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Body size and sexual dimorphism in *Geolycosa vultuosa* (C. L. Koch, 1838) (Araneae: Lycosidae)

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Abstract. We performed body measurements and analysed sexual size dimorphism of the burrowing wolf spider *Geolycosa vultuosa*. The body length of females was significantly greater than that of males, which was due to the larger opisthosoma. Males, on the other hand, had significantly longer legs, which probably facilitate their movement in search for mating partners. There is a female-biased SSD in the case of prosoma and opisthosoma length and width, and total body length and a male-biased SSD in the other computed indices. However, the SSD in *G. vultuosa* is not as pronounced as in some other spider species. The length of prosoma seems to be the best proxy of total body size as suggested by the pairwise correlations.

Key words. *Geolycosa vultuosa*, burrow, size dimorphism, prosoma length, leg length.

Introduction

Body size of spiders is highly variable among species, sometimes even within the same species (Gasnier et al. 2002). It is affected by the available food resources during development (Uetz et al. 2002), by altitude (Ameline et al. 2018, Hein et al. 2019), latitude (Puzin et al. 2014), urbanization (Dahirel et al 2019), density of spiders (Drapela et al. 2011), complexity of vegetation in the habitat (Stańska et al. 2018), and in turn, it can influence many life behaviours like individual fitness, fecundity, mating, reproductive investment, web building, diameter of the burrow entrance (Miller & Miller 1984, Carrel 2003, Bowden & Buddle 2012, Ameline et al. 2018, Dahirel et al. 2019, Hein et al. 2019). Sexual size dimorphism is common among spiders, with females being generally larger than males, as they invest more energy in reproduction (Moya-Larano et al. 2002, Framenau 2005, Logunov 2011, Stańska et al. 2018). A few studies reported situations with males being bigger than females (Gasnier et al. 2002), these including also species of spiders where males have high reproductive investment (Aisenberg et al. 2007).

With 2431 described species, Lycosidae is the sixth largest spider family in the world (World Spider Catalog 2020). The genus *Geolycosa* Montgomery, 1904 comprises large-sized spiders which live in burrows dug into the ground (Miller & Miller 1984, Fuhn & Niculescu-Burlacu 1971, Carrel 2003). From this genus, in Romania only the species *Geolycosa vultuosa* (C. L. Koch, 1838) is present, its global range including Slovakia, Hungary, south-eastern and eastern Europe, Turkey, Caucasus and Iran (World Spider Catalog 2020). It occurs in open dry habitats (Szinetár 2006), on sand dunes, in sand pits, xerophilous and mesic grasslands, fallows (Sas-Kovács & Sas-Kovács 2014a, Sas-Kovács & Sas-Kovács 2014b). Adults can be found between May (June) and September (October) (Fuhn & Niculescu-Burlacu 1971, Szinetár 2006), the mating taking place most likely in September (Szinetár 2006) or even later if fall is warm.

The aim of this study was to enlarge knowledge on *G. vultuosa* by collecting morphometric data and analyzing sexual size dimorphism. To our knowledge, little work has been performed on this species in this direction (Fuhn & Niculescu-Burlacu 1971).

Material and methods

The study was conducted in autumn of 2014 in an intensively grazed sandy grassland near Scărișoara Nouă locality, in Carei Plain, north-western Romania (47°38'27"N, 22°14'05"E, 142 m a.s.l.) (Figs 1, 2). In Carei Plain its distribution is

