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AGE AND SEXUAL VARIATION OF MORPHOMETRIC TRAITS IN *DAREVSKIA LINDHOLMI* (SZCZERBAK, 1962) (SAURIA, LACERTIDAE)

Based on results obtained by investigation of morphological differentiation of individuals of different age and sex, a highly correlated variation of 33 morphometric traits has been revealed in Lindholm's rock lizard, *Darevskia lindholmi* (Szczerbak, 1962). It has been proved that the increase of linear body dimensions reflects the basic (ontogenetic) trend of variation of traits during late ontogenesis of *D. lindholmi*. It has been shown that sexual differences of some traits in *D. lindholmi* are almost absent, while by the linear body dimensions (the value of the first canonical root) males are larger than females. The age-related morphological differentiation of this lizards significantly exceeds sexual differences among adult individuals.

Keywords: Darevskia lindholmi, late ontogenesis, morphometric traits, linear body dimensions, age and sexual variation.

Introduction

Lindholm's rock lizard, *Darevskia lindholmi (*Szczerbak, 1962), is the only rock lizard species common in the Crimean Mountains. The species status of *D. lindholmi* was confirmed by molecular genetic studies (MacCulloch et al., 2000; Doronin et al., 2013). Its distribution, aspects of ecology and biology was also investigated (Szczerbak, 1962, 1966; Darevsky, 1967; Kukushkin, 2009). In addition, taxonomic issues of genetic and morphological differentiation of *D. lindholmi* on both interpopulation and interspecific levels were studied as well (Szczerbak, 1962, 1966; Darevsky, 1967; MacCulloch et al., 2000; Dotsenko et al., 2008–2009; Doronin et al., 2013). However, the issues of age and sexual variation of morphometric traits and the differentiation of individuals by liner body dimensions have not been studied sufficiently yet. It is known that rock lizards are characterized by clearly expressed age-related variation and sexual dimorphism. For instance, males of *D. lindholmi* are notably larger than females, especially by the dimensions of the head (Darevsky, 1967). According to M. M. Shcherbak's data (1966), males have larger values of liner body dimensions than fe-

males, including the longer tale (Szczerbak, 1966). Data published by other authors (e. g. Doronin et al., 2013) also confirm this statement.

The aim of this work is to study and compare sexual differences and age variation of morphometric traits, as well as to evaluate the differentiation of individuals of *Darevskia lindholmi* by linear body dimensions.

Material and methods

Morphometric data of *D. lindholmi* obtained by processing scientific collections in the Department of Zoology of the National Museum of Natural History, National Academy of Science of Ukraine (Kyiv). The studied material was collected by M. M. Shcherbak in different locations in the Crimean Mountains during 1956–1976. In total, 43 individuals have been studied, among which there were 34 adults[1] (15 females and 16 males), 4 subadult females (L = 46,0–47,0 mm), and 8 juvenile lizards with no sex determination (L = 25,5–39,0 mm). Each lizard has been measured for the values of 33 morphometric traits by calliper, ruler, and eyepiece micrometer of MBS–9 stereomicroscope (magnification 1x8) with 0,1 mm accuracy. Measurements have been conducted according to the scheme proposed for investigation of true lizards of the family Lacertidae[2] (Maliuk, Peskov, 2011; Maliuk, 2014): 1 — total body length (from tip of snout to cloaca); 2 — trunk length (from throat fold to cloaca); 3 — glenoacetabular length; 4 — body width at the chest; 5 — body height at the chest; 6 — body width at the pelvis; 7 — body height at the pelvis; 8 — tail height at its base; 9 — tail width at its base; 10 — head length; 11 — distance from the tip of the nose to the auditory canal; 12 — head width ahead of auditory canals; 13 — pileus width between the 2nd and 3rd supraorbital scales; 14 — distance between the eye corners; 15 — distance between the nostrils; 16 — maximal head height; 17 — distance between the tip of the snout to the front edge of the eyes; 18 — distance between the front edge of the eyes to the auditory canals; 19 — eyes length; 20 — vertical diameter of auditory canals; 21 — distance between the tip of the snout to the edge of the collar; 22 — fore-limb length; 23 — arm length; 24 — forearm length; 25 — manus length; 26 — length of the 4th digit of the manus; 27 — length of the claw of the 4th digit of the manus; 28 — hind-limb length; 29 — thigh length; 30 — crus length; 31 — foot length; 32 — length of the 4th digit of the foot; 33 — length of the claw of the 4th digit of the foot.

