparisons of samples, the Tukey test was used, where the differences were considered significant at $P < 0.05$ (with taking into account the Bonferroni correction). Anthropogenic impact was evaluated by MANOVA using software Statistica (version 8, StatSoft, USA).

Results

In the three studied populations, the mean value of body length in females is greater than in males (Table 2). Sexual dimorphism of body length is most pronounced in the ecosystems with low and medium anthropogenic impact, where females are larger than males by 7.16% and 7.03% respectively. In the ecosystem with high anthropogenic impact, females are larger than males by 3.57%. Interpopulation differences in body length (Lb) in males are not significant (Table 2). There are no differences in head length (Lc) between the beetles in the sample. Significant differences in prothorax length (Lp) between males and females are typical for all studied populations. In the ecosystems with low and medium anthropogenic impact, females have longer elytra than males (by 8.53% and 6.59% respectively). Differences in Le between males and females are not significant (3.45%) in the ecosystem with high anthropogenic impact. Interpopulation differences in elytra length are significant in females, and no significant differences are revealed in males. In the studied populations, females have a wider head (Sc) (the differences are 3.75–12.86%) and prothorax (Sp1, Sp2, Spm) compared with males. The interpopulation variability of these linear parameters is significant in males, and no significant differences are revealed in females. However, regular changes in these linear parameters are not detected with an increase in anthropogenic effect. Males of the ecosystem with medium anthropogenic impact are the smallest of the studied beetles in length (Lp) and width (Sp1, Sp2, Spm) of prothorax and head width (Sc).

There are no differences in elytra width (Se), angles of prothorax (B1, B2, B), density of prothorax and elytra puncturing (P1, P2), contrast of the light spots at the top of elytra (Kl, Kr, K), distance between setae on elytra (L2l, L2r), distance from the base of the left elytra to the first setae (L1l), not only between males and females but also between populations. Only males of the ecosystem with medium anthropogenic impact differ in distance from the base of the right elytra to the first setae (L1r) from all investigated specimens.

According to the results of ANOVA, with increase in anthropogenic pressure, differences in body proportions are observed in females (Sc+Sp+Se)/3Lb, Le/Lp, Se/Spm, and Le/Se and in males Se/Spm. Morphometric indices Lp/Spm and Spm/Sp2 do not significantly differ (Table 3). Also differences in Lp/Spm and Spm/Sp2 are not found between males and females.

Table 2
Variability of morphometric characteristics of *B. aspericolle* body (x ± SD, n = 15) in the ecosystems under anthropogenic impact