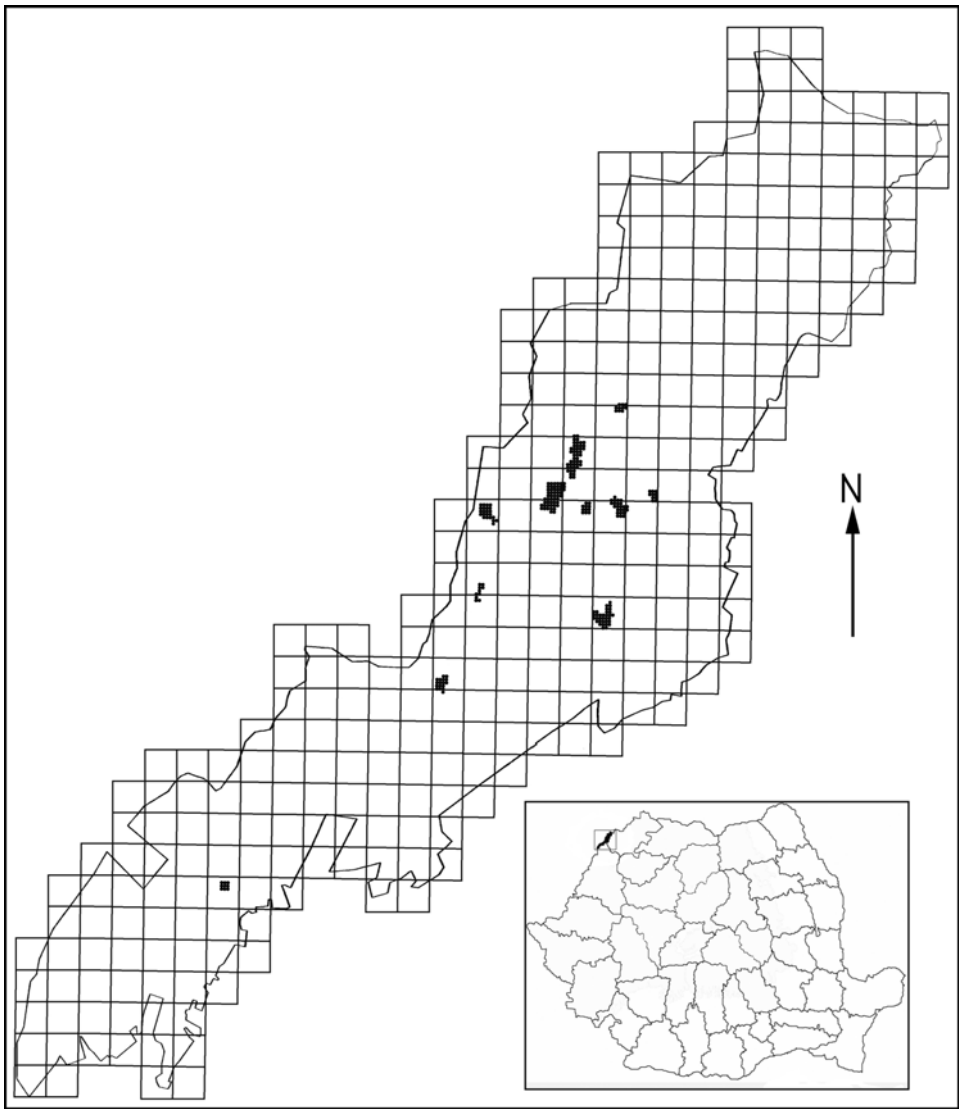

Figure 1. Distribution of *Geolycosa vultuosa* in the Carei Plain protected area (map from Sas-Kovács et al. 2014a).

well documented (Sas-Kovács & Sas-Kovács 2014a, Sas-Kovács & Sas-Kovács 2014b). The species can be easily identified in the field according to the features presented in Fuhn & Niculescu-Burlacu (1971) and Szinetár (2006).

A total number of 54 individuals of *Geolycosa vultuosa* were captured, of them 7 being females and 47 males. Males were easily collected as they were

Figure 2. View of the habitat of the studied *Geolycosa vultuosa* population.

wandering freely in the habitat, while females were generally captured at the entrance of their burrow. Spiders were placed one by one in glass Petri dishes that had graph paper glued on the bottom, and then were photographed with the help of a digital camera (Canon EOS 600D). Weight measurements were done with a digital scale. Weight measurement in females was possible only for two individuals, these having 480 mg and 500 mg, respectively, so this parameter will be discussed in more detail only for males. With the exception of seven individuals in very poor condition, the rest of the spiders were released into the habitat of origin after data collection.

