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Tick parasitism is associated with home range area in the sand lizard, *Lacerta agilis*

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Abstract. The sand lizard (*Lacerta agilis*) is a common species in Europe that inhabits a wide range of habitats, including anthropogenic environments. It is a frequent carrier of common ticks (*Ixodes ricinus*), which poses a severe threat to the lizards' health. We determined the living space used by lizards in a rapidly changing environment and ascertained the number of parasitic ticks found throughout the reptile's active season. We conducted telemetry research on a dynamically developing housing estate located on the outskirts of the city of Zielona Góra (western Poland) in 2016-2017. We obtained data from 16 adult lizards, from which we collected 2529 ticks. Using generalized linear models (GLMs), we determined the relationships among the number of transmitted parasites, size of occupied areas (minimum convex polygon, MCP), the weight of lizards, and sex of lizards. Results indicated that the number of ticks was negatively correlated with lizard body mass, but positively correlated with home range. Sex was not significantly associated with the number of ticks. Additionally, the parasite load was lower during the lizard's non-breeding season than during the breeding season and was lower for males than for females during the non-breeding season. Males have larger home ranges than females.

Keywords: built-up area, *Ixodes ricinus*, *Lacerta agilis*, MCP, parasitism, sand lizard, ticks.

Introduction

The fitness of wild animal populations depends on the effects of many biotic and abiotic factors. One of these factors is ectoparasitism, which can impact the health of the host (e.g., Siuda, 1993; Kurczewski, 2014). Ticks parasitise many reptiles, birds, and mammals, but generally prefer warm-blooded animals (Siuda, 1993; Slowik and Lane, 2009). Ectoparasites, the most common of which is the common tick (*Ixodes ricinus*), are harmful to small-sized lizard species (Blanke and Fearnley, 2015). A heavy load of parasites can make it difficult for lizards to obtain food and escape from predators (e.g., Kurczewski, 2014). In addition, *I. ricinus* is a vector for various pathogenic microorganisms (e.g., Stanek, 2009; Hvidsten et al., 2020). The wounds it inflicts heal slowly as a result of the secretion of substances that prevent blood clotting. That, in turn, facilitates the penetration of pathogens (Bauwens, Strijbosch and Stumpel, 1983; Siuda, 1993; Stanek, 2009; Megía-Palma et al., 2020). Ectoparasitic infestation may have physiological consequences in lizards, as reported e.g., by Megía-Palma, Martínez and Merino (2018), who in their experimental studies found that parasites adversely influence the expression of the structural-based coloration of male Iberian green lizards and adds evidence to the hypothesis that sexual ornaments in lizards function as honest signals. Boulinier et al. (1977) examined the genetic variability of host susceptibility to parasites. They investigated the potential correlation between parent and offspring ectoparasite load, and they suggested a heritable susceptibility to ectoparasitism by ticks in the host population; this character thus has the potential to respond to natural selection. According to other researchers (Molnár et al., 2013), an infection can significantly reduce an individual's fitness, so parasite load

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can have a strong effect on the evolution of reproductive systems and strategies.

Many studies of local sand lizard populations have examined preferred habitats, reproduction, population genetics, and protection (e.g., Olsson, 1993; Gullberg, Olsson and Tegelström, 1998; Moulton and Corbett, 1999; Madsen et al., 2000; Joger et al., 2007; Andres et al., 2014; Botond et al., 2015), as well as a lot of studies concerning home range and the use of habitat resources which are the most common forms of spatial analyses performed by ecologists. These data have been reported for *L. agilis* in Russia by Tertyshnikov (1970), in Sweden by Olsson (1986), and in England by Dent (1986) and Nicholson and Spellerberg (1989), however, none of these studies reported data explaining sexual differences of lizards in ectoparasite load include in the analyses the effect of the home range.

