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Anti-predatory behaviour of Common Wall Lizards (Lacertidae: *Podarcis muralis*) in habitats with different density levels of built-up in a Central European city

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The Common Wall Lizard (*Podarcis muralis*) is a small European lacertid species with the largest distribution range among *Podarcis* lizards (Sillero et al. 2014). In addition to its natural habitats, it is one of the most common reptile species in urbanized areas (e.g., Schulte et al. 2011, Dékány et al. 2015, Lazić et al. 2017, Vukov et al. 2020). Lizard density in natural and urban environments is affected by a number of factors, such as habitat diversity, availability of resources, presence of competitors and predators as well as human disturbance (Pérez-Mellado et al. 2008). Lizards occupy an intermediate place in the trophic food chain, for which reason they suffer from a high predation rate (Biaggini et al. 2010). Being heliothermic, Common Wall Lizards spend a lot of time in exposed situations basking in the sun to acquire warmth, and it is mostly during these periods that they are preyed upon by predators such as, e.g., Smooth Snakes (*Coronella austriaca*) (Rugiero et al. 1995), Common Kestrels (*Falco tinnunculus*) (Costantini & Dell'Omo 2010), or Domestic Cats (*Felis silvestris catus*) (Széles et al. 2018). In their interactions, both prey and predators constantly adapt their decision-making to physiological conditions and ecological circumstances (Pellitteri-Rosa et al. 2017). To survive in the presence of predators, potential prey must be able to assess risks quickly and adjust their escape behaviour according to the current risk level (Cooper Jr. 2006). The ability to successfully avoid predators will greatly affect the future fitness of the prey (Lima & Dill 1990). Fitness characteristics suggest that animals possess the ability to assess the risk of being preyed upon and make decisions based on their assessment of available information (Lima & Dill 1990). The degree of fear perceived by animals under certain circumstances is a motivational state that is influenced by many factors (Stankowich & Blumstein 2005). The most common defence strategy for lizards is escaping to a safe hiding place (e.g., Pough et al. 2004, Amo et al. 2005, Samia et al. 2016), therefore they are suitable as models for studying escape patterns (Martín 2001). Perceived levels of fear cannot be observed, but behavioural responses can be categorized and measured. Lizards usually respond to humans as they do to potential predators (Martín & López 1999) and their fear of predation or their perceived risk of predation can be quantified by measuring the distance at which they will respond to an approach with taking to flight (Stankowich & Blumstein 2005, Hawlena et al. 2009). As the degree of human presence differs between human-populated areas, individuals of the animal species living there can also be expected to exhibit differences in their anti-predator responses (Samia et al. 2015), which may be influenced to some extent by factors not directly related to predatory pressure (Pellitteri-Rosa et al. 2017). In larger cities, however, it is not easy to link the human presence and the anti-predator behaviour of some anthropogenic animal species to an urban gradient, as both are influenced by the existence of adequate habitats and built-up areas.

The aim of our study was to explore the anti-predatory behaviour of Common Wall Lizards in sectors with different degrees of built-up in the largest city of the Transdanubian region in Hungary, Pécs. We were specifically interested in assessing how human proximity and some environmental variables, such as time of observation, air temperature, and the number of passers-by, influence the flight-trigger distances and the distances fled by juvenile and adult lizards.

Our study was performed in the city of Pécs (46.070° N, 18.219° E) in southwestern Hungary with a human population of ca. 150,000. Due to its historical and cultural heritage, this city is an important tourist destination, whereas industry is less developed. It is situated on the southern slopes of the Mecsek Mountains, partly occupying the lowland known as the Pécs Plain. The altitude of the city extends from 115 to 416 m above sea level (average altitude 180 m a.s.l.; Ronczyk et al. 2015). The climate is transitional between oceanic and continental and influenced by the Mediterranean effect (Mezősi 2017). The annual mean temperature is 10.7 °C (lowest in January -0.3°C, and warmest in July 20.8°C). The mean annual precipitation amounts to 638 mm, ranging from 398 to 867 mm (Bötkös 2006). Such climate is considered to be highly suitable for the Common Wall Lizards, even in urban habitats (Trócsányi & Korsós 2004, Purger et al. 2017).