Length and width of the prosoma, opisthosoma and sternum, and length of the legs were measured for the studied males and females (Figs 3-5). Measurements were obtained using AxioVs40 v.4.8.2.0. In order to estimate the area of a spider we calculated its "rough area" (RA), which is the area of a circle with the radius being the average value of the leg lengths. We have also calculated the leg/prosoma ratio, by dividing the average value of leg length with prosoma length (LPRl) and width (LPRw). To quantify the degree of sexual size dimorphism (SSD) we divided the average value of an index of the males with the average value of the females. All these indices were calculated following Gasnier and his collaborators (2002). The opisthosoma area (OA) was calculated after the formula OA=π*opisthosoma length/2*opisthosoma width/2, following Moya-Larano and his collaborators (2003). Length measurements are given in millimetres.

A non-parametric ANOVA (Mann-Whitney U test), was used to compare the differences of sizes between males and females. Spearman's rank correlation was used to test the strength of the linear relationship between various paired data. All these tests were performed with STATISTICA v.8.0. (StatSoft. Inc.).

Results

We observed significant differences in several measured and computed indices. Total body length of females varied between 15.57 and 22.05 mm, and that of males between 14.65 and 18.65 mm. The body length of females was significantly greater than that of males ($U_{7,47}$=51, p<0.01). However, we did not found significant differences between sexes concerning the length and width of the prosoma. But both the opisthosoma length and width were larger in females ($U_{7,47}$=42, p<0.01 and $U_{7,47}$=4.5, p<0.0001). The opisthosoma area was also greater in females ($U_{7,47}$=22, p<0.0001). Males, on the other hand, had significantly longer legs (leg I, $U_{7,16}$=19, p<0.05; leg II, $U_{7,16}$=13, p<0.01; leg III, $U_{7,16}$=13, p<0.01; leg IV, $U_{7,16}$=26, p<0.05) (Fig. 6) and a greater RA ($U_{7,16}$=15, p<0.01). The other computed

Figure 3. Females of *Geolycosa vultuosa* in the field.

Figure 4. Male of *Geolycosa vultuosa* in the field.

indices also showed significant size differences in favour of males (LPRl, $U_{7,16}$=4, p<0.001;LPRw, $U_{7,16}$=7, p<0.01).

There is a female-biased SSD in the case of prosoma and opisthosoma length and width, and total body length (SSD-prosoma length=0,91; SSD-prosoma width=0.95; SSD-opisthosoma length=0.80; SSD-opisthosoma width=0.72; SSD-total body length=0.85), and a male-biased SSD in the other indices (SSD-leg I length=1.15; SSD-leg II length=1.18; SSD-leg III length=1.17; SSD-leg IV length=1.11; SSD-RA=1.32; SSD-LPRl=1.24; SSD-LPRw=1.20).