The minimum (min), maximum (max), and mean value (M), as well as the standard error (m), standard deviation (Sx), coefficient of variation (CV, %), and the error of measurement of the mean value (Cs, %) have been calculated for all of the studied morphometric traits. The samples have been compared by the mean value of the traits using Student's t-test. For the statistical analysis of the data we used standard methods such as univariate (basic statistics, nonparametric Kruskal-Wallis test) and multivariate (PCA, cluster and discriminant analysis) (Zaitsev, 1984; Kim et al., 1989). All calculations were performed with the statistical package STATISTICA, v. 6.0.

Results and discussion

The accuracy of sample means evaluation. Because of the small volume of the studied material (n = 43), in samples of adult males (n = 16) and females (n = 15) we have calculated the mean accuracy scores (Cs, %) for each character. In all cases, the value of Cs was lower than 5 % indicating sufficient accuracy of estimation of sample mean values of morphometric traits in relation to general parameters (Zaitsev, 1984).

Sexual differences by separate traits. The variation of the body length (L, mm) in adult mature females (CV = 8,91 %) and males (CV = 6,76 %) is almost the same

[1] According to Shcherbak's data (1966), adult mature females have snout-vent length >50 mm, while males > 55 mm.

[2] The scheme is based on body measurements traditionally used during studies on lizards (The sand lizard, 1976; Bannikov et al., 1977; Szczerbak, Szczerban', 1980).

(tabl. 1). By the mean value of the body length and the most (31–97 %) of other traits sexual differences have not been revealed (t = 0,25–1,88; P > 0,05). Males and females reliably differ only by one character, namely the distance between the tip of the snout and the edge of the collar (character 21), which is on average somewhat bigger (t = 2,07; P < 0,05) in males ($M_{♂}$ = 20,92 mm) than in females ($M_{♀}$ = 19,80 mm).

Factor analysis of character variation. The variation of 33 morphometric traits during late postembryonic development of Lindholm's rock lizard can be described by the first principal component for 89,1 % (tabl. 2). The values of factor loadings onto PC1 vary from 0,85 (body height at the pelvis) to 0,99 (distance from the tip of the nose to the auditory canal). This indicates the high correlation in variation of morphometric traits of Lindholm's rock lizard influenced by the factor of growth. Therefore, the

Table 1. **Variation of morphometric traits in adult males and females of** *D. lindholmi*

	Males (n = 16)				Females (n = 15)			
	min	max	M	Sx	min	max	M	Sx
1	51,0	63,0	57,58	3,892	50,0	65,0	57,18	5,093
2	32,0	41,0	36,58	2,720	31,0	44,0	37,26	3,904
3	23,0	32,0	27,23	2,644	23,5	33,0	27,92	3,154
4	5,5	8,3	6,87	0,869	5,2	8,8	6,88	1,136
5	4,8	7,3	6,21	0,707	4,8	8,0	6,19	1,054
6	6,0	8,1	7,08	0,616	5,3	9,0	7,38	1,187
7	4,0	7,4	5,75	0,995	4,9	7,5	6,13	0,894
8	5,0	6,3	5,60	0,433	4,4	6,4	5,44	0,644
9	3,9	5,4	4,69	0,489	3,1	5,5	4,46	0,776
10	12,7	15,3	14,27	0,911	11,9	15,4	13,66	1,127
11	13,1	16,0	14,79	0,999	12,1	15,8	14,05	1,187
12	7,0	9,9	8,56	0,802	6,4	9,8	8,19	1,036
13	5,0	6,8	5,90	0,621	5,1	6,7	5,80	0,486
14	4,3	5,8	5,07	0,541	4,2	5,5	4,89	0,417
15	1,6	2,0	1,85	0,138	1,5	2,1	1,78	0,186
16	5,1	7,1	5,99	0,645	4,5	7,0	5,79	0,799
17	5,0	6,6	5,79	0,543	4,5	6,5	5,69	0,600
18	4,9	6,8	5,76	0,584	4,3	6,6	5,60	0,688
19	2,0	2,7	2,34	0,221	2,0	2,5	2,27	0,167
20	2,0	2,6	2,18	0,177	1,8	2,4	2,08	0,163
21	18,5	23,0	20,92	1,552	17,0	22,0	19,80	1,461
22	17,3	23,7	20,56	1,943	16,4	22,0	19,26	1,899
23	4,7	7,3	6,14	0,723	5,2	6,7	5,94	0,458
24	4,0	6,4	5,34	0,682	4,4	5,9	5,02	0,485
25	7,3	10,6	9,08	0, 922	7,2	9,8	8,52	0,845
26	5,5	7,9	6,82	0,760	5,6	8,2	6,66	0,811
27	1,2	1,8	1,46	0,192	1,1	1,7	1,41	0,201
28	28,4	36,4	32,43	2,712	27,5	36,1	31,36	2,643
29	8,0	12,2	10,30	1,227	8,1	12,0	9,92	1,243
30	6,3	8,3	7,23	0,722	5,4	8,4	6,82	0,859
31	13,3	17,4	15,31	1,210	13,0	17,1	14,85	1,312
32	9,8	12,7	11,32	0,924	9,4	13,0	11,07	1,148
33	1,2	2,2	1,82	0,337	1,4	2,5	1,86	0,347

