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Winter activity of *Podarcis muralis* (Laurenti, 1768) and *P. erhardii* (Bedriaga, 1876) in urban and suburban habitats in the city of Blagoevgrad, Bulgaria

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Abstract. In Bulgaria, lizards hibernate in winter. Yet, individuals of many species have been found active in this period. Eight specific cases of winter activity of *Podarcis muralis* and *P. erhardii* in the country have been published, but this behavior has not been studied in detail. The purpose of this research was to observe and analyze the winter activity of these two species in the city of Blagoevgrad, SW Bulgaria. The observations were conducted at two sites during days with high solar radiation in December, January, and February 2015–2017. One of the sites was a typical urban territory, inhabited only by *P. muralis*. The other site was a suburban area, inhabited only by *P. erhardii*. The records of active individuals of *P. muralis* were about 8.5 times higher than those of *P. erhardii*. The lowest air temperature at which *P. muralis* was observed was -4°C, and for *P. erhardii* it was +0.5°C. Individuals of both species were only registered at positive substrate surface temperatures: from +14.5 to +32.5°C, with a mean value of +25.2°C ± 4.34 for *P. muralis*, and from +13 to +41°C, with a mean temperature of +29.8°C ± 5.82 for *P. erhardii*. Representatives of all age groups of *P. muralis* were often recorded with dorsoventrally flattened bodies while basking. On the other hand, few juveniles of *P. erhardii* were found active, and the lizards very rarely flattened their bodies during basking. It can be concluded that the activity of both species in the city of Blagoevgrad is regular (usual) on sunny and warm days throughout the winter period. The substrate surface temperature and air temperature are probably the most important environmental factors on which it depends.

Keywords: Balkan Peninsula, phenology, thermoregulation, basking, behavior, Lacertidae.

Introduction

Squamates are ectothermic and depend on external sources for heat gain. They can generate metabolic heat, but at very low levels and usually lose it quickly (Vitt & Caldwell 2014). Lizards can control their body temperatures through various behavioral patterns (Catsadorakis 1984), and basking is usually the preferred method (Vitt & Caldwell 2014).

As winter approaches in temperate zones and before temperatures drop below the critical minimum, most species of lizards enter hibernation. They retreat into suitable hibernacula where temperatures remain higher than ambient temperatures during winter (Vitt & Caldwell 2014), and, as a rule, do not fall below zero. A country's geographic location determines the climatic zone it belongs to and its climate characteristics. Bulgaria lies within the temperate zone, spanning from 41°14'05" to 44°12'45" N latitude (Nikolova 2002a). As a result, the country's winter lasts from the beginning of December to the end of February.

Reptiles in Bulgaria, including lizards, hibernate from late autumn to early spring. Yet, individuals of many species have been found active during this period. Most of these observations have been made in the warmest parts of the country and in places with favorable microclimatic conditions (Beshkov 1977).

Three species of the genus *Podarcis* Wagler, 1830, occur in Bulgaria. Two of them – the Common Wall Lizard, *P. muralis* (Laurenti 1768), and the Erhard's Wall Lizard, *P. erhardii* (Bedriaga 1876) – have similar habitat preferences (Beshkov & Nanev 2002). *Podarcis muralis* is naturally distributed across Central and Southern Europe. The species is absent from most parts of the Iberian Peninsula, the larger Mediterranean islands, the British Isles, and many of the Greek islands. The range of *P. erhardii* includes the Greek mainland (except for some southwest parts) and some parts of Bulgaria, North Macedonia, Serbia, and Albania (Speybroeck et al. 2016).