Characteristic	Females			Males		
	low anthropogenic impact	medium anthropogenic impact	high anthropogenic impact	low anthropogenic impact	medium anthropogenic impact	high anthropogenic impact
Lb	2445 ± 104^{a}	2376 ± 122^{ab}	2354 ± 122^{b}	2270 ± 118^{b}	2209 ± 127^{b}	2270 ± 122^{b}
Lc	395 ± 29^{a}	407 ± 22^{a}	388 ± 25^{a}	374 ± 35^{a}	370 ± 13^{a}	384 ± 23^{a}
Lp	537 ± 32^{a}	527 ± 27^{ab}	543 ± 32^{a}	511 ± 29^{b}	493 ± 13^{bc}	512 ± 33^{b}
Le	1513 ± 83^{a}	1441 ± 33^{ab}	1422 ± 102^{b}	1384 ± 89^{b}	1346 ± 124^{b}	1373 ± 102^{b}
Sc	585 ± 25^{a}	583 ± 13^{a}	586 ± 24^{a}	553 ± 30^{b}	508 ± 35^{bc}	564 ± 26^{ab}
Sp1	508 ± 29^{a}	502 ± 28^{a}	505 ± 24^{a}	478 ± 27^{b}	457 ± 14^{bc}	486 ± 22^{ab}
Sp2	444 ± 24^{a}	425 ± 27^{a}	434 ± 26^{a}	416 ± 22^{ab}	387 ± 21^{b}	417 ± 31^{ab}
Spm	634 ± 31^{a}	630 ± 20^{a}	634 ± 29^{a}	599 ± 26^{ab}	572 ± 15^{b}	608 ± 35^{ab}
Se	996 ± 47^{a}	985 ± 36^{a}	970 ± 46^{a}	931 ± 42^{a}	882 ± 12^{b}	930 ± 62^{a}
B1	103.0 ± 6.3^{a}	107.0 ± 9.3^{a}	103.1 ± 5.9^{a}	101.3 ± 5.3^{a}	107.0 ± 4.9^{a}	104.5 ± 5.4^{a}
B2	104.9 ± 6.2^{a}	107.7 ± 7.6^{a}	105.1 ± 6.0^{a}	102.8 ± 4.9^{a}	104.2 ± 5.5^{a}	105.2 ± 6.4^{a}
B	103.9 ± 5.7^{a}	107.3 ± 8.4^{a}	104.1 ± 5.6^{a}	102.1 ± 4.6^{a}	105.6 ± 5.2^{a}	104.9 ± 5.7^{a}
L2l	543 ± 45^{a}	528 ± 25^{a}	528 ± 49^{a}	515 ± 26^{a}	511 ± 20^{a}	530 ± 35^{a}
L1l	417 ± 34^{a}	401 ± 22^{a}	416 ± 34^{a}	387 ± 47^{a}	382 ± 32^{a}	396 ± 32^{a}
L2r	545 ± 43^{a}	547 ± 33^{a}	523 ± 50^{a}	514 ± 33^{a}	497 ± 34^{a}	533 ± 39^{a}
L1r	423 ± 36^{a}	410 ± 33^{a}	428 ± 38^{a}	409 ± 33^{a}	384 ± 16^{b}	398 ± 34^{ab}
P1	16.3 ± 2.2^{a}	17.1 ± 1.9^{a}	16.6 ± 2.0^{a}	16.9 ± 2.3^{a}	17.7 ± 1.6^{a}	16.1 ± 1.9^{a}
P2	20.4 ± 1.7^{a}	21.4 ± 1.4^{a}	19.8 ± 2.0^{a}	21.3 ± 2.8^{a}	21.0 ± 1.7^{a}	21.5 ± 2.1^{a}
Kl	2.26 ± 0.63^{a}	2.57 ± 0.53^{a}	2.47 ± 0.57^{a}	2.48 ± 0.59^{a}	2.89 ± 0.91^{a}	2.79 ± 0.80^{a}
Kr	2.68 ± 0.65^{a}	2.43 ± 0.53^{a}	2.66 ± 0.70^{a}	3.04 ± 0.71^{a}	3.13 ± 0.58^{a}	2.86 ± 0.86^{a}
K	2.47 ± 0.52^{a}	2.50 ± 0.50^{a}	2.56 ± 0.55^{a}	2.76 ± 0.56^{a}	3.17 ± 0.76^{a}	2.82 ± 0.64^{a}

Note: names of characteristics are given in section Material and methods; the same letters designate ecosystems for the males and females, differences between which are insignificant according to results of the Tukey test ($P < 0.05$) with Bonferroni correction.

Table 3
Variability of 6 morphometric indices of *B. aspericolle* body (x ± SD, n = 15) in ecosystems under anthropogenic impact