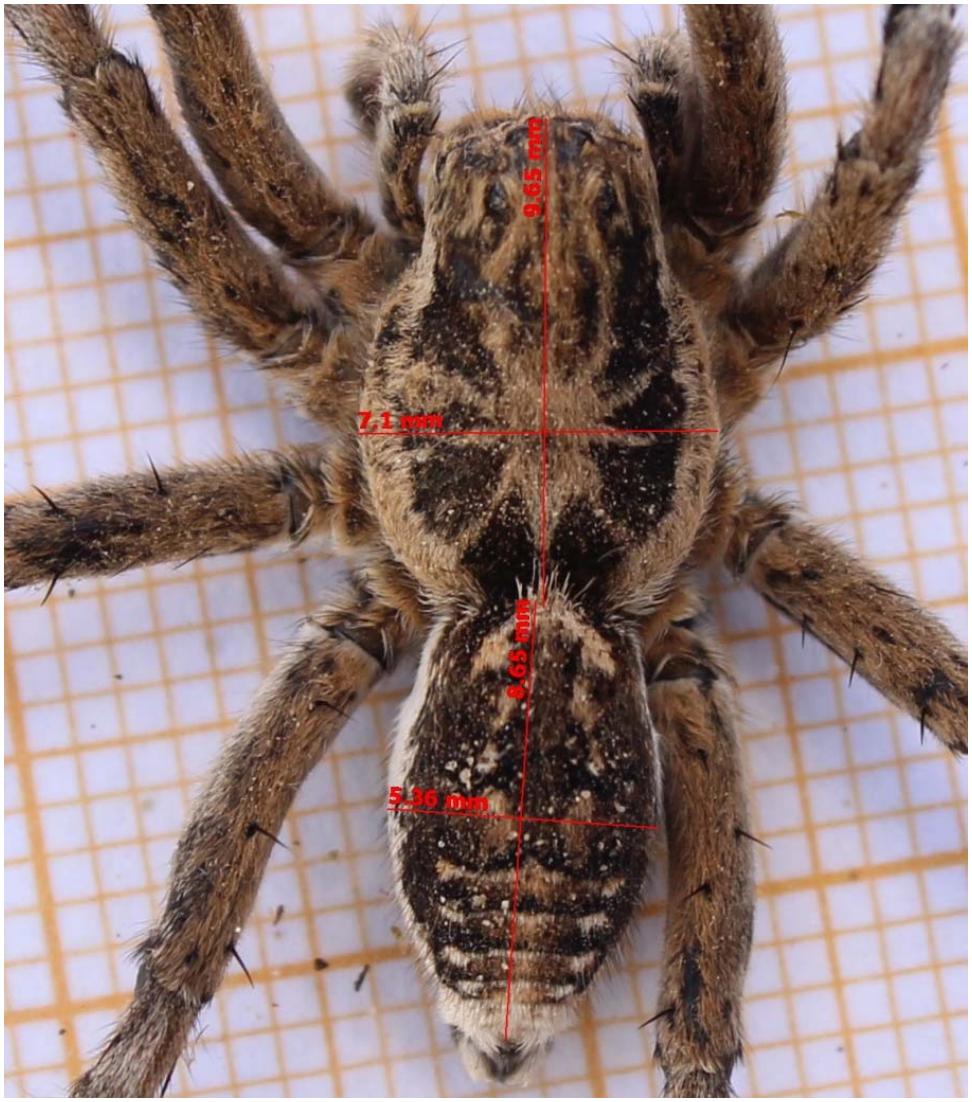

Figure 5. Performing measurements on a male of *Geolycosa vultuosa*.

Weight of male spiders of *G. vultuosa* varied between 210 and 670 mg, with an average of 670 mg. Pair combinations revealed statistically significant correlations ($p<0.05$) and positive in all cases in males. The strongest correlations (with the Spearman's R value being over 0.8) were obtained for the following pair of variables: prosoma length and prosoma width, prosoma length and body length, and opisthosoma length and body length. In the case of females, statistically signif-

