ACTA ZOOLOGICA BULGARICA

Acta Zool. Bulg., September 2024, 76 (3): 359-365

Terrestrial Ecology and Behaviour
Research Article

Published online 10 July 2024
DOI: https://doi.org/10.71424/azb76.3.002650

Monthly Activation Dynamics and Local Dispersion Patterns of Three Ecophysiologically-Different Woodlice Species (Isopoda: Oniscidea) in the Same Locality in Eastern Thrace, Turkey

Nesrin Kaynak Tulgar*[1], *Aytac Akcay*[2], *Elife Zerrin Bagci*[1] & *Sirri Kar*[1]

[1] Biology Department, Tekirdag Namik Kemal University, Tekirdag, Turkey;
Email: sirrikar@yahoo.com, https://orcid.org/0000-0002-3301-6215; nesrinkynk@gmail.com, https://orcid.org/0000-0003-3734-8804; ezbagci@nku.edu.tr, https://orcid.org/0000-0001-5920-0400
[2] Biostatistics Department, Veterinary Faculty, Ankara University, Ankara, Turkey;
Email: aytacakcay@ankara.edu.tr, https://orcid.org/0000-0001-6263-5181;

Abstract: The monthly activation dynamics, habitual shelter usage and local dispersion preference of the isopod species *Porcellio laevis*, *Porcellio dilatatus* and *Armadillo officinalis* (Isopoda: Oniscidea) in the same locality in Turkey were studied. The aim of the study was to examine how these species, which originated from North Africa, cooler parts of Europe and the Mediterranean basin, respectively, having different climate preferences, responded to the same climatic and environmental conditions. The study revealed that these species could subsist in sympatric populations under certain environmental circumstances. However, their geographical origin and possible evolutionary background were clearly reflected in the form of monthly activation, local dispersion and use of habitual shelters.

Key words: *Armadillo officinalis*, *Porcellio dilatatus*, *Porcellio laevis*, seasonality

Introduction

Terrestrial isopods (woodlice) constitute one of the most important members of decomposer communities (Warburg 1993). It was also reported that decomposition process of some species on agricultural and domestic organic wastes had the potential to be confidently used in the production of organic fertilizer (Arin et al. 2021). As the ecological importance of woodlice had been better understood in recent decades, a growing number of relevant studies had been performed aiming to perform a long-term monitoring of urban communities and multi-scale analyses of landscape properties. These investigations targeted to determine the potential drivers on woodlice phenology, diversity and distribution (Vilisics et al. 2018, Vona-Túri et al. 2019).

Turkey has different regions with various ecological and climate types (Ozturk et al. 2017), which is a prerequisite to be rich in terms of woodlice species on the country scale. However, there are only one detailed faunistic study, which is reporting 116 species belonging to 30 genera (Schmalfuss 2003). Some recent addi-

