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Diversity and distribution of scorpions according to habitats in the arid ecosystems of the central Algerian Sahara

Zineb SOUILEM [1,*], Salah Eddine SADINE [2], Linda ROUARI [2], Abdelwahab CHEDAD [3], Rabah ZEBSA [4], and Moussa HOUHAMDI [4]

1. Laboratory of Mathematics and Applied Sciences (LMSA), Faculty of Science and Technology, University of Ghardaïa, 47000 Ghardaïa, Algeria.
2. Laboratoire valorisation et conservation des écosystèmes arides (LVCEA), Faculté des Sciences de La nature et de la vie et sciences de la Terre, Université de Ghardaïa, 47000 Ghardaïa, Algeria.
3. Laboratoire de Recherche Agronomie Environnement (LRAE), Université Ahmed Ben Yahia El Wancharissi, Tissemsilt, Algeria.
4. Laboratory of Biology, Water and Environment, Faculty of Sciences of Nature and Life and Sciences of the Earth and the Universe, University of 8 May 1945, 24000 Guelma, Algeria
* Corresponding author: Z. Souilem, E-mail: zinebsouilem294@gmail.com

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Abstract. Scorpions are animals that are well adapted to life in the desert. Due to their adaptability and ecological plasticity, they have thrived throughout all geological eras for over 450 million years in deserts and uninhabited areas. The present work aims to contribute to understanding the effects of habitat on scorpion diversity in the arid ecosystems of the Sahara Desert of Algeria. Specimen collection was conducted from October 2022 to September 2023 across four dominant biotopes: Erg, Palm grove, Reg, and Urban area. The systematic list of scorpions comprises 10 species, divided into 6 genera, all belonging to the family Buthidae. This richness represents more than 83% of the estimated diversity. The rarefaction curves for scorpion species richness in the study area suggest that only 11 species may be present. Among the important results, the habitat has a significant effect on scorpion diversity and distribution in the central Algerian Sahara, with the highest richness in the palm grove, followed by reg and erg. However, the urban area had the fewest species, with only one.

Keywords: biodiversity, ecological descriptors, scorpions, Algeria, Sahara.

Introduction

Scorpions are primarily sedentary arthropods and live very attached to preferential biotopes (Vachon 1952, Brownell & Polis 2001, Sadine 2018). The processes of habitat selection usually involve responses to environmental conditions that promote the growth, survival, and reproductive success of this species (Uetz 1979, Polis 1980, Schowalter 2012, Lira et al. 2013).

The diversity and abundance of scorpions are influenced by the environmental factors (Polis 1990, Prendini 2005, Dias et al. 2006, Araújo et al. 2010, Nime et al. 2013, Pizarro-Araya et al. 2014, Nime et al. 2014, Lira et al. 2019, Chedad et al. 2020), which are the important determinants of the general geographical range of cryptozoic species (Koch 1977, Newlands 1978, Prendini 2005, Schwerdt et al. 2016). However, the abiotic conditions of Saharan ecosystems are highly unfavorable to the presence and survival of living beings (Chehma 2005).

Scorpions are well-adapted to life in the desert (Dunlop et al. 2008, Dehghani & Kassiri 2018). Due to their adaptability and ecological plasticity, they have persisted throughout all geological eras for over 450 million years in deserts and uninhabited areas (Cloudsley-Thompson 1992, Giribet & Edgecombe 2019).

Algeria, for example, with its vast

geographical extent and diverse ecosystems (Mekahlia et al. 2021, Sadine et al. 2023), attests to a high level of diversity, with more than 54 species of scorpions (Dupré et al. 2023), more than 64% of this diversity is concentrated in the Sahara which represents approximately 3/4 of the total surface of Algeria (Dubief 1952, Côté 1996) with different geomorphological forms that characterize the Algerian Sahara such as: Reg, Erg, Sebkha, Hamada and Depressions (Toutain 1979).

In this context, our study, conducted from October 2022 to September 2023 in arid ecosystems of the central Algerian Sahara, aims to anticipate the effects of habitat (Reg, Erg, palm grove, and urban area) on scorpion diversity and distribution.

Materials and methods

Study area

Our study area comprises the Ghardaïa region and its surroundings (Figure 1a), located in the central Sahara of Algeria, with an average elevation of 520 meters (Benkenzou et al. 2007). This region is characterized by a semi-arid to arid climate (Mihoub 2017), with a dry period lasting more than 12 months (January–December) (Figure 1b). The hottest month is July with an interannual monthly average temperature of 34.45 °C, and the coldest month is January with an interannual monthly average of 10.39 °C. The interannual average precipitation is 65.95 mm (Sadine et al. 2023).