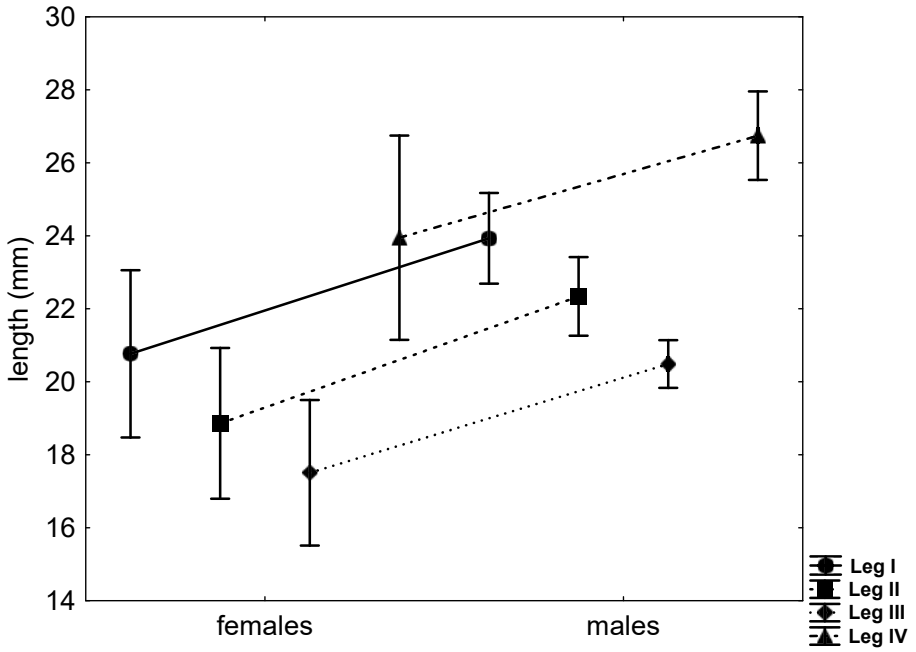

Figure 6. Means ± 0.95 confidence interval for leg lengths

icant ($p<0.05$) and positive correlations were obtained only for the prosoma length with its width, with opisthosoma width and body length (Spearman's R value over 0.9 for all pair of variables). Morphometric data are summarized in the Table 1.

Discussion

We did not found significant prosoma size differences between sexes, though this is a common feature among spiders, with both the width and/or length of prosoma being generally larger in females (Framenau 2005, Gasnier et al. 2002, Stańska et al. 2018), and occasionally in males (Gasnier et al. 2002, Aisenberg et al. 2007). In our case, the greater body length of females is due to the larger size of the opisthosoma, with an area of 51.36±11.67, compared to 29.83±5.54 in males. The study took place in fall when females prepare for hibernation and egg development, and accumulate energy reserves, and while the size of prosoma remains unchanged after the final moult, the opisthosoma can expand depending on the amount of food consumed (Foellmer & Fairbairn 2005). Larger females are able to produce larger egg clutches (Drapela et al. 2011, Bowden & Buddle 2012), but not necessarily larger eggs (Ameline et al. 2018).

Table 1. Morphometric data for the individuals of *Geolycosa vultuosa* (measurements in mm, SD=standard deviation, Min=minimum, Max=maximum, n=number of measured individuals)