In Bulgaria, the two species inhabit mainly rocky outcrops and hide in crevices, but are not typically found in the same localities in the country. *Podarcis muralis* is widespread and occurs up to 2150 m a.s.l. (Stojanov et al. 2011). The distribution of *P. erhardii* is limited to some southern parts of the country (Stojanov et al. 2011, Manolev et al. 2019, Koynova et al. 2022), where it occurs up to 1600 m a.s.l. (Beshkov 1961). *Podarcis muralis* has been recorded in various natural or man-made habitats in several cities in Bulgaria, including Blagoevgrad (Undjian 2000, Mollov 2005, Mollov & Velcheva 2010, Pulev & Sakelarieva 2011, 2013, Tzankov et al. 2015, Georgiev & Georgiev 2018). Information on individuals of *P. erhardii* in the periphery and surroundings of the city of Blagoevgrad was published by Pulev & Sakelarieva (2011, 2013). Both species occupy different areas in the city of Blagoevgrad. *Podarcis muralis* is found in densely or sparsely populated built-up regions and along the Blagoevgradska Bistritsa river. *Podarcis erhardii* inhabits sparsely populated built-up areas, the territory of Loven dom Park, and the Zoo (Pulev & Sakelarieva 2011, 2013, authors' unpublished data).

The activity period of both species in Bulgaria is from March to October (Stojanov et al. 2011). Despite that, individuals of *P. muralis* (Beshkov 1977, Undjian 2000, Beshkov & Nanev 2002, Biserkov et al. 2007, Stojanov et al. 2011, Tzankov et al. 2014) and *P. erhardii* (Beshkov 1977, Beshkov & Nanev 2002, Biserkov et al. 2007, Stojanov et al. 2011) can be found in the country during winter when the weather is sunny and warm. Specific data for *P. muralis* were

published by Buresch & Zonkow (1933) (16.02.1925), Undjian (2000) (31.01.1960), and Westerström (2005) (27.12.2000) and for *P. erhardii* by Buresch & Zonkow (1933) (12.02.1928), Pulev & Sakelarieva (2011) (06.02.2004), Grozdanov et al. (2016) (28.12.2015, 21.02.2015), and Malakova et al. (2018) (14.12.2017).

While records of activity among representatives of the family Lacertidae during the winter season in Bulgaria exist, this behavior has not been thoroughly studied. Only recently, the first specialized work on the winter activity of a lizard species that occurs in the country, the Snake-eyed Lizard *Ophisops elegans* (Ménétries 1832), was published by Krastev et al. (2023).

Pulev et al. (2020) and Mitrevichin et al. (2022) suggest that reptile activity in Bulgaria during winter generally depends on ambient temperatures, the geographic location of hibernation sites, slope orientation, altitude, and the species' ecological requirements. The depth of the hibernaculum and the soil's physical properties may also play a role in triggering the winter activity of some reptiles in the country.

The purpose of this research was thus to observe and analyze the winter activity of *P. muralis* and *P. erhardii* in the city of Blagoevgrad. This would likely provide a better understanding of the biological and ecological characteristics of the two species.

Materials and methods

The observations were conducted at two sites in south-western Bulgaria. Site 1 is a typical urban territory, located in the densely populated built-up area of the city of Blagoevgrad (Fig. 1). It was inhabited only by *P. muralis*. The habitat is a vertical stone wall (composed of polished granite boulders) measuring about 1.2 m in height and 180 m in length, with southwest exposure at an altitude of about 360 m. The lizards hibernate in the wall's crevices and bask on it. There are buildings and a paved area behind the wall, and railway tracks and gravel in front of it. The vegetation in the habitat is sparse, consisting only of herbaceous plants.

Site 2 is located in the territory of Loven dom Park and the Zoo (Fig. 1). It is a suburban area, inhabited only by *P. erhardii*. The habitat is a rock scarp with a height of 3–5 m and a length of 160 m with south, southwest, and southeast exposition and 70-80 degrees of inclination. The rocks in the habitat consist of disintegrated biotite and binary gneisses (Marinova 1991). The altitude is approximately 600 m. The lizards hibernate in the crevices and bask on the rock. Above the scarp, there is an artificial plantation of *Pinus nigra* and stones as well as an asphalt road in front of it. The plant community between the scarp and the asphalt road is dominated by *Paliurus spina-christi*, *Pinus nigra*, and *Quercus frainetto*.