Characteristic	Females			Males		
	low anthropogenic impact	medium anthropogenic impact	high anthropogenic impact	low anthropogenic impact	medium anthropogenic impact	high anthropogenic impact
(Sc+Sp+Se)/3Lb	0.302 ± 0.011^{a}	0.308 ± 0.004^{ab}	0.311 ± 0.012^{b}	0.306 ± 0.008^{ab}	0.295 ± 0.021^{b}	0.309 ± 0.011^{ab}
Lp/Spm	0.848 ± 0.053^{a}	0.836 ± 0.026^{a}	0.857 ± 0.035^{a}	0.854 ± 0.039^{a}	0.860 ± 0.016^{a}	0.843 ± 0.028^{a}
Le/Lp	2.821 ± 0.166^{a}	2.737 ± 0.118^{ab}	2.621 ± 0.161^{b}	2.711 ± 0.163^{b}	2.731 ± 0.272^{ab}	2.682 ± 0.154^{b}
Se/Spm	1.571 ± 0.040^{a}	1.564 ± 0.063^{ab}	1.531 ± 0.032^{b}	1.555 ± 0.037^{ab}	1.542 ± 0.027^{ab}	1.529 ± 0.030^{b}
Spm/Sp2	1.432 ± 0.048^{a}	1.485 ± 0.079^{a}	1.463 ± 0.055^{a}	1.441 ± 0.047^{a}	1.480 ± 0.075^{a}	1.461 ± 0.048^{a}
Le/Se	1.519 ± 0.066^{a}	1.463 ± 0.032^{b}	1.466 ± 0.083^{b}	1.486 ± 0.050^{b}	1.527 ± 0.153^{a}	1.478 ± 0.082^{ab}

Note: see Table 2.

Following the result of the Multivariate Analysis of Variance (MANOVA) for the morphometric characteristics of the studied *B. aspericolle* populations, no significant influence of anthropogenic factors (Table 4) on body length (Lb), prothorax length (Lp), prothorax width between front angles (Sp1) and back angles (Sp2), maximum prothorax width (Spm), elytra width (Se), distance between setae on the left (L2l) and right elytra (L2r), distance from the base of the elytra to the first setae (L1l, L1r) is revealed. Intensity of anthropogenic impact has an influence on elytra length (Le) and head width (Sc). These morphometric characteristics of *B. aspericolle* imagoes could be used in bioindication research in the future. Significant differences between males and females are observed on all linear parameters. Angles of the prothorax (B1, B2, B), density of prothorax and elytra puncturing (P1, P2), contrast of the light spots at the top of the elytra (Kr, Kl, K) do not show significant differences between ecosystems under different anthropogenic effect and between males and females. The only exception is the contrast in the light spots at the top of the right elytra (Kr), which is different in males and females.

According to the MANOVA results (Table 5) males of *B. aspericolle* do not differ from females in the six studied morphometric indexes. Intensity of anthropogenic pressure has an influence on four of the six studied body proportions: ratio of arithmetic mean value of the width of head, prothorax and elytra to body length ((Sc+Sp+Se)/3L), ratio of elytra length to prothorax length (Le/Lp), ratio of maximum width of elytra to maximum prothorax width (Se/Spm), ratio of maximum prothorax width to its width at the back edge (Spm/Sp2). These morphometric indexes could be also used in bioindication research.

Discussion

The body size of invertebrate animals is controlled by environmental factors (Grumo & Lovei, 2016; Tseng & Pari, 2019). Anthropogenic impact is one of the most important factors which influence the morphological variability of beetles. Research on morphometric variability of ground beetles under the influence of anthropogenic factors is intensively developing in our time (Weller & Ganzhorn, 2003; Lagisz, 2008; Sukhodolskaya & Saveliev, 2014). The response of different Carabidae species to anthropogenic pressure is diverse. The results of research are contradictory: in some species body size decreases, in others it increases or does not change with increase in anthropogenic impact (Sukhodolskaya, 2013).

Data on morphometric characteristics of the studied species is limited to general information about body length of *B. aspericolle*: Hurka (1996) – 2.0–2.5 mm, Neri (2011) – 2.0–2.8 mm. According to our data, mean body length values vary in the range of 2.35–2.44 mm in females and 2.21–2.27 mm in males. Changes in linear body dimensions are observed in females with increase in anthropogenic impact. This pattern is not followed for males. Following the result of ANOVA, in the ecosystem with high anthropogenic impact females are characterrized by decrease in body length by 3.72% and elytra length by 6.02% compared with females in the ecosystem with low anthropogenic impact. Similar data were obtained by Lagisz (2008) for *Pterostichus oblongopunctatus* (Fabricius, 1787) and by Sukhodolskaya (2013) for *Carabus aeruginosus* (Fischer von Waldheim, 1823). In the ecosystems with low and medium anthropogenic impact, sexual dimorphism is observed in body length, head width, prothorax length and width, elytra length. In the ecosystem with high anthropogenic impact, sexual dimorphism is observed only on head and prothorax width as in *B. varium* (Olivier, 1795) (Slin'ko et al., 2008). There is a significant decrease in absolute value of ratio of maximum width of elytra to maximum prothorax width (Se/Spm) at increase in anthropogenic transformation.