Sampling of scorpions

Scorpion specimens were collected approximately midway through each month between October 2022 and September 2023 from different biotopes: Erg, Palm grove, Reg, and Urban. The scorpion collection was conducted both at night and during the day. In this study, only adult individuals are used for identification, after having been killed and kept in 70% alcohol. For identification, we used a stereomicroscope, as described by Vachon (1974). The sampled individuals are placed in the Laboratory of Zoology at the University of Ghardaïa.

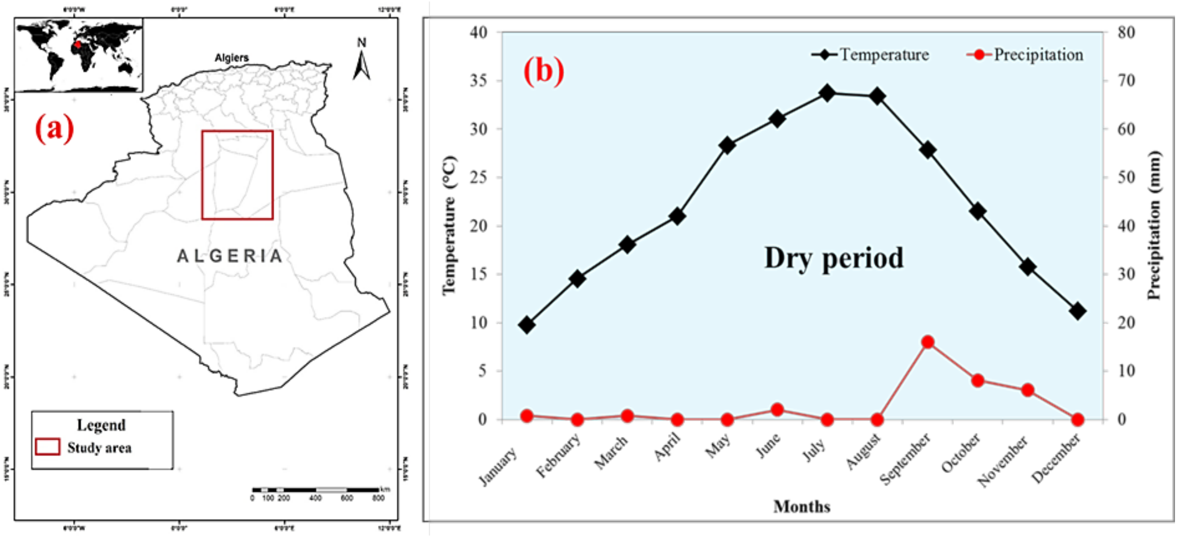

Figure 1. Description of the study area. (a) Map of Algeria, showing the study area. (b) Ombrothermic diagram of the study area (2022-2023).

Data analysis

Estimated species richness across different biotopes was calculated using EstimateS 9.1.0 (Colwell & Joshi 2013). S_{est} was estimated using the least biased and most precise estimator (Brose & Martinez 2004). Ecological indices were evaluated by calculating: Species richness (S) to explain the composition of the scorpion fauna;

Relative Abundance (AR %) for each species, determined as the ratio of the number of individuals for each species divided over the total number of individuals (Magurran 2004); Shannon's index (H′ = −∑(pi × log2pi)) was used to evaluate diversity of the scorpion fauna; Maximum of Shannon index: Hmax = log2(S); Evenness (E = H′/log2Sobs) was used to evaluate the evenness of species in each sampled biotope (Magurran 2004).

A Venn diagram was used to illustrate the similarity between biotopes. To analyze differences in scorpion assemblage composition between habitats, use a pairwise test.adonis2 (pairwise PERMANOVA) was used. To illustrate the relationships among species and biotopes in the study area, non-metric multidimensional scaling (NMDS) was performed. All models were fitted using the R package lme4 (Bates et al. 2015).

Results

During the 12 months from October 2022 to September 2023, we collected and examined 305 scorpions from the central Algerian Sahara.