According to Alisov's genetic classification, the Blagoevgrad region is located within the transitional continental climatic subzone of the European-continental climatic zone (Sabev & Stanev 1959). The boundaries of this climatic subzone are defined by the predominant precipitation regime, which marks a transition between the continental and Mediterranean types. According to the Köppen–Geiger's climate classification, Blagoevgrad has a Cfa climate (temperate climate with no dry season and hot summers). The Köppen–Geiger classification effectively delineates the trend of climate change. During the period 1961–1990, the predominant climate in Bulgaria was Cfb (61%), followed by Cfa (28.7%). In the period 1991–2020, a shift toward a warmer and/or drier climate was observed, affecting approximately 36% of the country's territory (Marinova & Bocheva 2023). The climatic conditions in the winter in the region of the city of Blagoevgrad are characterized by positive average monthly temperatures, with an average seasonal temperature of 2.4°C for the period 1991–2020 (National Institute of Meteorology and Hydrology 1998–2024).

The study on the activity of *P. muralis* and *P. erhardii* was conducted during the winter months from 2015 to 2017. The two winter seasons differed significantly in their thermal characteristics. The average winter air temperature in 2015–2016 was 4.2°C (1.8°C above the climatic norm). Normal temperature values were recorded in December and January, and abnormally high temperatures of –9.3°C, in February. The average winter temperature in 2016–2017 was 0.7°C, which was 1.7°C below the climatic norm. December and January were cold, with temperatures below normal (by 4.9°C in January), while February was warmer (5.5°C, 1.9°C above normal) (National Institute of Meteorology and Hydrology 1998–2024).

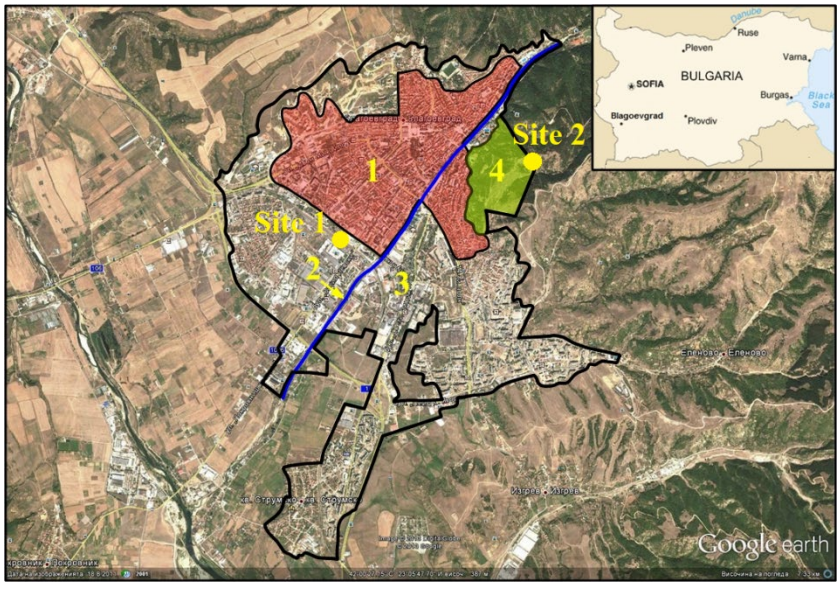

Figure 1. Location of the study sites (Site 1 and Site 2 as dots) in the city of Blagoevgrad [the map is after Pulev & Sakelarieva (2013), where 1 denotes densely populated and built up areas, 2 – the Blagoevgradska Bistritsa river and its banks, 3 – sparsely populated and built up areas and city periphery, and 4 – Loven Dom Park and the Zoo].