	Males			Females		
	Mean±SD (n)	Min	Max	Mean±SD (n)	Min	Max
Body length	16.67±1.10 (47)	14.65	18.86	19.45±2.34 (7)	15.57	22.05
Prosoma length	8.98±0.48 (47)	7.94	9.74	9.86±1.40 (7)	8.58	11.86
Prosoma width	6.54±0.32 (47)	5.71	7.17	6.88±1.13 (7)	5.26	8.42
Opisthosoma length	7.69±0.72 (47)	6.48	9.12	9.59±1.37 (7)	6.94	10.88
Opisthosoma width	4.90±0.49 (47)	3.94	6.43	6.73±0.68 (7)	5.52	7.29
Sternum length	4.12±0.32 (7)	3.57	4.6	4.06±0.49 (6)	3.31	4.57
Sternum width	3.18±0.37 (7)	2.69	3.57	3.43±0.40 (6)	3.02	3.98
Weight (mg)	473.40±97.31 (44)	210	670	-	-	-
Femur I	7.02±0.32 (7)	6.48	7.59	6.42±0.55 (6)	5.88	7.17
Patella I	2.70±0.19 (7)	2.42	2.94	2.82±0.45 (6)	2.29	3.52
Tibia I	5.80±0.40 (7)	5.41	6.65	4.78±0.42 (6)	4.15	5.21
Metatarsus I	6.29±0.32 (7)	6.00	6.78	4.52±0.43 (6)	4.03	5.10
Tarsus I	3.43±0.24 (7)	3.16	3.87	2.87±0.19 (6)	2.69	3.10
Leg I length	23.93±2.33 (16)	19.04	27.84	20.76±2.47 (7)	16.76	23.94
Femur II	6.50±0.29 (7)	6.24	7.11	5.80±0.66 (6)	5.11	6.54
Patella II	2.44±0.16 (7)	2.17	2.67	2.44±0.40 (6)	2.01	3.00
Tibia II	5.10±0.24 (7)	4.75	5.52	4.11±0.32 (6)	3.58	4.46
Metatarsus II	5.82±0.45 (7)	5.41	6.62	4.21±0.55 (6)	3.45	4.95
Tarsus II	3.35±0.19 (7)	3.12	3.71	2.72±0.28 (6)	2.42	3.18
Leg II length	22.33±2.02 (16)	17.34	24.75	18.86±2.23 (7)	16.21	21.99
Femur III	5.80±0.28 (7)	5.32	6.23	5.36±0.54 (6)	4.64	6.05
Patella III	2.20±0.18 (7)	2.03	2.58	2.34±0.32 (6)	1.85	2.67
Tibia III	3.87±0.21 (7)	3.67	4.27	3.35±0.25 (6)	2.90	3.62
Metatarsus III	5.50±0.35 (7)	5.17	6.15	4.26±0.51 (6)	3.67	5.12
Tarsus III	3.27±0.23 (7)	2.87	3.58	2.75±0.23 (6)	2.47	3.04
Leg III length	20.48±1.22 (16)	18.35	22.70	17.50±2.15 (7)	14.07	20.51
Femur IV	7.28±0.32 (7)	6.68	7.70	6.90±0.74 (6)	5.82	7.89
Patella IV	2.50±0.10 (7)	2.36	2.66	2.69±0.31 (6)	2.37	3.18
Tibia IV	5.64±0.25 (7)	5.32	6.07	5.18±0.47 (6)	4.59	5.76
Metatarsus IV	7.55±0.40 7()	7.11	8.36	6.51±0.81 (6)	5.66	7.77
Tarsus IV	3.97±0.24 (7)	3.68	4.28	3.38±0.27 (6)	3.02	3.75
Leg IV length	26.74±2.27 (16)	20.86	29.08	23.94±3.02 (7)	19.47	28.10

Males, on the other hand, were more concerned with mating, the copulation in this species taking place in autumn (Fuhn & Niculescu-Burlacu 1971).They have longer legs which facilitate movement in search of sexual partners (Gasnier et al. 2002, Foellmer & Fairbairn 2005, Framenau 2005, Sas-Kovács et al. 2015), and may also play role in avoiding predators (Moya-Larano et al. 2002). Females remain in burrows all the time, occasionally coming to the surface to seize a possible prey or to widen their burrow, being active in the vicinity of the burrow entrance (Chikhale et. al. 2013). Mating take place at the entrance of the burrow because below, its diameter is just enough to allow the passage of a single individuals (Miller & Miller 1987). Females are most likely to encounter males with high mobility, which are usually also the fittest (Ahtiainen et al. 2004). Nevertheless, males lose energy reserves during roving for suitable mates, but this, as it was shown for the orb-weaving spider *Argiope aurantia*, is not size dependent, with larger males not being necessarily in advantage (Foellmer & Fairbairn 2005).

Framenau (2005) studying two species of wolf spiders with different life history found, similar to us, that males had considerably longer legs than females, but this was true only in the case of *Venatrix lapidosa*, whose females also excavate burrows, and not in *Artoria* in which both the males and females are vagrant. *G. vultuosa* is also a burrowing wolf spider, but longer legs in males had also been reported in *Alopecosa psammophila* (Sas-Kovács et al. 2015), a wolf spider species in which burrow construction behaviour has not yet been revealed. Thus, this gender specific difference does not seem to be limited to Lycosidae species with sedentary females.