*Corresponding author: sirrikar@yahoo.com, https://orcid.org/0000-0002-3301-6215

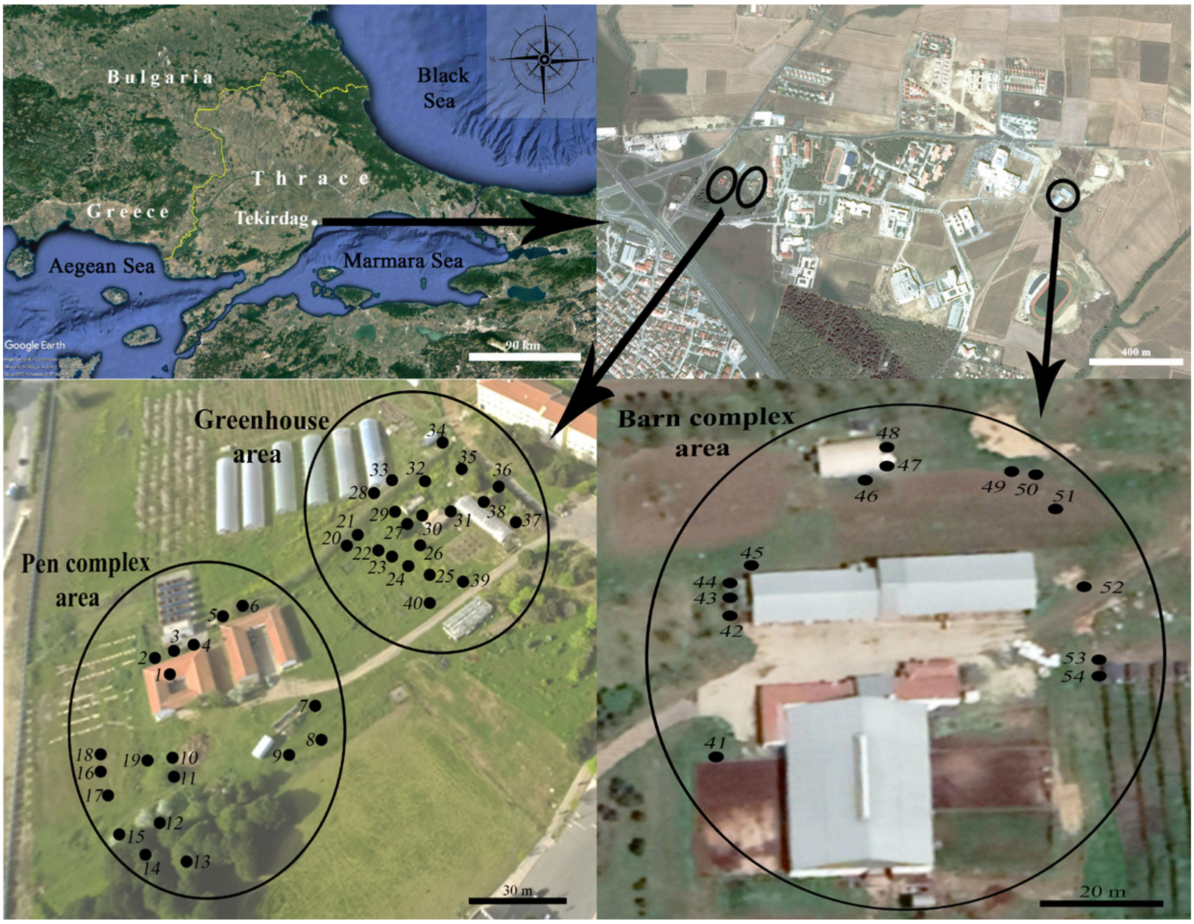

Fig. 1. Geographic location of the study area (https://earth.google.com/web) and the shelters (shown as black marks).

tions were proposed by Ozgen et al. (2018). Even though there are no detailed data on the distribution and density of species such as *Porcellio laevis* Latreille, 1804, *Porcellio dilatatus* Brandt, 1833 and *Armadillo officinalis* Dumèril, 1816, it is well known that Turkey is within their natural distribution range (Schmalfuss 2003). They are the significant members of the woodlice fauna in Greece (Alexiou & Sfenthourakis 2013) and Bulgaria (Beron 2020), which are neighbouring countries of Eastern Thrace region of Turkey.

The study was aimed to investigate:

(i) the comparative monthly dynamics of shelter use pattern of the species in the same locality;

(ii) the possible effects of structural and climatic environmental parameters on these dynamics at the local scale;

(iii) the effects of the different evolutionary and phylogenetic history, eco-physiological features and geographical origins on the phenological parameters of the species co-occurring in the same locality. The original distribution ranges of these species include North Africa for *P. laevis*, the hotter parts of Mediterranean basin for *A. officinalis* and the cooler European territories for *P. dilatatus* (Warburg et al. 1984, Warburg 1993).

Materials and Methods

This one-year study was conducted on monthly basis in a selected peri-urban locality (40°58'N, 27°30'E, altitude *c.* 40 m) on the coast of the Sea of Marmara in Eastern Thrace (Fig. 1), where *P. laevis*, *P. dilatatus*, and *A. officinalis* are naturally common. The region is under the influence of "hot dry summer sub-climate type (Csa)" according to the Köppen-Geiger classification (Ozturk et al. 2017). Monthly meteorological values from January to December recorded in the area during the study period (April 2016 – March 2017) were as follows (Turkish State Meteorological Service, https://mgm.gov.tr):

Average temperature (°C): 1.9, 6.4, 9.0, 15.6, 17.9, 23.6, 25.6, 25.7, 21.7, 16.0, 11.5 and 3.8;

Aaverage relative humidity (%): 84.5, 81.8, 82.5, 72.9, 75.3, 72.8, 67.0, 69.2, 68.9, 93.5, 81.4 and 75.8;

Total precipitation (mm=kg/m^2): 107.0, 38.8, 32.1, 18.3, 28.4, 34.9, 0.1, 0.1, 3.9, 84.3, 82.2 and 37.1.