Using radio-telemetry in research facilitates repeated localisation of individuals and can provide knowledge on home range, behavioural patterns and habitat use within populations (Cagnacci et al., 2010; Signer and Balkenhol, 2014). By using radio telemetry, capture-recapture and tick counting in sampled lizards, we can expect to measure the degree of ectoparasitic infestation. Considering that extensive land use can affect the typical behaviours of lizards, we can also expect that some characteristics of individuals could affect their exposure to ectoparasitism, including home range size, sex and body mass.

The aims of this study were: a) to investigate associations between areas inhabited by lizards and the type, location on the body, and the number of ticks that parasitise them in a rapidly transforming suburban area; and b) to determine the relationships between the size of the area occupied by the lizards and their sex and body mass. Also, tick infestation during and after the *L. agilis*' breeding season was considered.

Materials and methods

Study area

The research was conducted in the city of Zielona Góra (western Poland; 51°52.276′N; 15°27.381′E). Currently, this area contains a diverse array of habitats, but houses are being built in various sections of the region alongside extensively cultivated fields and wastelands. In January of 2016, the largest proportion (69.9%) of the land cover comprised grasslands, arable lands, and mosaics of fresh meadows (*Arrhenatheretalia elatioris*); another 23.5% was riparian forest (Alno-Ulmion); 6.3% was built-up area; 1% was roads; and 0.4% was water. By November of 2017, the proportion of built-up area had increased to approximately 10-11%, at the expense of wastelands. Herbaceous vegetation in this area was dominated by common bent grass (*Agrostis capillaris*), false oat-grass (*Arrhenatherum elatius*), common meadow-grass (*Poa pratensis*), bull grass (*Bromus hordeaceus*), wood small-reed (*Calamagrostis epigejos*), and fescue pale (*Festuca pallens*). Shrubs present in the area included hawthorn (*Crataegus* spp.), dog rose (*Rosa canina*), black elder (*Sambucus nigra*), and blackberries (*Rubus* spp.). Trees present in the area were black alder (*Alnus glutinosa*) and silver birch (*Betula pendula*). The study took place in a lowland area at an altitude of 75-82 m above sea level (a.s.l.), and 10-15% of the area is periodically submerged. The long-term average annual temperature is 8-8.5°C, the average number of days per year with snow cover is 40-50 days and the frost-free period lasts for approximately 188 days. The average annual rainfall is approximately 600 mm, and the growing season lasts for approximately 223 days (Zajchowska, 1972; Demidowicz, Konopczyński and Susek, 2016).

Radio-telemetry

The radio-telemetry study was conducted from spring to autumn of 2016 and 2017. The focus was between late March and late June when lizards mate and lay eggs (the breeding season), and from early July to early November when lizards engage in intensive feeding, end their seasonal activities and prepare for hibernation (the non-breeding season). We began capturing lizards during the first week they could be found above ground and ended after we received signals from underground hiding places for several consecutive days; we assumed the lizard was in hibernation (Wone and Beauchamp, 2003). Lizards were captured by hand, measured using Hogetex calipers with an accuracy of ±0.1 mm and weighed using a ProScale LCS100 with an accuracy of ±0.1 g. We used Holohil System Ltd. type BD-2 transmitters weighing 0.7-0.9 g and transmitters of our own design weighing 0.6-1.1 g for radio telemetry. We attached the transmitters to the dorsum of each lizard using surgical glue. Every 5-8 weeks, we re-captured lizards and replaced the transmitters. To verify secure attachment of the transmitters, we placed each lizard in an individual box (60 cm long × 40 cm wide × 40 cm high) with soil, hiding places and access to water, where they remained overnight before being released the next day in the location where they were captured.

Using an Australis 26K tracking receiver, ICOM IC-R20 type radio-tracking receiver, and Yagi or wand-type antennas, we radio-located the lizards one to three times each week between 10:00 h and 20:00 h. We recorded the locations of the lizards using a Garmin GPSMAP64S device on a 1:10 000 topographical map. Based on the coordinates obtained from the tracked animals, we generated a point-based geographic information system layer. We estimated the home range of each lizard via the minimum convex polygon (MCP) method (Mohr, 1947) and determined individual home range areas using the 'adehabitatHR' package in R (Calenge, 2006).