Our results on body size and length of the prosoma of the *G. vultuosa* individuals mirror findings of other studies on this species (e.g. Fuhn & Niculescu-Burlacu 1971), indicating that this characteristic is well conserved in many circumstances. However, not all *Geolycosa* species are this big, for example *G. xera archboldi* and *G. hubbelli* have a mean prosoma width of only 3.55 mm, and 4.47 mm, respectively (Carrel 2003). Although there is sexual size dimorphism in *G. vultuosa*, this is not as pronounced as in some other spider species. For example, considering the RA index (rough area), we obtained that males are 1.32 larger than females, while Gasnier and his collaborators (2002) received for SSD-RA values between 1.32 and 2.78, for various Ctenidae species. Nevertheless, the greatest differences in this size index were obtained for those species in which there was a significant gender difference in prosoma length too. Few lycosid species exhibit extreme sexual size dimorphism with males reaching a maximum 50% of females' size (see in: Logunov 2011). It should also be noted, that these dimorphisms, i.e. in RA, longer legs, become evident only after the spider reaches sexual maturity (Gasnier et al. 2002, Framenau 2005).

Weight gain and size of spiders can be influenced by a multitude of factors, such as prey availability (Bowden & Buddle 2012, Dahirel et al. 2011), or in the case of burrowing spiders the size and the average distance of the nearest neighbour, the average value of the neighbours within a radius of one meter (Marshalll 1999). However, Marshall (1999) conducting research on a population of *G. xera archboldi* in central Florida found that mass gain was influenced only by the size of the nearest neighbour, though in a negative manner. Interestingly, in our study, weight was only moderately correlated with the other measured parameters. It was the worst performing variable in this sense. All the others yielded strong or very strong correlations in the pairwise combinations. This has importance for situations when there is not enough time and/or resources for complex measurements and a single parameter that reflects the total body condition, is required. Several studies use prosoma width in this regard (Framenau 2005, Bowden & Buddle 2012, Ameline et al. 2018, Dahirel et al. 2019, Hein et al. 2019, Beckers et al. 2020), since while the width of prosoma is a parameter with a relatively fixed value in the case of an adult spider, the total weight or body length varies with the ingestion of food or water (Uetz et al. 2002). In our study, the length of prosoma seems to be rather a good proxy of body size (Figs 7, 8), which in turn, can offer indications on the development conditions of its owner (Ameline et al. 2018), and can be efficiently used even for discrimination between subspecies (Puzin et al. 2014). Use of the prosoma length as a proxy of body size has been suggested before for spiders with elongated carapace (Gasnier et al. 2002).

Because of the moderately large sample size, and a little underrepresented female number, our result is robust, but still may represent a good starting point for future researches comparing the biometric features of different *G. vultuosa* populations according to habitat conditions. The Carei Plain is an ideal land in this sense, as here the species populations are relatively stable and even expanding due to the generation of new habitats through the excessive grazing practiced in the area (Sas-Kovács & Sas-Kovács 2014a).

Conclusions

Length and width of the prosoma, opisthosoma and sternum, and length of the legs were measured for 54 individuals of *Geolycosa vultuosa*, which is a large-sized burrowing wolf spider species, occurring predominantly in open sandy habitats. Total body length of females varied between 15.57 and 22.05 mm, and that of males between 14.65 and 18.65 mm. The body length of females was significantly greater than that of males, and this is due to the larger size of the opisthosoma, with an area of 51.36±11.67 in females, compared to 29.83±5.54 in males. The