increase of linear body dimensions during postembryonic development of Lindholm's rock lizard is the main reason for the basic (ontogenetic) trend of variation of 33 morphometric traits of this species.

Table 2. **Factor loadings of 33 morphometric traits on the first three principal components**

N	Morphometric features, mm	PC1	PC2	PC3
1	total body length	–0,98	0,03	–0,03
2	trunk length	–0,95	0,06	–0,02
3	glenoacetabular length	–0,93	0,04	–0,03
4	body width at the chest	–0,93	0,19	–0,23
5	body height at the chest	–0,94	0,23	–0,10
6	body width at the pelvis	–0,93	0,22	0,10
7	body height at the pelvis	–0,85	0,44	0,07
8	tail height at its base	–0,97	0,10	–0,01
9	tail width at its base	–0,92	0,29	0,09
10	head length	–0,98	–0,12	–0,03
11	distance from the tip of the nose to the auditory canal	–0,99	–0,09	–0,02
12	head width ahead of auditory canals	–0,98	0,05	0,01
13	pileus width between the 2nd and 3rd supraorbital scales	–0,96	0,03	–0,10
14	distance between the eye corners	–0,96	–0,01	–0,03
15	distance between the nostrils	–0,86	0,09	0,17
16	maximal head height	–0,97	0,06	0,04
17	distance between the tip of the snout to the front edge of the eyes	–0,98	–0,03	–0,02
18	distance between the front edge of the eyes to the auditory canals	–0,98	–0,02	–0,04
19	eyes length	–0,90	–0,06	0,26
20	vertical diameter of auditory canals	–0,94	0,00	0,17
21	distance between the tip of the snout to the edge of the collar	–0,98	–0,08	–0,07
22	fore-limb length	–0,97	–0,14	–0,01
23	arm length	–0,93	–0,18	–0,16
24	forearm length	–0,91	–0,29	–0,21
25	manus length	–0,95	–0,05	0,07
26	length of the 4th digit of the manus	–0,94	–0,04	0,05
27	length of the claw of the 4th digit of the manus	–0,90	–0,25	0,26
28	hind-limb length	–0,98	–0,08	–0,06
29	thigh length	–0,96	0,03	–0,05
30	crus length	–0,93	–0,08	–0,21
31	foot length	–0,97	–0,01	0,05
32	length of the 4th digit of the foot	–0,95	0,01	–0,02
33	length of the claw of the 4th digit of the foot	–0,87	–0,32	0,18
	of total variance, %	89,06	2,42	1,40

The distribution of individuals by the values of PC1 reflects the increase of linear body dimensions of lizards during late ontogenesis by 33 morphometric traits. The body length (L, mm) within the studied samples varies from 25,5 mm in juveniles to 63 mm in adult males and to 65 mm in adult females (fig. 1).