Fieldwork was conducted from July through October, in 2015 (18 days of sampling), in 2016 (13 days), and in 2017 (18 days). We searched for Common Wall Lizards in a random approach by walking through the city between 8 and 19 h. The survey was random because we did not plan the routes for the field surveys in advance. We assumed that there were Common Wall Lizards in all parts of the city. We specifically cared to get as far as possible from the city centre and always choose a different route, in order to avoid repetitions. Field surveys were carried out by the same person (R. Bocz), always wearing the same trainers and similar bluish grey (jeans) clothing (Putman et al. 2017). When a lizard was spotted, the surveyor made no unnecessary movements, did not wave, and slowly approached the lizard in the manner a predator would do. If several lizards were present at a site, the surveyor always headed for the nearest animal and recorded only its predatory response and fleeing behaviour (Cooper Jr. & Avalos 2010, Cooper Jr. & Blumstein 2015, Pellitteri-Rosa et al. 2017). We measured two distances: the flight-triggering distance (FD) – i.e., the distance the lizard allowed the observer to approach before fleeing; and the distance fled (DF) – i.e., the distance from the lizard's initial position to a hiding place or to where it stopped its flight (Braun et al. 2010, Cooper Jr. & Avalos 2010, Williams et al. 2020). We estimated the density of built-up within a radius of 10 metres around the site of observation of the Common Wall Lizard and classified the results as highly built-up (more than 66% of the circle covered by concrete, stones or buildings), moderately built-up (between 33 and 66%, concrete, stones or buildings interspersed with small green patches), and less built-up (less than 33% covered by concrete, stones or buildings, semi-natural habitats dominate, e.g., grassland, lawn, garden), respectively. We recorded the coordinates of each point of encounter, and our earlier geodata records were checked with Google Maps. We recorded the date, exact time, age class of the lizards observed (juvenile or adult), air temperature, and the number of passers-by at the moment of the lizard's escape. We considered the age of lizards important because we presumed that adult lizards were more experienced than their juvenile counterparts, and they might have already become used to passers-by.

Since variables were not normally distributed, we tested the differences in mean DF between adults and juveniles with a Mann-Whitney U test. To evaluate the effects of the four (dependent) predictor variables on DF, we constructed a generalized linear mixed-effect model (GLMM) with a linear probability distribution using an identity link function. The GLMM modelled the relationship between DF and the four variables (independent variables), i.e., FD and time as fixed effects and air temperature and number of passers-by as covariates, with ID nested within site 'year' as the random factor. The predictor variables were inserted into a multicollinearity test, in order to check the strengths of relationship between the variables. The independent variables displayed no multicollinearity (maximum variance inflation factor = 1.117). The differences in FD and DF of lizards between highly, moderately and less built-up habitats, respectively, were tested with Kruskal-Wallis and Dunn's pairwise post hoc tests with Bonferroni's correction. The normality of the variables was tested with a Shapiro-Wilk test, and the homogeneity of variances was checked with Bartlett tests. Statistical analyses were performed in SPSS 23.0 software (SPSS Inc., Chicago, USA).

We observed 337 Common Wall Lizards escaping. The majority of observation sites (83%; n = 280), were highly built-up habitats, 13% (n = 44) were moderately built-up, and only 4% (n = 17) were less built-up and, e.g., semi-natural habitats. The mean DF was 1.4 ± 0.95 m, ranging from 0 (indicating that a hiding place was right at the point where a lizard was spotted) to 6.5 m. The DF did not differ between adult (1.5 ± 0.96 m, range 0 to 6.5 m), and juvenile lizards (1.3 ± 0.92 m, range 0 to 6.3 m; Mann-Whitney U test, U = 11045, $p = 0.054$).

The GLMM showed that DF correlated positively with FD and time (Table 1.), indicating that Common Wall Lizards fled over a larger distance when the perceived predator had come closer, and as the day was progressing. However, the covariates temperature and number of passers-by did not influence the DF of the Common Wall Lizards observed (Table 1).

The FD increased significantly towards the less built-up (semi-natural) habitats (Kruskal-Wallis test, H = 6.53, df = 2, $p < 0.038$). Dunn's pairwise post hoc tests showed that the FD was significantly longer in semi-natural habitats than in moderately and highly built-up habitats (Dunn's pairwise post hoc test, $p = 0.027$). We found no significant differences in DF between the three habitat categories (H = 2.51, df = 2, $p = 0.281$, Table 2.).

According to our results, lizards that allowed the surveyor to approach closer (FD was shorter) fled over greater distances (DF was longer), meaning that "tame" lizards fled farther than those that were more "worried". This finding is consistent with previous studies, in which it was reported that tameness and wariness of lizards may be related to differences in predation pressure (Deigo-Rasilla 2003a).