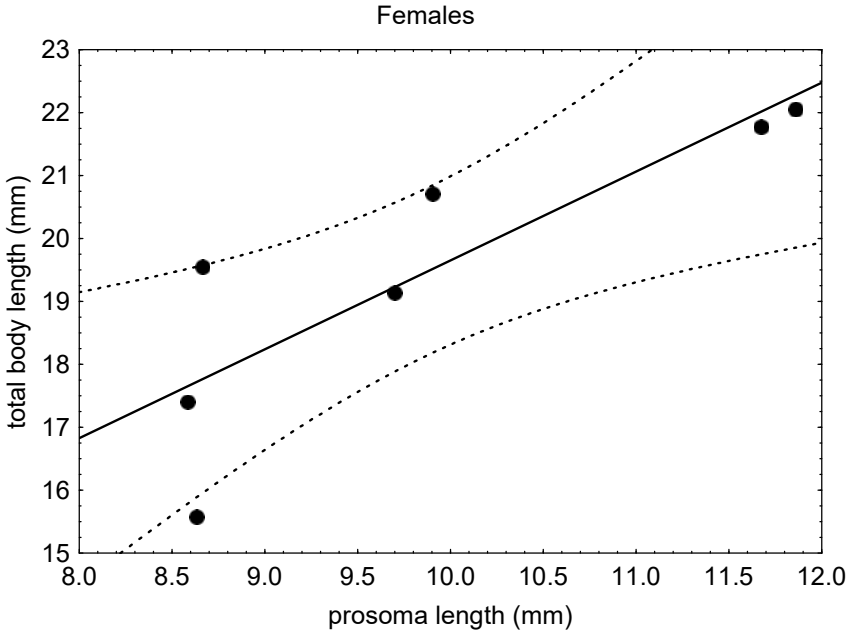

Figure 7. Correlation between prosoma length and body length in females.

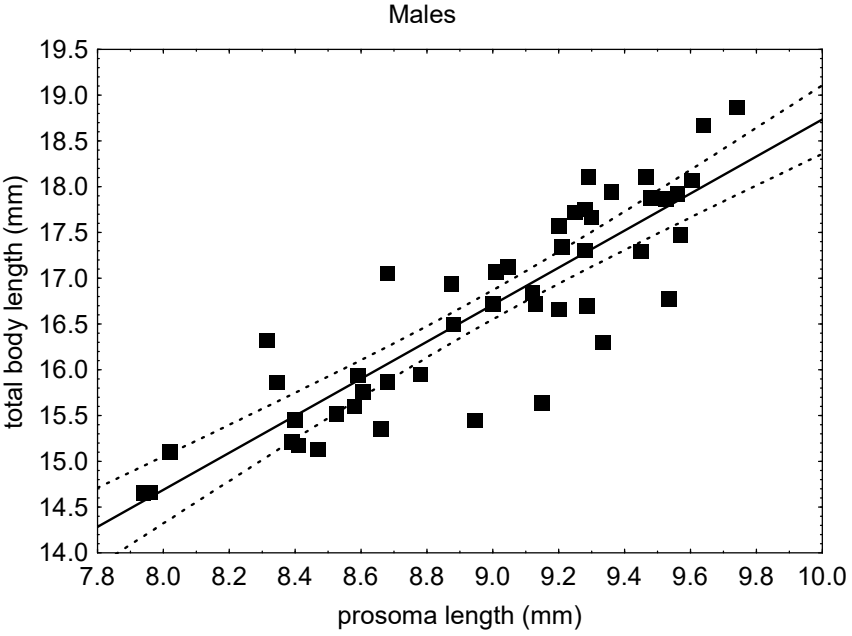

Figure 8. Correlation between prosoma length and body length in males.

opisthosoma expands if the spider eats, and in autumn females prepared for hibernation and egg development, thus accumulated energy reserves. Males had significantly longer legs and a greater rough area. Longer legs may facilitate movement in order to find the right sexual partner, and to avoid predators.

Weight of male spiders varied between 210 and 670 mg, with an average of 670 mg. Pairwise analyses showed statistically significant correlations ($p<0.05$) and positive in all cases in males, but weight was only moderately correlated with the other measured parameters. In the case of females, statistically significant ($p<0.05$) and positive correlations were obtained for the prosoma length with its width, and with opisthosoma width and body length. According to our results, the best parameter to predict body size of *G. vultuosa* is prosoma length.

The sexual size dimorphism, although exists in the case of this species too, is not that marked. There is a female-biased SSD in the case of prosoma and opisthosoma length and width, and total body length and a male-biased SSD in the other considered indices.

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