According to M. M. Shcherbak's data (1966), the maximum body length of adult mature individuals from Crimea can reach over 70 mm (in males L_{max} = 72,6 mm, in females L_{max} = 71,2 mm).

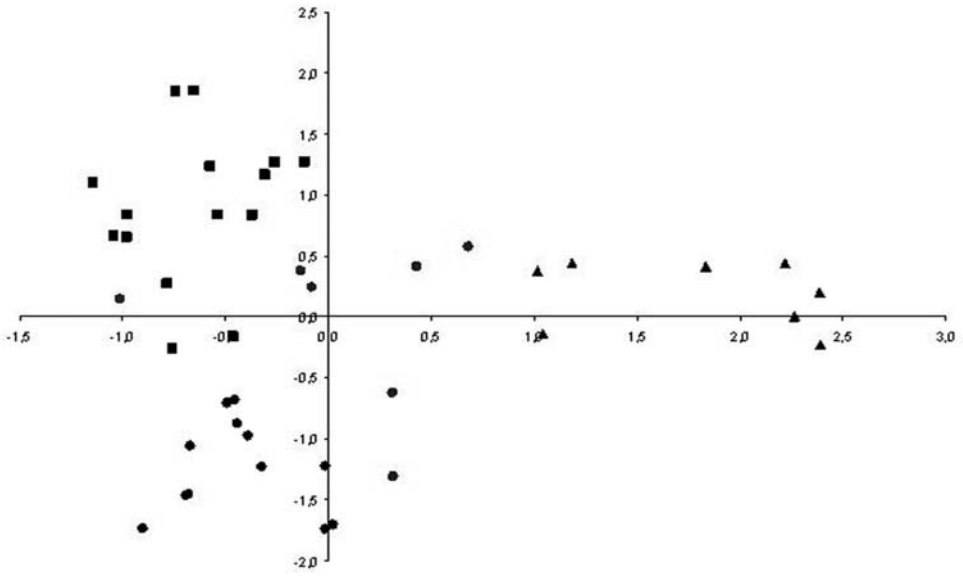

Fig. 1. The distribution of individuals of *Darevskia lindholmi* in the space of values of PC1 and PC2. (Juvenile lizards are marked by triangles, males by rectangles, and females by circles).

PC2 has a small part (2,42 %) of residual dispersion of 33 traits in the studied sample and small values of factor loadings that varies from –0,32 to 0,44 (tabl. 2). Considering that correlation between the body length and PC2 is almost absent (0,03) it can be concluded that this component describes the variation of the relative values of some of the morphometric traits which characterize the change of proportions of different body parts during late ontogenesis of *D. lindholmi*.

In juvenile lizards having body length from 25,5 to 27 mm, proportions of the body almost do not change, while in subadult immature (L = 38,0–47,0 mm) and adult mature (L = 50,0–65,0 mm) individuals differentiation by body proportions notably increases (fig. 1). In the same time, in a part of adult males (43,0 %) and females (60,0 %) having positive values of PC2 the relative value of six traits (7, 9, 5, 6, 4, and 8)[3] increases along with the increase of the value of PC2. Conversely, the value of six other traits (33, 24, 27, 23, 22, and 10) decreases (fig. 1, tabl. 2). The first group of traits characterizes the variation of proportions of the body (4–7) and the tail (8, 9), while the second group characterizes the variation of proportions of the head (10) and the limbs (22–24, 27, 33). In the other part of adult males (56,2 %) and females (40,0 %) having negative values of PC2, a completely opposite kind of variation of body proportions can be observed. With the increase of the values of PC2 decreases the relative value of traits of the first group (7, 9, 5, 6, 4, and 8) and increases of the second (33, 24, 27, 23, 22, and 10).

[3]Here and further, the numbers of the characters are indicated according to the increase of their factor loadings.

The above-mentioned data and data presented on fig. 1 indicate that the variation of body proportions in Lindholm's rock lizard significantly increases with the age. At the same time, the influence of the age on the variation of linear body dimensions (Kruskal-Wallis test: H = 18,29468; p = 0,0001) is larger, than on the variation of body proportions (Kruskal-Wallis test: H = 7,185434; p = 0,0275). Reliable differences between males and females by linear body dimensions (Kruskal-Wallis test: H = 3,219048; p = 0,0728) and body proportions (Kruskal-Wallis test H: = 0,6857143; p = 0,4076) have not been revealed.