Table 4
MANOVA results for morphometric characteristics of the studied populations of *B. aspericolle*

Characteristic	Factor	*F*	*P*
Lb	Anthropogenic impact	2.43	0.093
	Sex	21.39	<0.001
	Anthropogenic impact * Sex	1.87	0.159
Lc	Anthropogenic impact	0.07	0.928
	Sex	7.25	0.008
	Anthropogenic impact * Sex	1.66	0.194
Lp	Anthropogenic impact	1.11	0.332
	Sex	13.15	<0.001
	Anthropogenic impact * Sex	0.10	0.901
Le	Anthropogenic impact	3.88	0.024
	Sex	13.43	<0.001
	Anthropogenic impact * Sex	2.07	0.311
Sc	Anthropogenic impact	6.36	0.003
	Sex	44.15	<0.001
	Anthropogenic impact * Sex	5.18	0.007
Sp1	Anthropogenic impact	1.25	0.290
	Sex	19.79	<0.001
	Anthropogenic impact * Sex	1.07	0.348
Sp2	Anthropogenic impact	3.05	0.052
	Sex	16.03	<0.001
	Anthropogenic impact * Sex	0.82	0.443
Spm	Anthropogenic impact	1.6	0.206
	Sex	25.54	<0.001
	Anthropogenic impact * Sex	1.12	0.329
Se	Anthropogenic impact	1.92	0.151
	Sex	29.99	<0.001
	Anthropogenic impact * Sex	1.81	0.169
B1	Anthropogenic impact	2.65	0.075
	Sex	0.00	0.965
	Anthropogenic impact * Sex	0.69	0.502
B2	Anthropogenic impact	0.81	0.450
	Sex	1.30	0.256
	Anthropogenic impact * Sex	0.53	0.590
B	Anthropogenic impact	1.76	0.176
	Sex	0.39	0.532
	Anthropogenic impact * Sex	0.62	0.539
L2l	Anthropogenic impact	0.22	0.806
	Sex	1.80	0.183
	Anthropogenic impact * Sex	1.54	0.220
L1l	Anthropogenic impact	0.55	0.579
	Sex	5.34	0.022
	Anthropogenic impact * Sex	0.29	0.749
L2r	Anthropogenic impact	0.13	0.882
	Sex	4.23	0.042
	Anthropogenic impact * Sex	3.48	0.034
L1r	Anthropogenic impact	1.06	0.349
	Sex	6.02	0.016
	Anthropogenic impact * Sex	0.64	0.530
P1	Anthropogenic impact	0.96	0.388
	Sex	0.15	0.702
	Anthropogenic impact * Sex	0.82	0.442
P2	Anthropogenic impact	0.24	0.788
	Sex	1.53	0.219
	Anthropogenic impact * Sex	0.97	0.382
Kl	Anthropogenic impact	2.78	0.066
	Sex	3.55	0.062
	Anthropogenic impact * Sex	0.13	0.876
Kr	Anthropogenic impact	0.28	0.757
	Sex	6.74	0.011
	Anthropogenic impact * Sex	0.88	0.417
K	Anthropogenic impact	0.65	0.525
	Sex	7.32	0.008
	Anthropogenic impact * Sex	0.48	0.621

Note: names of characteristics are given in section Material and methods.