The research was primarily conducted on sunny days. Each observation lasted for 30 minutes during the warmest part of the day – at Site 1 from 12:30 p.m. to 4:45 p.m. and at Site 2 from 11:50 a.m. to 4:00 p.m. The lizards' behavior was recorded at a distance to avoid disturbing them and skewing the results. Site 1 was visited 50 times in 49 days: 18 times in 2015–2016 and 32 times in 2016–2017. Site 2 was visited 48 times over 48 days: 16 in 2015–2016 and 32 in 2016–2017.

The following parameters were recorded during the study: date and time of observation; number of individuals observed; age groups (adults, subadults, and juveniles – conditional grouping, since body length was not measured); behavior (locomotor activity, basking, and fighting); environmental conditions; minimum night/morning air temperature measured before each observation; air and substrate surface temperatures measured during the observation. Air temperatures were measured with a temperature sensor (Greisinger – EASYlog24RFT), and an infrared thermometer (UT303D) was used to calculate the substrate surface temperature. All temperature values were rounded to the nearest half degree (0.5°C). Wind force was determined using a four-level scale: 1 – no wind; 2 – light wind, 3 – moderate wind; 4 – strong wind. Data were described by the arithmetic mean, standard deviation, and range.

Results

Podarcis muralis

A total of 779 individual observations were recorded at Site 1 during 44 of 50 visits. The number of records during 14 visits (out of 18) in 2015–2016 was 342: 14 in December during 1 visit, 125 in January during 8 visits (out of 12), and 203 in February during 5 visits (Fig. 2, Supplementary Table 1; Fig. 1). In 2016–2017, there were 437 registrations of individuals during 30 visits (out of 32): 249 in December during 21 visits, 2 in January during 2 visits (out of 4), and 186 in February during 7 visits (Fig. 2, Supplementary Table 1). The maximum number of active individuals was at the end of both winters – 58 on February 15, 2016, and 47 on February 27, 2017. Single individuals were observed three times, shortly after the middle of the winter seasons – on January 23, 2016, and on January 28 and 30, 2017.

The mean number of registrations per individual was 17.70 ± 15.32 (range 1–58), respectively, 22.80 ± 18.95 in 2015–2016 and 14.56 ± 12.73 in 2016–2017. No lizards were observed in 6 out of 50 times when the study site was visited – 4 times in January 2016 and 2 times in January 2017. The adults were most often present in 41 of the cases, followed by the subadults in 36 cases, and the juveniles in 35 cases. All age groups were represented in 33 out of 44 cases.

Basking was the predominant behavior observed. In fact, it was observed in all 44 visits in which active lizards were recorded. Basking was the only behavior observed in 25 of the visits, and some individuals also exhibited locomotor activity in the remaining 19 visits. In 47 of 48 observations of active individuals, most lizards flattened their bodies dorsoventrally while basking.