Table 1. Area dispersion and monthly distribution characteristics of the isopods.

Area dispersion characteristics of the isopods						
Feature of the shelter In the pen building		**Location of the shelters**				
		In the open environment			**Total**	
		Pen complex area	**Barn complex area**	**Greenhouse area**		
Counts		1	18	14	21	54
Total sheltering space (m^2)		1	3.6	2.8	4.2	11.6
Average size (m^2) of the space per shelter (range)		1	0.2 (0.05-0.5)	0.2 (0.05-0.5)	0.2 (0.05-0.6)	0.2 (0.05-0.5)
Annual numbers of isopods at the areas	*P. laevis*	2395 (100%)	609 (42.4%)	502 (62.3%)	17 (4.2%)	3,523
	P. dilatatus	0	787 (54.8%)	296 (36.8%)	130 (32.3%)	1,213
	A. officinalis	0	40 (2.8%)	7 (0.9%)	255 (63.4%)	302
	Total	**2395**	**1436**	**805**	**402**	**5,038**
Monthly distribution characteristics of the isopods						
		In the pen building	**All over the open environment**			**Total**
Months		***P. laevis***	***P. laevis***	***P. dilatatus***	***A. officinalis***	
Jan		*N/D*	55	120	0	175
Feb		*N/D*	45	121	2	168
Mar		*N/D*	42	215	22	279
Apr		35	230	204	91	560
May		100	182	90	54	426
Jun		110	109	70	54	343
July		300	78	16	21	415
Aug		230	34	22	4	290
Sept		200	100	28	3	331
Oct		400	55	29	23	507
Nov		500	117	115	14	746
Dec		520	81	183	14	798
Total		**2395**	**1128**	**1213**	**302**	**5,038**

For the study, the following three neighbouring areas were selected: (i) pen complex area used for about 60 sheep, (ii) greenhouse area containing greenhouses and gardens and (iii) barn complex area used for about 25 cattle (Fig. 1). To monitor the monthly activation characteristics of the woodlice, their daytime aggregating or sheltering places (most densely populated / habitual shelters) preferred by the woodlice in their active seasons (Warburg 1993) were targeted. Our approach was based on the fact: that most woodlice species are nocturnal and, during the day, they tend to aggregate at humid, shadowy and shallow spaces, mostly on the ground level under or between the objects. In the seasons where the climatic conditions are more challenging, they mostly prefer to retreat to more sheltered areas to circumvent the conditions in a relatively less active situation (Warburg 1993).

Before the study, the general features of habitual shelters were determined in the study area. The objects made of mostly flat materials (wood, stone, tile and nylon) with a sheltering space of 1–2 cm underneath and naturally used intensively by woodlice were selected. Due to the management procedures of livestock enterprises, only one focus could be used indoors and only nine months of monitoring could be performed on this focus (Table 1).

The isopods at the shelters were counted once a month for a year between April 2016 and March 2017. To eliminate the possible impact of the daily change in weather conditions or the possible transition of isopods between foci, the counting of isopods in all foci was carried out on the same day of each month. Isopods were counted directly in their focus and left exactly. At the shelters with high isopod numbers, photographs were also taken to overcome the possible counting errors. Isopod species were determined morphologically using the keys (Harding & Sutton 1985, Schmalfuss 1996, Shultz 2018).

As for data analysis, the correlations between the monthly average values of climatic parameters (temperature, precipitation and humidity) and isopod numbers at the shelters were calculated with Spearman's Rho correlation coefficient. The significance of the differences in terms of the number of species at the shelters according to months and seasons was performed by the Kruskal-Wallis test and Dunn test was applied in multiple comparisons. All statistical analysis were performed with SPSS 14.01 (License No: 9869264) package program.

Results

During the study, 645 inspections were performed in the 54 shelters. In 250 (38.8%) of those examinations, 5,038 isopods were counted, including 3,523 *P. laevis*, 1,213 *P. dilatatus*, and 302 *A. officinalis* (Table 1). In addition, early-stage offspring (smaller than *c.* 4 mm) were seen in different shelters in February (*P. laevis*), March (*P. dilatatus* and *A. officinalis*), April (*P. dilatatus* and *A. officinalis*), May (*P. laevis*), June (all three species) and July (*P. laevis* and *A. officinalis*). Furthermore, a few isopod specimens other than these species were also encountered; however, detailed data on the offspring and the other species were not recorded.