Whenever it was possible to track and capture an individual, we removed the ectoparasites from it using tweezers. Tweezers were disinfected before removing each tick, and the lizard was released in the same capture location. We determined the developmental stages of the ticks and their species affiliations using the determination key of Ixodida (Siuda, 1993). We used a Nikon SMZ 3000 stereomicroscope equipped with software for taking measurements and photos of the ticks (Nikon NIS Elements-D). Parasites were preserved in 80% ethanol and deposited in a collection at the Faculty of Biological Sciences of the University in Zielona Góra.

Statistical analyses

We ran two generalised linear models (GLMs; Guisan and Zimmermann, 2000) to explore the associations between the number of ticks or the occupied area (both modelled as response variables, separately) and body mass, the sex of individual lizards and the season as predictors. We used Pearson's product-moment correlations to explore the relationships among predictors (body mass, sex and season) to avoid overly redundant covariates. Only predictors with Pearson's product-moment correlation values below 0.6 were included to avoid multi-collinearity (Graham, 2003).

The first model accounted for variations in the number of ticks found in relation to body mass, home range (MCP area), and interactions between sex (male/female) and season (breeding/non-breeding). We fitted the model assuming a Poisson distribution for the "number of ticks" after we have determined the type of distribution of the variable (Box and Cox, 1964) using the package 'MASS' (Venables and Ripley, 2002). The second model accounted for variations in home range (MCP area) in relation to interactions between sex (male/female) and season (breeding/non-breeding). MCP area was log-transformed after exploring the type of distribution of the variable (Box and Cox, 1964). We assumed a log-normal distribution in the model fitted for the MCP area, and we have controlled that residuals of the model fit normality, following a homoscedastic distribution. We used the Akaike's Information Criterion (AIC) to determine the model that 'best' explained variations in the data (lower AIC; Burnham and Anderson, 2002). Confidence intervals for significant variables were estimated using MASS (Venables and Ripley, 2002). All statistical tests were performed using R software version 3.2.4 (R Development Core Team, 2019).

Results

Catching and tracking

We caught a total of 44 adult lizards (22 individuals during each season), and the data from eight males and eight females (four of each per season) were included in the analysis. Thus, the study included data from 16 individuals (36.4%) that we were able to track throughout the entire season of activity. For the remaining 28 individuals (63.6%), the data was incomplete. We either lost contact with them (18 individuals; 40.9%), or they died on the roads (7 individuals; 15.9%) or were killed by birds (stuck in the thorns of bushes) (3 individuals; 6.8%). Estimates of home range area calculated via the MCP method are known to depend upon sample size (White and Garrott, 1990). Our estimates of home range area reached a plateau with 12 sightings per lizard (the minimum number of 10 sightings per individual was reported for lizards by Ferner (1974)). The average number of sightings we obtained for lizards was well above this threshold, and we excluded from further analyses those lizards with fewer sightings. Thus, we could include 16 lizards in the home range calculations. A total of 402 lizard locations were recorded. Individuals were relocated 12-35 times and were captured/re-captured 12-31 times. Male snout-vent-lengths (SVL) ranged from 61 to 69 mm and body weights ranged from 15.7 to 16.8 g; in females, those values ranged from 67 to 75 mm and from 17.8 to 19.1 g, respectively (table 1).

Home range and ticks obtained from lizards

Overall, the area occupied and the distances covered by lizards were different between males and females (16 individuals in total) (table 2). During the breeding season, males occupied a larger area (3.2 $\pm$ 2.2 ha) than females (0.4 $\pm$ 0.4 ha) (table 2). After the breeding season, females occupied a larger area (0.5 $\pm$ 0.9 ha) than males (0.2 $\pm$ 0.2 ha) (table 2). The average MCP area for all males was 3.5 $\pm$ 2.2 ha (min = 0.9 ha, max = 8.0 ha). For females, the average

Table 1. Characteristics of individual sand lizards captured in western Poland in 2016 and 2017. SVL = snout-vent length.