<u>Taxonomic and scorpion composition</u>

Based on identification keys, our investigation revealed that the systematic list of scorpion diversity comprises 10 species across 6 genera, all belonging to the family Buthidae. They are presented by taxonomic orders in Table 1. Based on extrapolation of species number, the accumulation curve indicates that the sampling effort presents a very high proportion of existing species S = 10 Sest (Chao 1) = 10.498 ± 1.319 (Figure 2). At the limit, this region can host 12 scorpion species; our finding (10 species) represents more than 83% of the estimated diversity.

The richness estimated for the different habitats (Erg, Reg, and Palm grove) is summarized in Figure 3. The accumulation curve indicates that the sampling effort in the Erg revealed a very high proportion of existing species, S = 6 S_{est} (Chao 1) = 6.676 ± 2.172.

In the Palm grove, the accumulation curve indicates that the sampling effort revealed a high proportion of existing species (S = 5, Sest = 5.994 ± 2.186, Chao1). The number of species remains stable at 5 for the Reg biotope.

These results show that our scorpion inventory was complete, indicating that no rare or new species were discovered despite the increased sampling effort.

<u>The relative abundance (RA %)</u>

Seasonal abundance of species during the survey period varied significantly across biotopes, as summarized in Figure 4. These results show that the most dominant species is *Androctonus amoreuxi* (58.36%), followed by *Androctonus australis* (24.59%). The lowest abundance was observed for *Orthochirus innesi* at approximately 0.32%. The Palm grove shows that *A. amoreuxi* was the most common species across all seasons, with abundance ranging from 22 individuals (69%) in winter to 84 in summer (61%).

Table 1. Systematic list of scorpion species captured in the study area.

Genus	Species	Endemism	References
Androctonus	*A. aeneas* C.L. Koch, 1839	/	Sadine 2018
	A. amoreuxi (Audouin, 1825)	/	Sadine 2018
	A. australis (Linnaeus, 1758)	/	Sadine 2018
Buthacus	*B. deserticus* Sadine, Souilem, Lourenço & Ythier, 2024	This region	Current study
	B. samiae Lourenço & Sadine, 2015	This region	Lourenço & Sadine 2015
	B. spinatus Lourenço, Bissati & Sadine, 2016	This region	Lourenço et al. 2016
Buthiscus	*B. bicalcaratus* Birula, 1905	/	Current study
Buthus	*B. saharicus* Sadine, Bissati & Lourenço, 2016	For Algeria	Sadine et al. 2016
Lissothus	*L. chaambi* Lourenço & Sadine, 2014	This region	Lourenço & Sadine 2014
Orthochirus	*O. innesi* Simon, 1910	/	Sadine 2020
6 genera	10 species		

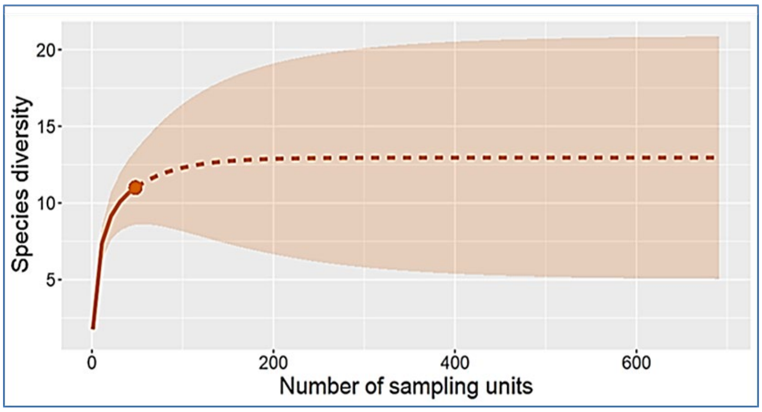

Figure 2. Rarefaction curves of scorpion species richness estimated in the study area.

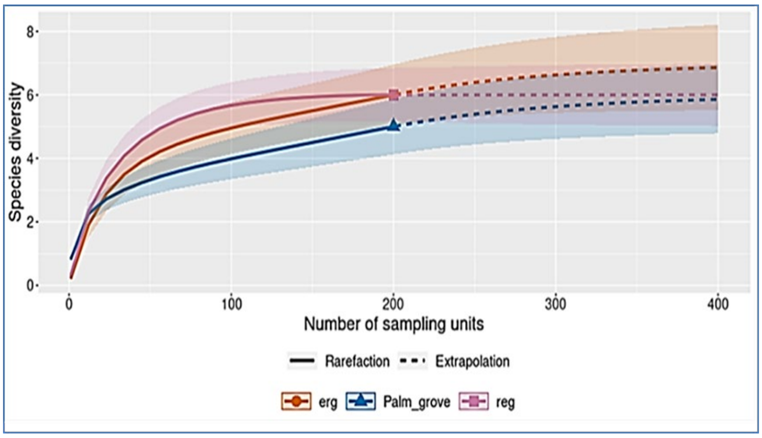

Figure 3. Rarefaction curves of scorpion species richness estimated in the three biotopes, erg, reg, and palm grove (except urban areas) in the central Sahara of Algeria.