The shelter in the pen building was monitored for only nine months (April – December). In this shelter with about 1 m^2 sheltering space, a total of 2,395 *P. laevis* were counted; no specimens of the other species were seen (Table 1). Some temporary shelters in the barn and pen buildings were checked whenever the opportunity was found and, likewise, no species other than *P. laevis* were encountered there either (no detailed data presented).

Isopods were detected in 241 (37.9%) out of 636 inspections performed in the 53 shelters in the vicinity of the pen complex area, barn complex area and in the greenhouse area. *Porcellio laevis*, *P. dilatatus* and *A. officinalis* were seen in 106 (16.7%), 141 (22.2%) and 76 (11.9%) of the inspections, respectively. In these shelters in the open environment, a total of 2,643 isopods were counted. The highest number was recorded in the barn complex area, pen complex area and greenhouse area for *P. laevis*, *P. dilatatus* and *A. officinalis*, respectively (Table 1).

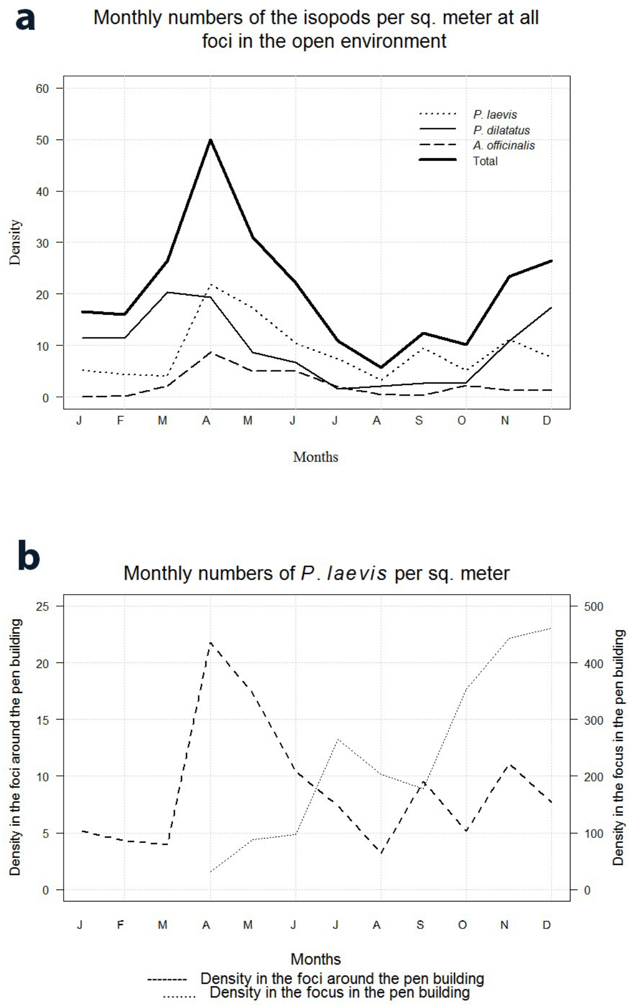

Fig. 2. Monthly densities of the species at the shelters in the open environment (a) and *P. laevis* in and around the pen building (b).

The analyses revealed a statistically significant difference (p<0.001) between the numbers of the species according to the areas.

Statistical analysis revealed that both number of total woodlice and number of individual species recorded at the shelters in the open environment showed statistically significant differences by months (p<0.001) and seasons (p<0.001) (Table 1, Fig. 2). The highest number of total isopods was found in April (525 individuals, 19.9% of the annual total), while the lowest number was in August (60 individuals, 2.3% of the annual total). The number (1,130 individuals) in the spring was highest. For the species, the highest seasonal number of individuals was recorded in the spring but the peak for *P. laevis* and *A. officinalis* was observed in April. For *P. dilatatus*, the peak was in March. After the spring peak, the number of *A. officinalis* gradually decreased in the following seasons, reaching its lowest level in winter; no specimens were recorded at the shelters