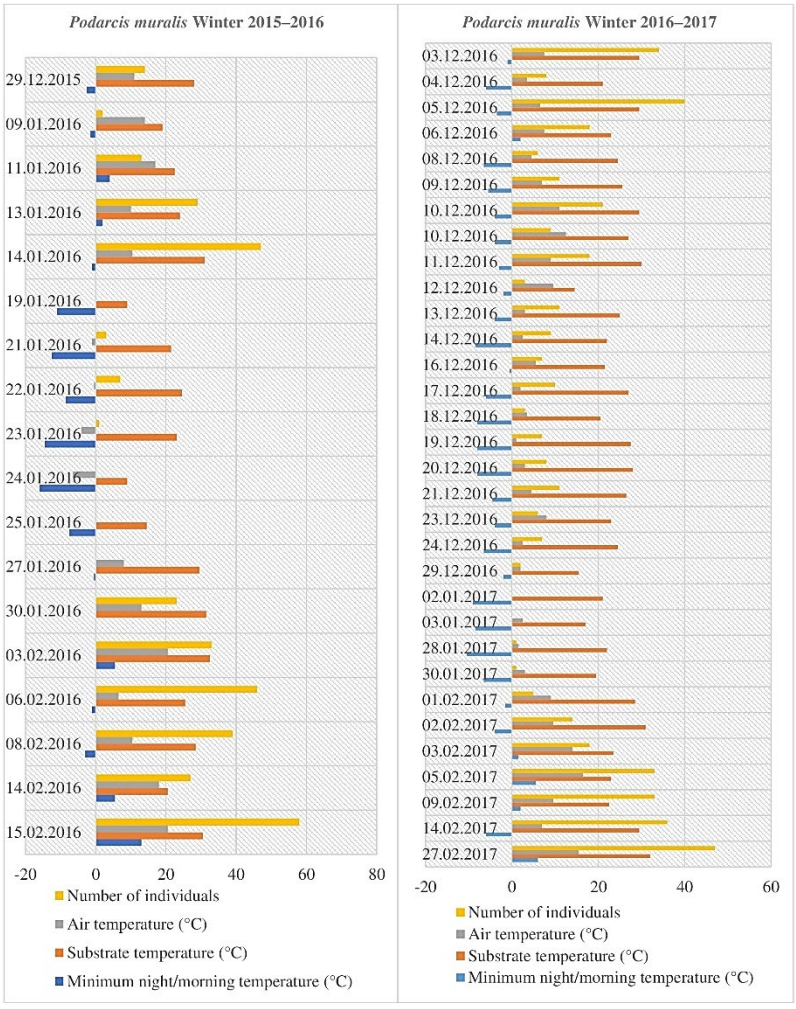

Figure 2. Some parameters recorded during the study of *Podarcis muralis*.

Active individuals were primarily observed on sunny days without wind – in 30 visits, followed by sunny days with slight, moderate, or strong wind – in 11 visits, and most rarely in partly cloudy weather – in three visits. On the six visits when no lizards were recorded, the weather was sunny with no wind on five visits, and partly cloudy on one visit. Individuals were registered across a wide range of air temperatures measured during the observation: from -4 to +20.5°C, with a mean air temperature of +7.9°C ± 5.81°C. However, individuals were observed only at positive substrate surface temperatures, ranging from +14.5 to +32.5°C, with a mean of +25.2°C ± 4.34.

The mean air temperature when no lizards were found was +0.7°C ± 4.68 (range from -6.5 to +8°C), and the mean substrate surface temperature was +16.7°C ± 7.82 (range from +9 to +29.5°C). The mean night/morning air temperature before visiting the study site during the day with no lizards was -8.8°C ± 5.04 (range from -16 to -0.5°C).

Podarcis erhardii

Altogether, 92 observations of active individuals were recorded in Site 2 during 31 out of 48 visits. The number of records during 13 visits (out of 16) in 2015–2016 was 54: 9 in December during 4 visits, 13 in January during 4 visits (out of 7), and 32 in February during 5 visits (Fig. 3, Supplementary Table 2; Fig. 2). In 2016–2017, there were 38 registrations of active individuals during 18 visits (out of 32): 19 in December during 11 visits (out of 20), 0 in January during 5 visits, and 19 in February during 7 visits (Fig. 3, Supplementary Table 2). The maximum number of records was at the end of the first and the beginning of the second winter: 12 individuals on February 15, 2016, and 5 on December 3, 2016, respectively. In many cases, only one individual was observed, mainly in December, i.e., at the beginning of winter.

The mean number of registrations of individuals was 2.96 ± 2.40 (range 1–12), respectively 4.15 ± 3.13 in 2015–2016 and 2.1 ± 1.18 in 2016–2017. No lizards were found in 17 out of 48 times when the study site was visited – 3 times in January 2016, 9 times in December 2016, and 5 times in January 2017. Adult individuals were observed during all visits when activity was recorded. Subadults and juveniles were recorded five times each. All age groups were represented once, or in 3.2% of the cases when active individuals were observed. Only adults were registered in 22 out of 31 visits.