	Ind No.	SVL (mm)	Body mass (g)	Tracking dates	No. of relocations	No. of captures
			Males			
	T2	66	15.7	28.03-04.10.2016	35	31
	T3	68	16.2	28.03-09.10.2016	19	18
	T6	67	16.0	07.04-20.10.2016	16	14
	T8	69	15.7	07.04-05.10.2016	17	17
	T9	69	16.8	30.03-28.10.2017	32	24
	T11	61	15.7	30.03-05.11.2017	33	22
	T13	67	15.7	30.03-28.10.2017	32	22
	T15	63	15.7	30.03-05.11.2017	29	26
Mean ± SD		66.2 ± 2.9	15.9 ± 0.4		26.6 ± 7.9	21.7 ± 5.4
			Females			
	T1	69	18.2	28.03-05.10.2016	27	24
	T4	71	19.1	01.04-19.10.2016	23	19
	T5	69	18.2	07.04-19.10.2016	12	12
	T7	70	18.7	07.04-02.10.2016	17	17
	T10	75	17.8	31.03-10.10.2017	25	21
	T12	70	17.8	30.03-23.09.2017	28	20
	T14	67	18.6	30.03-05.11.2017	29	21
	T16	70	19.0	30.03-28.10.2017	28	25
Mean ± SD		70.1 ± 2.3	18.4 ± 0.5		23.6 ± 6.1	19.8 ± 4.1

MCP area for females was 1.0 ± 1.5 ha (min = 0.3 ha, max = 4.8 ha) (figs. 1 A, B; table 2). When analysing the distance travelled by males, the smallest distance found was 346 m and the largest was 2167 m. For females, the smallest distance travelled was 295 m (individual T7) and the largest was 1086 m (individual T1) (table 2).

The number of ticks collected from 8 males and 8 females sand lizards is showed in table 2. Overall, throughout the study period, males had 192.5 ± 96.9 ticks, while females 123.6 ± 50.4 ticks. During the breeding season, for males were recorded 146.5 ± 75.8 ticks, and for females 71.0 ± 34.5 ticks. After the breeding season, we observed 46.0 ± 29.6 ticks for males, and 52.6 ± 26.2 ticks for females (table 2).

Throughout the study period, from the 16 lizards, a total of 2529 common ticks were obtained, including 628 larvae, 1899 nymphs, and two adult females. We found the largest accumulations of ticks in the armpits of the forelimbs (72.6%), in the region of the eardrum (22.5%) and at the neck (3.3%). In other body regions (hind limbs, sides of the body, and mouth), the number of parasites was low (1.6% combined).

The results of the GLM indicated that the number of ticks found on a lizard was negatively correlated with body mass but was strongly and positively correlated with home range area (table 3A, fig. 2A). A very important result of our research is the fact that the sex of lizards was not significantly associated with the number of ticks it hosted (table 3A). Additionally, the number of parasites on the lizards was lower during the non-breeding season than during the breeding season and was lower for males than for females during the non-breeding season (table 3A). Home range areas were larger for males than for females (table 3B, fig. 2B). However, home range area decreased for males during the non-breeding season (table 3B).

Discussion

Sand lizards are a widespread species in Europe (Speybroeck et al., 2016), including in Poland, where they primarily inhabit lowland and mountain areas up to 900-1100 m a.s.l. (Sura, 2018). These lizards can live in various environments,

Table 2. Summary of radio-tracking data and number of ticks found for sand lizards captured in western Poland in 2016 and 2017, shown for both seasons combined and for each season individually. MCP = minimum convex polygon.