Table 1. Results of the generalized linear mixed-effect model testing of the effects of flight-trigger distance (FD), time, air temperature, and number of passers-by on distance fled (DF) in Common Wall Lizards.

Independent variables	Estimate ± SE	F	df_1, df_2	p value
(Intercept)	5.5±0.69	13.24	1, 282	< 0.001
Flight-trigger distance	6.1±0.61	8.79	161, 196	< 0.001
Time	0.6±0.43	4.51	9, 304	< 0.001
Air temperature	0.1±0.12	1.08	1, 276	0.299
Passers-by	0.0±0.17	0.02	1, 313	0.884

Table 2. Flight-trigger distance (FD ± SD) and distance fled (DF ± SD) of Common Wall Lizards in the three different habitat categories within the city of Pécs.

Habitat type:	Highly built-up	Moderately built-up	Less built-up
Flight-trigger distance (m)	1.9±0.78	2.0±0.81	2.7±1.42
Distance fled (m)	1.4±0.95	1.6±0.80	1.5±1.38

Urban animals are able to learn to adjust their responses to the intensity of human presence (Oosten et al. 2010, Rodríguez-Prieto et al. 2010). They do not flee if it is not actually necessary, because this may reduce their fitness and result in a shortage of energy and time required for hunting and parental care (Frid & Dill 2002).

We found that the DF of the lizards increased as the day progressed, however, it did not correlate with changes in air temperature and the number of passers-by. In most cases, the lizards likely responded only to the person approaching them, and the number of passers-by at this moment did not affect their escape behaviour. Earlier studies have reported that there is no consistent effect of body or ambient temperature on lizards' flight responses, as some species fled over greater distances when warm whereas others did not (Stankowich & Blumstein 2005). These contradictory results may be due to the fact that the activity pattern of Common Wall Lizards is bimodal, with the animals being more passive during the warm hours around midday (Braña 1991). The lizards' behaviour is also affected by the lighting conditions at night. For example, Common Wall Lizards living in cities can exhibit high activity even at night when light is available from artificial sources (Carretero et al. 2012).

Our study shows a tendency of flight-trigger distances increasing along a gradient from highly built-up habitats to semi-natural habitats, indicating that Common Wall Lizards are "tamer" in urban habitats, allowing humans to approach them closer. Still it is difficult to decide when we can talk about an anti-predator response in Common Wall Lizards, or to which degree they have adapted to the presence of humans in urban habitats. Recently, lizard tolerance induced by human disturbance has received much attention, and it has been reported that populations exposed to greater disturbances were more tolerant of humans than less disturbed ones (Samia et al. 2015). For example, lizards at tourist sites were less easily worried and their flight-trigger distances were shorter than in habitats that were less disturbed by humans (Diego-Rasilla 2003b). Reducing escape responses to the continuous or frequent presence of humans can be an adaptation, as humans are generally ignorant or have a more positive attitude towards urban animals (Liker 2020).

In our study, the distance fled was shorter in highly built-up habitats than in the moderately built-up or semi-natural ones. We recorded fewer lizard observations in the downtown sectors, probably due to the highly built-up character of that area and the greater numbers of humans present limiting the living space for lizards. Our observations were made in habitats differing greatly in the quantity and type of escape routes and hiding places available to lizards, therefore the differences in lizard flight behaviour can be partly explained by these circumstances. In an urban environment, the predators of Common Wall Lizards are primarily cats and other predatory mammals as well as birds, rather than humans whose constant presence they have become accustomed to. In moderately built-up and semi-natural habitats, the lizards encounter fewer humans and are more likely to respond to human presence just like they do to a potential predator. Moreover, the number of predators is higher in semi-natural habitats than in more urbanized settings, requiring the lizards to be more vigilant (Rebolo-Ifrán et al. 2017).

The results of our study performed in an urban environment draw attention to the fact that although Common Wall Lizard respond to human approach, this study of escape behaviour should not necessarily be regarded as a reaction to a predator, since a human's behaviour and speed of movement differ significantly from those of real predators. This is also indicated by the fact that more disturbance-tolerant individuals have been found in cities than in natural habitats (Samia et al. 2015). To find out if lizards consider humans as predators, comparative studies are needed in which lizards are also approached by real predator models (e.g., cat; Least Weasel *Mustela nivalis*; Red Fox *Vulpes vulpes*), and conclusions should be drawn based on the escape distances and behaviour triggered by these.

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