The MANOVA results show significant influence of anthropogenic factors on two of 13 linear parameters: head width and elytra length. Also four morphometric indices change significantly. In the future these morphometric characteristics of *B. aspericolle* imago could be used in bioindication studies. The sex of the specimen affects all linear characteristics. It can be supposed that absence of spatial heterogeneity of *B. aspericolle* populations is compensated by pronounced sexual dimorphism. A similar fact is observed for *B. articulatum*, which we studied earlier (Brygadyrenko & Fedorchenko, 2008; Brygadyrenko & Slynko, 2015). The absence of significant changes in morphometric indices between males and females suggests that the body proportions of *B. aspericolle* stay unchanged with a variation in linear dimensions. This phenomenon is typical of *B. varium* and *B. articulatum* (Slin'ko et al., 2008; Brygadyrenko & Slynko, 2015) and is not typical of many other species of ground beetles, in which females have longer and wider elytra than males (Brygadyrenko & Reshetniak, 2014).

Table 5
MANOVA results of morphometric indexes of studied populations of *B. aspericolle*

Characteristic	Factor	*F*	*P*
(Sc+Sp+Se)/3Lb	Anthropogenic impact	3.66	0.029
	Sex	1.61	0.207
	Anthropogenic impact * Sex	2.48	0.089
Lp/Sp2	Anthropogenic impact	0.01	0.989
	Sex	0.28	0.596
	Anthropogenic impact * Sex	1.17	0.314
Le/Lp	Anthropogenic impact	5.58	0.005
	Sex	0.18	0.674
	Anthropogenic impact * Sex	3.13	0.048
Se/Spm	Anthropogenic impact	8.72	<0.001
	Sex	1.75	0.189
	Anthropogenic impact * Sex	0.48	0.623
Spm/Sp2	Anthropogenic impact	4.30	0.016
	Sex	0.00	0.975
	Anthropogenic impact * Sex	0.17	0.840
Le/Se	Anthropogenic impact	2.06	0.133
	Sex	0.53	0.469
	Anthropogenic impact * Sex	2.21	0.115

Note: see Table 4.

The study of morphological variability is very important for understanding ecological processes in populations of beetles. Changes in the state of beetles are probably caused by entry of pollutants into their intestines and by changes in the number and activity of their parasites (Brygadyrenko & Reshetniak, 2016). It is possible to use both linear characteristics and indices for study of morphological variability of *B. aspericolle* under the influence of anthropogenic factors. Linear body sizes are more informative for identification of intrapopulational variability of *B. aspericolle* in anthropogenically transformed semi-aquatic ecosystems.

Conclusions

Particular attention should be paid to further study of the morphological variability of other semi-aquatic ground beetles under the influence of various environmental and anthropogenic factors. A significant amount of factual material on different species is required for such research. Research on the variations of linear characteristics and metric indices will provide an opportunity to identify the causes and mechanisms of species stabilization in natural and anthropogenically transformed ecosystems in the future.

References

Abdurakhmanov, G. M., Nakhibasheva, G. M., Klycheva, S. M., Magomedova, S. T., & Elderhanova, Z. M. (2010). Vidovoy sostav i geograficheskoe rasprostranenie zhuzhelits roda *Bembidion* Respubliki Dagestan [Species structure and geographical distribution of ground beetles of genus *Bembidion* of Daghestan Republic]. The South of Russia: Ecology, Development, 2, 56–61 (in Russian).

Arndt, E., & Putchkov, A. V. (1997). Phylogenetic investigation of Cicindelidae (Insecta: Coleoptera) using larval morphological characters. Zoologischer Anzeiger, 234(3–4), 231–241.

Brygadyrenko, V. V. (2016). Evaluation of ecological niches of abundant species of *Poecilus* and *Pterostichus* (Coleoptera: Carabidae) in forests of the steppe zone of Ukraine. Entomologica Fennica, 27(2), 81–100.

Brygadyrenko, V. V. (2016). Evaluation of ecological niches of abundant species of *Poecilus* and *Pterostichus* (Coleoptera: Carabidae) in forests of the steppe zone of Ukraine. Entomologica Fennica, 27(2), 81–100.

Brygadyrenko, V. V., & Fedorchenko, D. O. (2008). Morfologichna minlyvist' populjacii' *Carabus hungaricus scythes* (Coleoptera, Carabidae) v umovah ostrova Hortycja (Zaporiz'ka oblast') [Morphological variability of populations *Carabus hungaricus scythus* (Coleoptera, Carabidae) on the Khortitsa island (Zaporizhzhya province)]. Visnyk of Dnipropetrovsk University, Biology, Ecology, 16(1), 20–27.