	Ind. No.	Sex	Total distance moved (m)	Total MCP home range (ha)	Breeding MCP home range (ha)	Non-breeding MCP home range (ha)	No. of ticks (min-max)	No. of ticks (breeding)	No. of ticks (non-breeding)	No. of all ticks
	T2	male	2167	8.0	7.817	0.763	1-23	190	38	228
	T3	male	346	0.9	0.923	0.002	1-43	100	12	112
	T6	male	613	2.5	2.466	0.034	1-7	22	24	46
	T8	male	641	2.2	1.551	0.037	1-46	93	35	128
	T9	male	610	1.6	1.490	0.055	1-30	113	41	154
	T11	male	896	4.2	3.374	0.184	1-57	189	77	266
	T13	male	1094	4.3	4.048	0.177	1-43	241	38	279
	T15	male	1326	4.4	4.185	0.535	1-43	224	103	327
Mean ± SD			961.6 ± 577.5	3.5 ± 2.2	3.2 ± 2.2	0.2 ± 0.2		146.5 ± 75.8	46.0 ± 29.6	192.5 ± 96.9
	T1	female	1086	4.8	0.863	2.709	1-17	75	87	162
	T4	female	530	0.6	0.477	0.069	1-17	75	26	101
	T5	female	361	0.4	0.424	0.024	1-16	37	8	45
	T7	female	295	0.3	0.066	0.139	1-19	46	60	106
	T10	female	517	0.4	0.179	0.313	1-9	33	42	75
	T12	female	388	0.3	0.115	0.091	1-36	141	56	197
	T14	female	656	1.1	1.079	0.111	1-21	81	66	147
	T16	female	405	0.3	0.141	0.292	1-21	80	76	156
Mean ± SD			529.7 ± 252.1	1.0 ± 1.5	0.4 ± 0.4	0.5 ± 0.9		71.0 ± 34.5	52.6 ± 26.2	123.6 ± 50.4

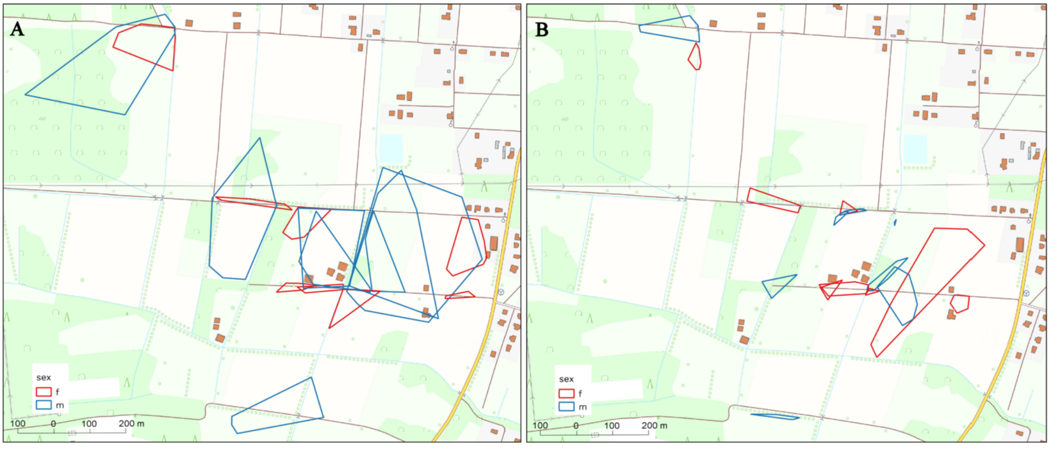

Figure 1. Minimum convex polygon (MCP) estimates showing home range areas for male and female sand lizards during: (A) the breeding season (late March/early April to end of June) and (B) the non-breeding season (early July to October/November).

Table 3. Results of generalised linear models accounting for: (A) the number of ticks found on sand lizards in Zielona Góra, in relation to body mass, home range (minimum convex polygon, or MCP, area), and interactions between sex (male vs. female) and season (breeding vs. non-breeding) and (B) log-transformed home range areas (minimum convex polygon, or MCP, in ha) of sand lizards in Zielona Góra, in relation to interactions between sex (male vs. female) and season (breeding vs. non-breeding). Confidence intervals: 2.50-97.50%.