As in the other species, basking was the main behavior observed. It was the only behavior observed in 18 of 31 cases in which active lizards were recorded. In five other cases, some individuals exhibited locomotor activity; in four cases,

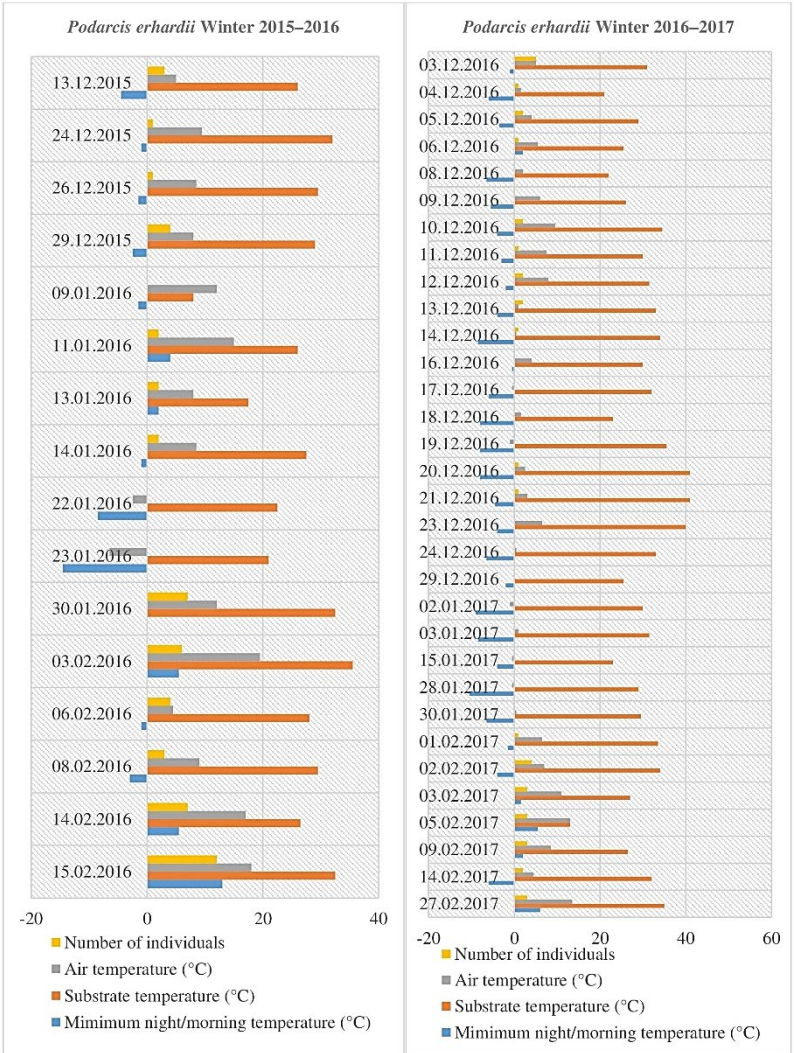

Figure 3. Some parameters recorded during the study of *Podarcis erhardii*.

only locomotor activity was observed. A fight between two males was observed four times when the number of active individuals was 4 or more. Perhaps that aggression is aimed at maintaining individual distance. Only two individuals were observed to flatten their bodies dorsoventrally on two different occasions.

Active individuals were mainly registered on sunny days without wind – in 23 cases, followed by sunny days with slight or moderate wind – in 6 cases, and most rarely in partly cloudy weather – in 2 cases. During the 17 visits when no lizards were observed, the weather was sunny with no wind – on 14 occasions, partly cloudy – on 2 occasions, and cloudy – on 1 occasion.

Lizards were recorded at a wide range of air temperatures, from +0.5 to +19.5°C, with a mean air temperature of +8.2°C ± 4.89. They were also observed over a wide range of substrate surface temperatures, from +13 to +41°C, with a mean of +29.8°C ± 5.82. The mean night/morning air temperature recorded before visiting the study site during the day was -0.9°C ± 4.64 (range from -8.5 to +13°C).