Brygadyrenko, V. V., & Korolev, O. V. (2015). Morphological polymorphism in an urban population of *Pterostichus melanarius* (Illiger, 1798) (Coleoptera, Carabidae). Graellsia, 71(1), e025.

Brygadyrenko, V. V., & Reshetniak, D. Y. (2014). 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 Oecolica, 41, 109–133.

Brygadyrenko, V. V., & Reshetniak, D. Y. (2016). Morphometric variability of *Clitellocephalus ophoni* (Eugregarinida, Gregarinidae) in the intestines of *Harpalus rufipes* (Coleoptera, Carabidae). Archives of Biological Sciences, 68(3), 587–601.

Brygadyrenko, V. V., & Slynko, V. O. (2015). Morphological variability of *Bembidion articulatum* (Coleoptera, Carabidae) populations: Linear dimensions depend on sex, while morphological indices depend on ecosystems. International Journal of Applied Environmental Sciences, 10, 163–187.

Di Grumo, D., & Lovei, G. (2016). Body size inequality in ground beetle (Coleoptera: Carabidae) assemblages as a potential method to monitor environmental impacts of transgenic crops. Periodicum Biologorum, 118(3), 223–230.

Eremina, M. A., & Gruntenko, N. E. (2017). Neyroendokrinnaya stress-reaktsiya nasekomyih: Istoriya razvitiya kontseptsii [The neuroendocrine stress-response in insects: The history of the development of the concept]. Vavilov Journal of Genetics and Breeding, 21(7), 825–832 (in Russian).

Hanna, M. E., Bednářová, A., Rakshit, K., Chaudhuri, A., O'Donnell, J. M., & Krishnan, N. (2015). Perturbations in dopamine synthesis lead to discrete physiological effects and impact oxidative stress response in *Drosophila*. Journal of Insect Physiology, 73, 11–19.

Hirashima, A., Sukhanova, M. J., & Rauschenbach, I. Y. (2000). Genetic control of biogenic-amine systems in *Drosophila* under normal and stress conditions. Biochemical Genetics, 38(5–6), 163–176.

Hurka, K. (1996). Carabidae of the Czech and Slovak Republics. Kabourek, Zlin.

Lagisz, M. (2008). Changes in morphology of the ground beetle *Pterostichus oblongopunctatus* F. (Coleoptera; Carabidae) from vicinities of a zinc and lead smelter. Environmental Toxicology and Chemistry, 27(8), 1744–1747.

Makarov, K. V., & Matalin, A. V. (2009). Ground-beetle communities in the Lake Elton region, southern Russia: A case study of a local fauna (Coleoptera: Carabidae). In: Marusik, Y., & Fet, V. (Ed.). Species and communities in extreme environments. Festschrift towards the 75th anniversary and a laudatio in honour of academician Yuri Ivanovich Chernov. Pensoft Publishers & KMK Scientific Press, Sofia – Moscow. Pp. 357–384.

Matalin, A., & Makarov, M. (2011). Using demographic data to better interpret pitfall trap catches. ZooKeys, 100, 223–254.

Michailov, V. A. (2013). K faune, bioekologii i rasprostraneniyu zhestkokrylyh (Coleoptera) ostrova Dzharyilgach [On the fauna, bio-ecology and distribution of Coleoptera of Dzharylgach island]. Naukovi Zapiski Derzhavnogo Prirodoznavchogo Muzeyu, 29, 113–120 (in Russian).

Mirth, C. K., Tang, H. Y., Makohon-Moore, S. C., Salhadar, S., Gokhale, R. H., Warner, R. D., Koyama, T., Riddiford, L. M., & Shingleton, A. W. (2014). Juvenile hormone regulates body size and perturbs insulin signaling in *Drosophila*. Proceedings of the National Academy of Sciences, 111(19), 7018–7023.