Variable	Estimate	2.50%	97.50%	Std. Error	*z* value	*p*
		A				
Intercept	7.280	5.336	9.233	0.994	7.323	<0.001
Body mass (g)	−0.167	−0.273	−0.061	0.054	−3.092	0.002
MCP area (ha)	0.121	0.096	0.146	0.013	9.546	<0.001
Sex (Male)	−0.073	−0.346	0.199	0.139	−0.526	0.599
Season (Non-breeding)	−0.312	−0.439	−0.187	0.064	−4.857	<0.001
Interaction (Male: non-breeding)	−0.439	−0.635	−0.243	0.100	−4.398	<0.001
		B				
Intercept	−1.278	−2.196	−0.359	0.469	−2.725	0.011
Sex (Male)	2.248	0.948	3.547	0.663	3.390	0.002
Season (Non-breeding)	−0.520	−1.819	0.779	0.663	−0.785	0.439
Interaction (Male: non-breeding)	−2.964	−4.802	−1.126	0.938	−3.161	0.004

including the human environment, where much of its habitat experiences rapid and significant transformation, as exemplified by the suburban areas of Zielona Góra where we conducted our research.

Sand lizards usually exhibit small individual home range areas, which indicates stable habitats characterised by adequate sunlight, a large number of hiding places, a variety of available food and low predation pressure (Kurczewski, 2014; Blanke and Fearnley, 2015). In a population studied in England, individual ranges of this species were reported to be approximately 2000 m^2 (0.2 ha) for males, whereas females had ranges that were comparable to or smaller than those of males, depending on the type of habitat (Nicholson and Spellerberg, 1989). This study examined open heathland that was heterogeneous in nature with a disused railway site, a bog, a small lake, and a mixed deciduous woodland. The researchers analysed data obtained from more than three catches of 16 males and 12 females. A similar study conducted in Sweden

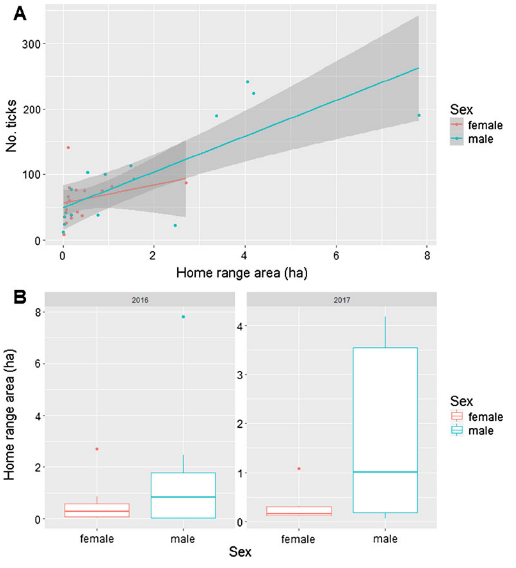

Figure 2. (A) Associations between number of ticks infecting individual sand lizards and area of home ranges (minimum convex polygons) of sand lizards in Zielona Góra. Grey regions around the lines represent 95% confidence intervals. (B) Differences in home range areas (minimum convex polygons) between male and female sand lizards in Zielona Góra over two years of study.

(from April to June) showed an even smaller average area of movement; for 29 males, the average area was 1110 m^2 (0.11 ha), and for 19 females, the average area was 156 m^2 (0.02 ha) (Olsson, 1986). That study was conducted on a large southeast-facing slope consisting primarily of bare rock alternating with shrub and bush vegetation. Further data were reported by Dent (1986), who conducted research in England on plantation compartments where trees had not yet reached the thicket stage. The average areas for five males and ten females were 1681 m^2 (0.17 ha) and 1100 m^2 (0.11 ha), respectively, indicating greater activity for males.

Compared to the results of studies relating to the individual home range areas for male and female lizards the English (Dent, 1986; Nicholson and Spellerberg, 1989) and Swedish populations (Olsson, 1986), our research has shown much greater ranges in female and male sand lizards (average total MCP 1.0 ± 1.5 ha and 3.5 ± 2.2 ha, respectively; table 2). In addition, the results of our research have shown a significant relationship between home range and ectoparasite load of lizards, which is certainly a novelty in our study (table 3A, fig. 2A).