The mean air temperature when no lizards were found was +1.3°C ± 4.1 (range from -6.5 to +12°C), and the mean substrate surface temperature was +27.1°C ± 7.19 (range from +8 to +40°C). The mean night/morning temperature recorded before visiting the study site during the day when no lizards were registered was -6.5°C ± 3.47 (range from -14.5 to +0.5°C).

Discussion

Cities and suburbs offer many suitable habitats for *P. muralis*. According to Bády & Vagi (2012), the species is the most abundant reptile in Hungary's urban environments. The above-ground winter activity of *P. muralis* in an urban habitat was studied by Rugiero (1995), who reported that active lizards were found on all sampling dates and their activity was somewhat regular. Bády & Vagi (2012) concluded that the species had found suitable conditions in the urban habitat where its density was higher than that in the close-to-natural habitat. Falaschi (2021) concluded that temperature and phenology are the most influential drivers of detection probability, which was highest earlier in the active season (April) and at 24—28°C, decreasing at lower or higher temperatures.

In our study, the number of active *P. muralis* individuals in both winter seasons was about 8.5 times that of *P. erhardii*. On the one hand, the population of *P. muralis* was much more abundant and at a higher density, since the habitat (a stone wall) provides better conditions, particularly more crevices for shelter and hibernation. According to Bády & Vagi (2012), the population density of *P. muralis* in an urban habitat is also affected by thermal factors, better food supply, or fewer competitors and predators.

On the other hand, *P. erhardii* is a more thermophilic species and is more strongly dependent on the substrate surface temperature and minimum air temperature than *P. muralis* (Fig. 4). This is also confirmed by the values of the air and substrate surface temperatures, the mean ones, as well as those measured at the time of observations. According to Catsadorakis (1984), the activity of the lizards of *P. erhardii* was correlated with ambient temperatures (mean, min, max) in spring, and it was strongly associated with mean air temperature in the sun, up to 30–32.5°C. In our study, the mean air temperature (+8.2°C) was 0.3°C higher than the one at which individuals of *P. muralis* were observed. No active individuals of *P. erhardii* were recorded at sub-zero air temperatures in the two winters. At the same time, several active individuals of *P. muralis* (10 adults and 1 subadult) were registered, basking at sub-zero air temperatures at the beginning of the third decade of January 2016 (Supplementary Table 1; Table 2).

The minimum air temperatures at which both species were observed – *P. muralis* at -4°C and *P. erhardii* at +0.5°C – starkly contrast with values reported in other publications: 15°C (Westerström 2005) and about 12°C (Biserkov et al. 2007, Tzankov et al. 2014) for *P. muralis*, and approximately 15°C (Pulev & Sakelarieva 2011) and 15.7°C (Malakova et al. 2018) for *P. erhardii*.

Obviously, both factors, substrate surface and air temperature, play a key role in the winter activity of the studied species. All individuals of *P. muralis* and *P. erhardii* were observed only at positive substrate temperatures. Popova et al. (2023) studied another lacertid species – *Lacerta agilis bosnica* Schreiber, 1912 – from Bulgaria and also found that the air and substrate temperatures had a significant role in the activity and behavior of the species. Probably, substrate surface temperature values are more critical for the activity of petrophilic species (such as many representatives of the genus *Podarcis*) in winter than air temperatures.

The warming of the substrate depends on the amount of total solar radiation absorbed. Thus, the substrate's temperature is determined by the intensity of solar radiation, altitude, exposure, inclination, rock composition, and rock color. When Strijbosch et al. (1989) studied the distribution and ecology of lizards in the Greek province of Evros, they concluded that the activity patterns of all species (including *P. muralis* and *P. erhardii*) were strongly influenced by exposition and altitude. The activity occurred earlier on the southern slopes than on the northern ones, and at lower altitudes than at higher ones.