Moskalev, A., Zhikrivetskaya, S., Krasnov, G., Shaposhnikov, M., Proshkina, E., Borisoglebsky, D., Danilov, A., Peregudova, D., Sharapova, I., Dobrovolskaya, E., Solovev, I., Zemskaya, N., Shilova, L., Snezhkina, A., & Kudryavtseva, A. (2015). A comparison of the transcriptome of *Drosophila melanogaster* in response to entomopathogenic fungus, ionizing, starvation and cold shock. BMC Genomics, 16(13), S8.

Müller-Motzfeld, G. (2007). Die Salz- und Küstenlaufkäfer Deutschlands – Verbreitung und Gefährdung. Angewandte Carabidologie, 8, 17–27.

Nakhibasheva, G. M., Mukhtarova, G. M., Ismailova, K. A., & Klycheva, S. M. (2011). Analiz zhiznennyih form imago zhuzhelits Tersko-Kumskoy nizmennosti Dagestana [Analyze of the living form of carabidae's imago in Tersko-Kumsckay lowland of Dagestan]. Polythematic Online Scientific Journal of Kuban State Agrarian University, 69(5), 1–15 (in Russian).

Neri, P., Bonavita, P., Gudenzi, I., Magrini, P., & Toledano, L. (2011). Bembidiina della fauna italo-corsa: Chiavi di identificazione (Insecta Coleoptera Carabidae). Quaderno di Studi e Notizie di Storia Naturale della Romagna, 33, 1–183.

Nitzu, E. (2003). Contributions to the knowledge of the tribus Bembidiini (Coleoptera: Carabidae) from Romania. Travaux du Muséum National d'Histoire Naturelle "Grigore Antipa", 45, 179–185.

Puchkov, O. V., & Slynko, V. O. (2011). *Bembidion aspericolle* (Germar, 1872). In: Paxomov, O. Y. (Ed.). Chervona knyga Dnipropetrovskoyi oblasti. Tvarynnyj svit. Novyj Druk, Dnipropetrovsk. P. 69 (in Ukrainian).

Putchkov, A. V. (2011). Ground beetles of the Ukraine (Coleoptera, Carabidae). ZooKeys, 100, 503–515.

Putchkov, A. V. (2012). Faunisticheskiy obzor karaboidnyh zhukov (Coleoptera, Caraboidea) Ukrainy [A review of the caraboids-beetles (Coleoptera, Caraboidea) of Ukraine]. Ukrayinskiy Entomologichniy Zhurnal, 2(5), 3–44 (in Russian).

Putchkov, A. V., & Brygadyrenko, V. V. (2018). Ridkisni tverdokryli nadrodyny Caraboidea (Coleoptera, Adephaga) Dnipropetrovskoyi oblasti [Rare beetles of the Caraboidea superfamily (Coleoptera, Adephaga) in Dnipropetrovsk oblast]. Zhurfond, Dnipro.

Ratti, E. (1983). Gli elementi caratteristici della coleotterofauna dei giuncheti alofili della laguna di venezia. Società Veneziana di Scienze Naturali, 8, 37–46.

Rauschenbach, I. Y., Gruntenko, N. E., Bownes, M., Karpova, E. K., Chentsova, N. A., Sukhanova, M. Z., & Adon'eva, N. V. (2003). Ecdysteroids and juvenile hormone control the early and late stages of oogenesis, respectively, during stress in *Drosophila*. Doklady Biological Sciences, 389, 127–129.

Rauschenbach, I. Y., Sukhanova, M. Z., Hirashima, A., Sutsugu, E., & Kuano, E. (2000). Role of the ecdysteroid system in the regulation of *Drosophila* reproduction under environmental stress. Doklady Biological Sciences, 375, 641–643.

Sarup, P., Sørensen, P., & Loeschcke, V. (2014). The long-term effects of a life-prolonging heat treatment on the *Drosophila melanogaster* transcriptome suggest that heat shock proteins extend lifespan. Experimental Gerontology, 50, 34–39.

Selye, H. (1976). Stress without distress. In: Serban, G. (Ed.). Psychopathology of human adaptation. Springer, Boston. Pp. 137–146.