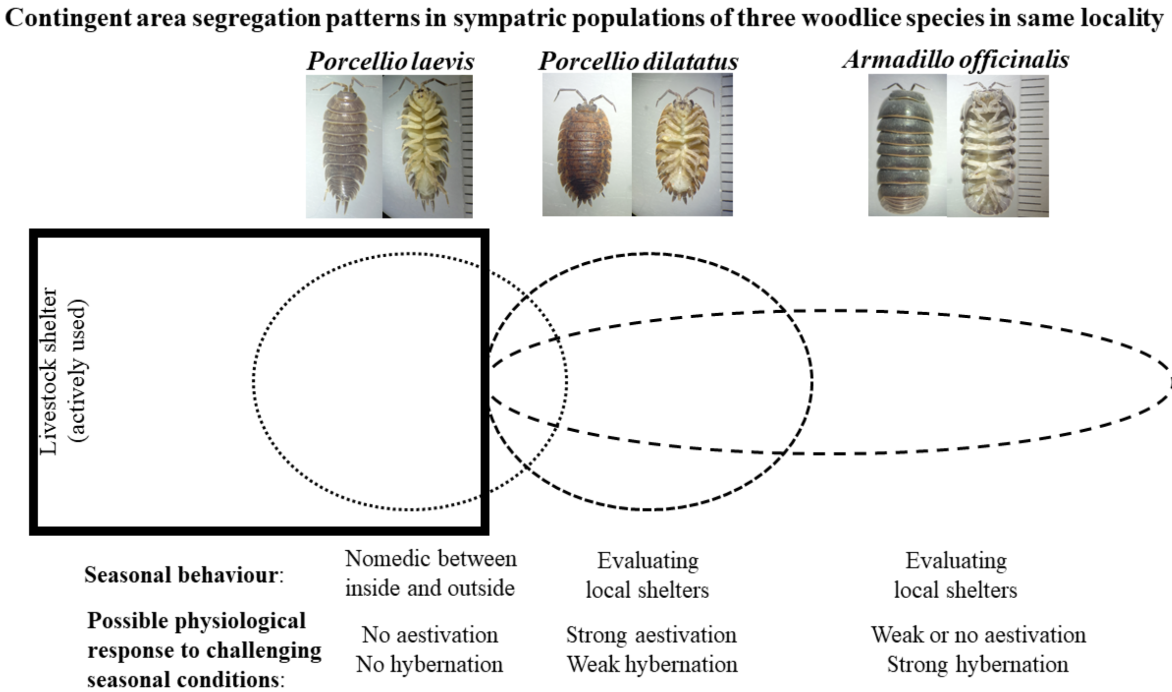

Fig. 3. Segregation mechanisms allowing the sympatry of *Porcellio laevis*, *P. dilatatus* and *Armadillo officinalis* in the studied area.

in January. The second highest level of *P. dilatatus* was observed in winter and the lowest level in summer. In *P. laevis*, the lowest seasonal number was observed in winter and the lowest monthly number in August; however, in this species, changes in population density in the non-spring seasons were not as dramatic as in others. The data recorded for nine months (from April to December) at the shelter located in the pen building showed that the highest and lowest numbers of isopod (*P. laevis*) were in December (520) and April (35), respectively (Table 1, Fig. 2).

The analysis revealed that monthly total isopod numbers at the habitual shelters in the open environment and monthly average temperatures were negatively correlated ($p<0.05$). When the species were evaluated individually, the degree of this effect was statistically significant only in *P. dilatatus* ($p<0.01$) and *A. officinalis* ($p<0.01$) but not in *P. laevis*. A certain degree of positive correlation was determined between the monthly total precipitation and isopod numbers at the shelters in *P. laevis* and in *P. dilatatus* but a significantly negative correlation in *A. officinalis* ($p<0.05$). Similarly, monthly average humidity level was determined to be somewhat assistive for the population density at the shelters for *P. laevis*, significantly supportive for *P. dilatatus* ($p<0.01$), but significantly repressive for *A. officinalis* ($p<0.05$).

Discussion

The results of the study indicate that *P. laevis, P. dilatatus* and *A. officinalis* can subsist in sympatric populations in a restricted habitat (Fig. 3). However, examination of the isopod distribution in the area on a fine scale revealed some variable boundaries between the populations (Table 1). In fact, it is well known that there is a close relationship between the features of the habitat and isopod diversity in restricted areas (Warburg 1993). Some differences such as urbanization may not affect their species richness, as long as the keystone habitats exist in the area for the species participating in the community (Kashani & Hamidnia 2016, Vilisics et al. 2018).