Factor analysis of morphological diversity of lizards by linear body dimensions has been conducted by processing DE matrix that contained information on generalized differences between them according to linear body dimensions[4]. Such analysis allows not only reveal size- and age-related heterogeneity of the studied sample (Peskov, Sinyavska, 2013), but also to evaluate the reliability of the correct age determination for each individual (tabl. 3).

Table 3. **Correlation coefficients of morphological distances (DE) with the principal components**

№ individuals	Age	Sex	L, mm	PC1	PC2
2–6	juvenis	—	25,5–33,0	**0,877–0,952**	0,278–0,460
7	?	♀	36,0	0,695	0,686
1, 8–12	subadul-tus	♀	38,0–47,0	-0,401–0,573	**0,784–0,955**
13–27	adultus	♀	50,0–65,0	**-0,765– -0,994**	-0,229–0,629
28–43	adultus	♂	54,0–63,0	**-0,916– -0,992**	-0,212–0,370
			Prp.Totl	79,84	18,11

Comment: statistically significant correlation coefficients are given in bold.

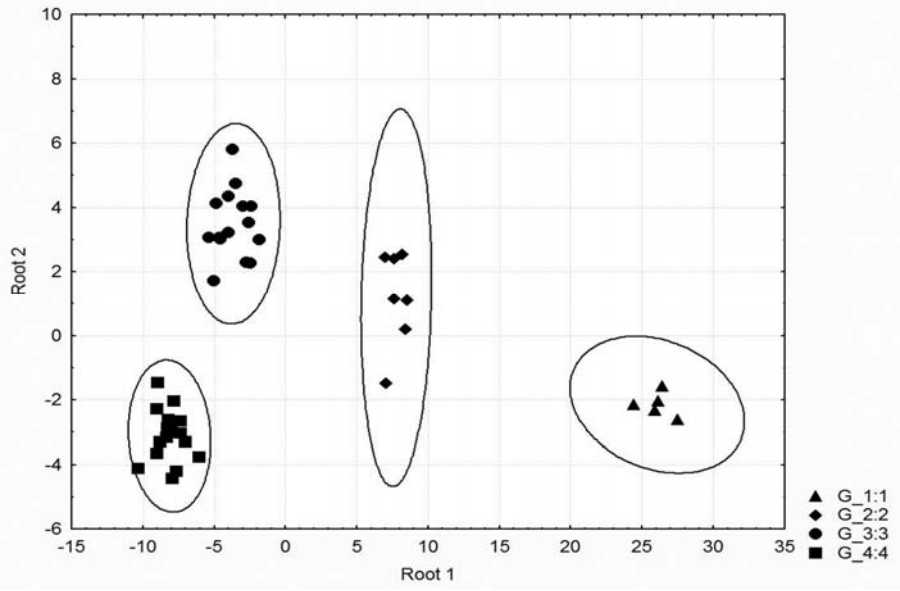

***Fig.* 2.** Distribution of juvenile (triangle), subadult (diamond), and adult (males — rectangle, females — circle) individuals of Lindholm's rock lizard in the space of values of the first and second canonical roots.

[4]To concern space the DE matrix is not presented in the article.

The morphological diversity of *D. lindholmi* is sufficiently (97,95 %) characterized by PC1 and PC2 (tabl. 3). In the same time, the first principal component (PC1) reflects the maximum differences between juvenile and adult individuals by the linear body dimensions marking the former ones with high positive correlations (0,877–0,952), while the others with negative correlations (males from –0,916 to –0,992; females from –0,765 to –0,994). PC2 marks the group of subadult individuals with high positive correlations (0,784–0,955). A female with L = 39,0 mm has practically the same, but statistically unreliable correlation coefficients with PC1 (0,695) and PC2 (0,686), hence it is hard to include it with certainty into one of the age groups. Based on the results of discriminant analysis (fig. 2) it has been revealed that this female (L = 36,0 mm) is nearly 2,3 times closer to subadults (SqMD = 181,98) than to juveniles (SqMD = 425,40) by its linear body dimensions, thus it was included into the subadultus group.