Over 428 days of research, we collected 2529 ticks from 16 lizards, indicating that sand lizards are important hosts for these parasites. These lizards help to maintain the tick population by feeding primarily larvae and nymphs. Adult forms were very rarely found; in Wielkopolski National Park, Kurczewski (2014) found only three adults, and we found two; i.e., 0.08% of total observations. Observations reported by other researchers confirm that lizards can be the carriers of a diverse number of ticks, ranging from a few to over 100 on a single individual (Jansen, 2002). Our research shows that the highest number of *I. ricinus* found on a male lizard at one time was 57 and on a female was 36. These values may represent underestimates, as evidenced by a male *L. agilis* that was caught in May 2018 in a damp mid-forest clearing 5 km from our research site carrying 230 ticks.

Research conducted on different populations of sand lizards confirms that the number of ticks can differ among males, females, and juveniles (e.g., Chilton, Bull and Andrews, 1992; Prendeville and Henley, 2000). Rahmel and Meyer (1988) observed local tick infestations in Germany on as many as 94.4% of males and 83.2% of females. In Poland (Wielkopolski National Park), a previous study found ticks on 40% of males and 29.2% of females (Kurczewski, 2014). An important result of our research is that the sex of the lizards was not significantly associated with the number of ticks it hosted (table 3A). A large number of parasites on males is often explained by their greater mobility, especially during the breeding season (e.g., Kurczewski, 2014). Although, Olsson et al. (2000) demonstrate in a field experiment that male sand lizards exposed to elevated testosterone suffered from increased mass loss and tick load compared to control males. As researchers suggest, these results could be due to an elevated basal metabolic rate from increased plasma testosterone levels, the increased parasite load was statistically independent of the loss in body condition and is likely to be due to compromised immune function. Our research shows that the average number of ticks on males was three times higher during the breeding season than the non-breeding season (146.5 ± 75.8 and 46.0 ± 29.6, respectively; table 2). The average number of ticks on females was almost two times lower than on males, but comparable during and after breeding season (71.0 ± 34.5 and 52.6 ± 26.2, respectively; table 2). Generally, the areas of male movement in different species of lizards are larger (Perry and Garland, 2002), a consequence of their high testosterone levels, which is also known to decrease immune performance and increase their susceptibility to infections (e.g., Salvador et al., 1995; Uller and Olsson, 2003; Oppliger et al., 2004).

Studies show that there are clear preferences for tick attachment sites on host bodies (Burridge and Simmons, 2003). *I. ricinus* usually prefers the area around the forelegs (e.g., Bauwens, Strijbosch and Stumpel, 1983; Apperson et al., 1993; Ra et al., 2011). Kurczewski (2014) reported finding ticks almost exclusively in this area. In this area of the body, scales are small and do not adhere closely to each other, which may be the primary factor determining the parasites' feeding location (Salvador, Veiga and Civantos, 1999). The area around the forelegs also has a thinner skin and an increased blood vessel density compared to the skin around the hind legs (White, 1976). In addition, hiding under the armpit prevents the lizard from removing the ticks and provides better protection against strong sun exposure and lower temperatures, which is preferred by these parasites (e.g., Randolph and Storey, 1999; Kurczewski, 2014). Our observations confirm the tendency of ticks to accumulate primarily in the area of the forelegs (72.6%).

The population size of various species of reptiles is systematically decreasing, which is caused by the impacts of many factors, among others: habitat loss and degradation, introduced invasive species, environmental pollution, disease, unsustainable use, and global climate change (Gibbons et al., 2000). The results of our research suggest that extensive land-use changes in suburban areas targeted for construction investments can affect the typical behaviours of lizards, causing them to expand their home ranges and increase their moving distances, thus increasing their degree of infestation by *I. ricinus*. In turn, as reported by other researchers (e.g., Uller and Olsson, 2003), a large number of ectoparasites has a negative effect on the physiology, condition, behaviour, ecology and survival of lizards.

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