The number of all the species at the shelters in the open environment showed a statistically significant difference according to the area ($p<0.001$) (Table 1). During the nine-months monitoring period (from April to December) at the shelters in the pen building, a total of 2,395 *P. laevis* were recorded but other species were not available (Table 1). The synanthropic character of *P. laevis* and its association with stables, cattle yards and dung heaps is well known (Pierce 1907, Harding 2016). Consistently, in different locations of Thrace, we have often encountered *P. laevis* as the only species in burrows and crevices that were at ground level in the inner walls of barns with traditional structure and low ventilation, which were actively used for cattle sheltering. *Porcellio dilatatus* was also reported as frequent in ruined buildings that are not actively used by residents, either people or animals (Harding & Sutton 1985). We encountered *P. dilatatus* and *A. officinalis* rarely in some ground-level cavities and crevices (*A. officinalis*, sometimes at the higher parts of the wall) on the exterior surfaces of the livestock shelter's walls (particularly in the late autumn and rainy periods). However, we encountered neither of these species in buildings actively used for animals.

The analysis carried out to determine any relationships between the monthly climatic parameters and isopod numbers at the shelters in the open environment revealed consistent results with the known climatic preferences of the species. It is known that drought resistance of *A. officinalis* is higher than other species due to its conglobating behaviour and integument structure (Warburg 1993). *Porcellio laevis* has a higher interest in relatively higher temperature (Warburg 1993) and occurs under warmer conditions than *P. dilatatus* (Warburg et al. 1984). However, temperature values above 25 °C can be challenging even for *P. laevis* (Dailey et al. 2009). Our analysis revealed negative correlation between the counts of only *A. officinalis* at the habitual shelters and both monthly total precipitation ($p<0.05$) and monthly average humidity ($p<0.05$). This negativity of excessive wetness due to rain and humidity values above a certain level may indeed be acceptable for *A. officinalis*, which is a xerophilic species with high drought compliance (Messina et al. 2012).

The total number of isopods in the habitual shelters showed significant differences over months ($p<0.001$) and seasons ($p<0.001$). It was peaking in spring, decreasing in summer, bottoming in August and starting to rise again in the autumn, mostly in line with the reports from Slovakia (Rudy et al. 2018), Sicily (Messina et al. 2012) and some other parts of Mediterranean basin (Warburg et al. 1984). Similarly, for each species as well, the numbers exhibited a statistically significant difference by months and seasons, and the differences between the species appeared to be mostly related to their climatic preferences (Warburg 1993). The highest seasonal number of individuals in all three species was found in the spring but the peaks of more thermophilous Mediterranean species *P. laevis* and *A. officinalis* (Warburg 1993) were observed about one month later (in April) than the cold-resistant European species *P. dilatatus* (in March) (Warburg et al. 1984). After the spring peak, the number of xerophilic *A. officinalis* (Messina et al. 2012) decreased gradually in the following months, reaching its lowest level in winter; no individual was seen in January. The second highest level of *P. dilatatus* was observed in winter and the lowest in summer.

Depending on the species and regions, woodlice can reduce their activities in challenging cold winter and hot and dry summer conditions above certain levels (Collinge 1944, Brereton 1957). During these periods, isopods recede from habitual aggregating shelters to more sheltered, more limited areas such as cracks and crevices and, possible, sociological motives can be replaced by survival urge (Broly et al. 2015, Ghemari et al. 2016). In this study, the numerical decrease of *P. dilatatus* during hot months and *A. officinalis* in winter months seems to be associated with such a contingent change of activity. However, the results indicate that this may not be the same rule for *P. laevis*. During the nine-month monitoring of the shelter in the pen building, a total of 2,395 *P. laevis* were counted; this count was 986 in the same period in the 18 shelters in the vicinity of this building (Table 1). Furthermore, the monthly course of indoor and outdoor densities of *P. laevis* also followed opposite trends, particularly at certain periods (Table 1). These data suggest that *P. laevis* may not exhibit a kind of serious inactivation as behavioural resistance to compelling winter and summer conditions, at least under the influence of the climatic and environmental conditions in our study area. Instead, this species, which is so fast (Pierce 1907) and can benefit from effective locomotory activity to avoid desiccation and to find suitable microhabitat (Dailey et al. 2009), may use a kind of contingent short-distance nomadic behaviour between inside (domestic, nidicolous) and outside (peridomestic) to resist against harsh environmental conditions. This influential and most probably instantaneous behaviour may explain its effective spread towards the northern parts of the Western Palaearctic, despite its North African origin; it may also explain its lifestyle closely related with livestock shelters (Ghemari et al. 2016, Harding 2016).

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Received: 20.07.2022
Accepted: 28.06.2024