Discriminant analysis of morphological differentiation has been performed to estimate the level and character of generalized differences (SqMD) between individuals of different age and sex.

Discriminant analysis allows fully (100 %) determine by both the age and sex of each individual of Lidholm's rock lizard. Considering the distribution of individuals from juveniles to adult mature males, it can be stated that males are notably larger than females by linear body dimensions (fig. 2). According to linear body dimensions, the most differentiated from each other are the juveniles and adult males (SqMD = 1199,14), while the least differentiated are the adult males and females (SqMD = 66,35). Subadult females are closer to adult females (SqMD = 166,88) and males (SqMD = 280.38) than to juvenile individuals (SqMD = 397,21). Based on the presented results, it can be concluded that in Lindholm's rock lizard, as well as in many other vertebrate species, the age-related diversity of linear body dimensions is significantly higher than their sexual diversity (Vasiljev et al., 2004; Pavlinov et al., 2008; Peskov et al., 2012). It should be also noted that sexual differences in linear body dimensions in *D. lindholmi* are comparable with interpopulation differences by the value of SqMD calculated by the body proportions and features of pholidosis, while age-related differences are comparable with interspecies differences (Dotsenko et al., 2008–2009).

Conclusions

According to the results of this study, the variation of 33 morphometric traits during late ontogenesis of *D. lindholmi* for 91,5 % is characterized by the first two principal components (PC1 and PC2). PC1, which has 89,1 % of residual dispersion, has high factor loadings of all traits indicating their correlated variation. The increase of linear body dimensions (absolute values of morphometric traits) from the juvenile (L = 25,5–33,0 mm) to adult (L = 50,0–65,0 mm) individuals reflects the basic (ontogenetic) trend of variation of traits during late ontogenesis of *D. lindholmi*. Sexual differences according to separate traits of Lindholm's rock lizard are practically absent, while, according to linear body dimensions (value of the first canonical root), males are larger than females. Age-related morphological differentiation of the lizards is significantly higher than sexual differences in adult individuals.

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ВІКОВА І СТАТЕВА МІНЛИВІСТЬ МОРФОМЕТРИЧНИХ ОЗНАК У *DAREVSKIA LINDHOLMI* (SZCZERBAK, 1962) (SAURIA, LACERTIDAE)

За результатами дослідження морфологічної диференціації особин різного віку і статі виявлено високий рівень корелятивної мінливості 33 морфометричних ознак у ящірки Ліндгольма. Доведено, що збільшення лінійних розмірів тіла відображає основний (онтогенетичний) тренд мінливості ознак у пізньому онтогенезі *D. lindholmi*. Показано, що статеві відмінності за окремими ознаками у ящірки Ліндгольма практично відсутні, в той час як за лінійними розмірами тіла (значення першої канонічної змінної) самці крупніші за самок. Морфологічна диференціація ящірок за віком значно перевищує статеві відмінності між дорослими ящірками.

К л ю ч о в і с л о в а: *Darevskia lindholmi*, пізній онтогенез, морфометричні ознаки, лінійні розміри тіла, вікова і статева мінливість.

В. Н. Песков, И. А. Синявская

ВОЗРАСТНАЯ И ПОЛОВАЯ ИЗМЕНЧИВОСТЬ МОРФОМЕТРИЧЕСКИХ ПРИЗНАКОВ У *DAREVSKIA LINDHOLMI* (SZCZERBAK, 1962) (SAURIA, LACERTIDAE)

По результатам исследования морфологической дифференциации особей разного возраста и пола выявлено высокий уровень коррелятивной изменчивости 33 морфометрических признаков у ящерицы Линдгольма. Доказано, что увеличение линейных размеров тела отражает основной (онтогенетический) тренд изменчивости признаков в позднем онтогенезе *D. lindholmi*. Показано, что половые различия по отдельным признакам у ящерицы Линдгольма практически отсутствуют, в то время как по линейным размерам тела (значение первой канонической переменной) самцы крупнее самок. Морфологическая дифференциация ящериц по возрасту значительно превышает половые различия между взрослыми ящерицами.

К л ю ч е в ы е с л о в а**:** *Darevskia lindholmi*, поздний онтогенез, морфометрические признаки, линейные размеры тела, половая и возрастная изменчивость.