In Bulgaria, the amount of solar radiation received on southern slopes can be several times that on northern slopes (Mateeva 2002). Although Study Site 2 was at a higher altitude (by more than 200 m), the rocks there received more solar radiation, i.e., were warmer. They have southern exposition and a suitable inclination, therefore the sun's rays fell almost perpendicularly, whereas at Study Site 1, which faced southwest, they fell at a smaller angle. As a result, the substrate temperature at Site 2 was higher. Despite the higher altitude, the mean and maximum values observed for *P. erhardii* were 4.6 and 8.5 degrees higher, respectively, than those for *P. muralis*.

In Bulgaria, including the Blagoevgrad region, total solar radiation – direct and diffuse – is lowest in December and January, and the lowest temperatures were recorded in January (Nikolova 2002b, Velev 2002). Accordingly, the fewest individuals of both studied species were registered in January, almost all in January 2016. Large amplitudes in average temperatures were observed then. A short-term cold was registered at the beginning of the month, and a more significant one from 16 to 25 January, when a minimum

temperature of -16.4°C was measured. There were also sunny days with positive temperatures when some lizards were observed. January 2017 was especially cold. A minimum temperature of -19.0°C was recorded in the city of Blagoevgrad, and a temperature of -22.5°C was measured in the conditions of a more pronounced temperature inversion in the surroundings (TWC Product and Technology LLC 2014–2025). Actually, no individuals of *P. erhardii* were observed in January 2017, and only 2 individuals of *P. muralis* were registered at the very end of the month (Supplementary Table 1; Table 2).

The most records for individuals of both species occurred in February; half of all records of *P. muralis* and more than half of those of *P. erhardii* were observed during the two winter seasons. Most of them were registered in February 2016, when temperatures were above the norm almost every day, and the positive temperature anomaly reached 6.3°C. There was not a single day with a sub-zero average daily temperature (TWC Product and Technology LLC 2014–2023), and the maximum temperature recorded at the Blagoevgrad hydro-meteorological station reached 22.8°C (National Institute of Meteorology and Hydrology 1998–2024).

Many lizards are effective heliothermic thermoregulators that prefer sunny, open surfaces (Bády & Vagi 2012). Their activity patterns are determined by climate and weather, particularly by the levels of sunlight (Avery 1978). They warm their bodies mainly by basking in the sun, but also indirectly from the surrounding substrate (Vitt & Caldwell 2014). *Podarcis muralis* is morphologically adapted to a rock-dwelling life (Herczeg et al. 2007). Body flattening is a behavioral adaptation in *P. muralis* that allows it to absorb more solar radiation at lower temperatures. The dark color of the body (especially on both sides, i.e., laterally – up to black) also increases absorption. *Podarcis erhardii* probably relies more on indirect heat gain, which is why it prefers warmer substrates in winter. The main behavior of the two species in this study was basking, but other activities, such as locomotion and fighting (only in *P. erhardii*), were also recorded. Such behavior was also reported by Rugiero (1995). The lizards of *P. muralis* tended to aggregate. Clusters, i.e., several individuals together, were observed. The narrow time window of activity can explain this, the sunbathing around the hibernaculum (they did not disperse), the higher population density, and the species' biological features. On the contrary, *P. erhardii* was more aggressive, and fights between two males were observed. Usually, the individuals of *P. erhardii* avoided each other unless they were a pair. This intraspecific aggression seems to be normal for the species (Donihue et al. 2016).

We can conclude that the winter activity of both lizards in the city of Blagoevgrad is regular (usual) on sunny and warm days. The substrate surface temperature and air temperature (both of which depend on solar radiation) are probably the most important environmental factors affecting it. We suggest that only those populations that hibernate in habitats with suitable microclimatic and weather conditions can have winter-active individuals. Since the two studied species hibernate in the rocks, which they inhabit during the active season, activity in winter has its prerequisites and can be expected to some extent. The results of the research also confirmed to some extent that *P. erhardii* is more thermophilic than *P. muralis*. Future research is needed to make a more detailed analysis.

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