Selye, H. (1982). Stress bez distressa [Stress without distress]. Progress, Moscow (in Russian).

Sigida, R. (2009). Galofilnyye vidy zhuzhelitsy – kak indicatory zasolennykh biotopov Stepnoy zony Predkavkazia [Salt-loving species of carabids as indicators salted biotopes of Steppe zone of Ciscaucasia]. Vestnik Moskovskogo Gosudarstvennogo Oblastnogo Universiteta, 3, 49–56 (in Russian).

Slin'ko, V. O., Brygadyrenko, V. V., & Pakhomov, O. Y. (2008). Morfologicheskaja izmenchivost' *Bembidion varium* (Carabidae, Coleoptera) v uslovijah antropogennogo vozdejstvija [Morphological variability of *Bembidion varium* (Carabidae, Coleoptera) in the conditions of anthropogenic pressure]. Proceedings of the National Academy of Sciences of Azerbaijan (Biological Sciences), 64(5–6), 200–206 (in Russian).

Sukhanova, M. J., Shumnaya, L. V., Grenback, L. G., Gruntenko, N. E., Khlebodarova, T. M., & Rauschenbach, I. Y. (1997). Tyrosine decarboxylase and dopa decarboxylase in *Drosophila virilis* under normal conditions and heat stress: Genetic and physiological aspects. Biochemical Genetics, 35(3–4), 91–103.

Sukhodolskaya, R. (2013). Intraspecific body size variation in ground beetles (Coleoptera, Carabidae) in urban – suburban – rural – natural gradient. Acta Biologica Universitatis Daugavpiliensis, 13(1), 121–128.

Sukhodolskaya, R. (2016). Intra-specific body size variation of ground beetles (Coleoptera: Carabidae) in latitudinal gradient. Periodicum Biologorum, 118(3), 273–280.

Sukhodolskaya, R. A., & Saveliev, A. A. (2014). Effects of ecological factors on size-related traits in the ground beetle *Carabus granulatus* L. (Coleoptera, Carabidae). Russian Journal of Ecology, 45(5), 414–420.

Tilly, A. S. (2012). Zhuki-zhuzhelitsy (Coleoptera, Carabidae) zasolennykh pochv stepnogo Zavolzhia Samarskoy oblasti [Carabidae (Coleoptera) of saline soils on the Steppe Zone of Samara region]. Izvestiya Samarskogo Nauchnogo Tsentra Rossiyskoy Akademii Nauk, 14(1), 125–131 (in Russian).

Trost, M. (2003). Die Laufkäferfauna des Flächennaturdenkmals "Salzstelle bei TeutschenthalBahnhof" im Süden Sachsen-Anhalts. Naturschutz im Land Sachsen-Anhalt, 40(1), 19–32.

Trost, M. (2006). Die historische und aktuelle Bestandssituation der halobionten und halophilen Laufkäferfauna (Coleoptera, Carabidae) im Gebiet der Mansfelder Seen westlich von Halle/Saale (Sachsen-Anhalt). Hercynia N. F., 39, 121–149.

Tseng, M., & Soleimani Pari, S. (2018). Body size explains interspecific variation in size-latitude relationships in geographically widespread beetle species. Ecological Entomology, 44(1), 151–156.

Weller, B., & Ganzhorn, J. U. (2004). Carabid beetle community composition, body size, and fluctuating asymmetry along an urban-rural gradient. Basic and Applied Ecology, 5(2), 193–201.

Zakharenko, L. P., Karpova, E. K., & Rauschenbach, I. Y. (2014). P-M hybrid dysgenesis affects juvenile hormone metabolism in *Drosophila melanogaster* females. Russian Journal of Genetics, 50(7), 772–774.

Zhuravel, N., Polchaninova, N., Lezhenina, I., Drovgalenko, O., & Putchkov, A. (2016). Preliminary survey of the ground-dwelling arthropods of the floodplain meadows in the southeast of Poltava region (Ukraine). Biological Bulletin of Bogdan Chmelnitskiy Melitopol State Pedagogical University, 6(3), 5–17.