The values obtained in the erg biotope indicate that *A. amoreuxi* was the most abundant species during the summer, followed by *Buthiscus bicalcaratus* (4 individuals). *Buthacus spinatus* was the most abundant species across the three seasons of winter, spring, and autumn, with a mean number of individuals of approximately 3. *Buthacus deserticus* is a more abundant species in autumn, with 3 individuals.

The exact figure shows that *A. amoreuxi* and *B. deserticus* were the dominant species in the reg region during the summer, with 14 individuals and 4 individuals, respectively. In the spring season, the most dominant species were *Lissothus chaambi* and *A. amoreuxi*, with 3 and 8 individuals, respectively. The most dominant species in the fall and winter seasons were *A. amoreuxi* (14 individuals) and *L. chaambi* (6 individuals), respectively. Contrariwise, the urban area is monospecific, frequented by *A. australis*.

<u>Variation in diversity parameters</u>

The ecological descriptors applied to scorpion species across different biotopes in the study area are presented in Figure 5. This study shows that the Shannon diversity index (H') has a mean of approximately 0.40 ± 0.39. The highest value of the average of the maximum Shannon index was obtained in the palm grove biotope (0.40 ± 0.31). Then the Reg biotope (0.38 ± 0.43) and the erg biotope (0.33 ± 0.43). The zero value was obtained in the urban area (Figure 5).

The mean maximum Shannon index was approximately 0.59±0.69. The values of this parameter varied from 0.45 ± 0.52 in the erg to

0.68 ± 0.5 in the palm grove. The values obtained in the Reg biotype and in urban areas are approximately 0.48 ± 0.49 and 0 (Figure 5).

The average value of regularity was of the order of 0.51 ± 0.11. The highest flatness values were observed in the reg biotope and the palm grove, with values of approximately 0.72 ± 0.36 and 0.70 ± 0.20, respectively. The erg biotope is represented with a value of 0.65 ± 0.45. The value of 0 was obtained in the urban area (Figure 5).

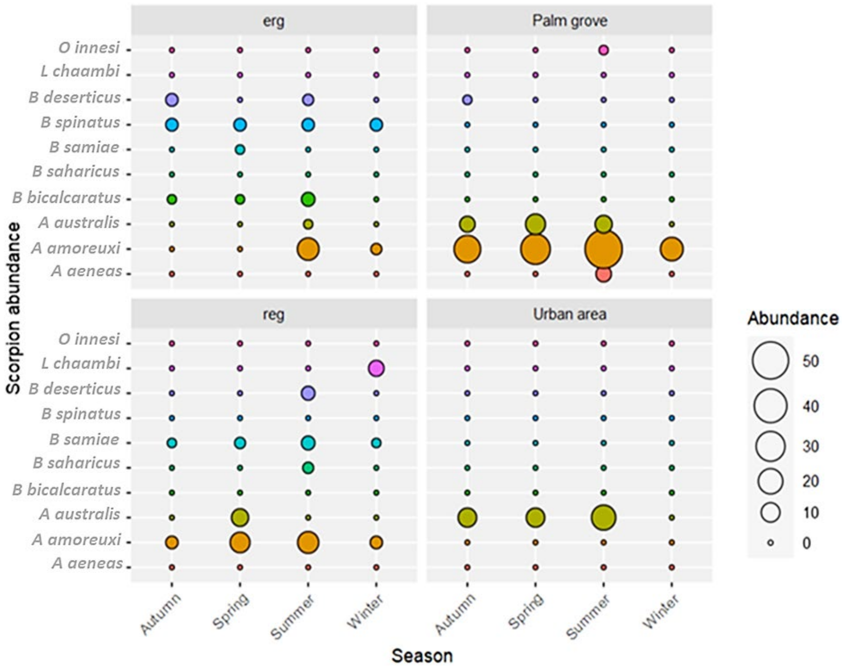

Figure 4. Scorpion abundance according to the seasons in the Ghardaïa region (central Sahara of Algeria).

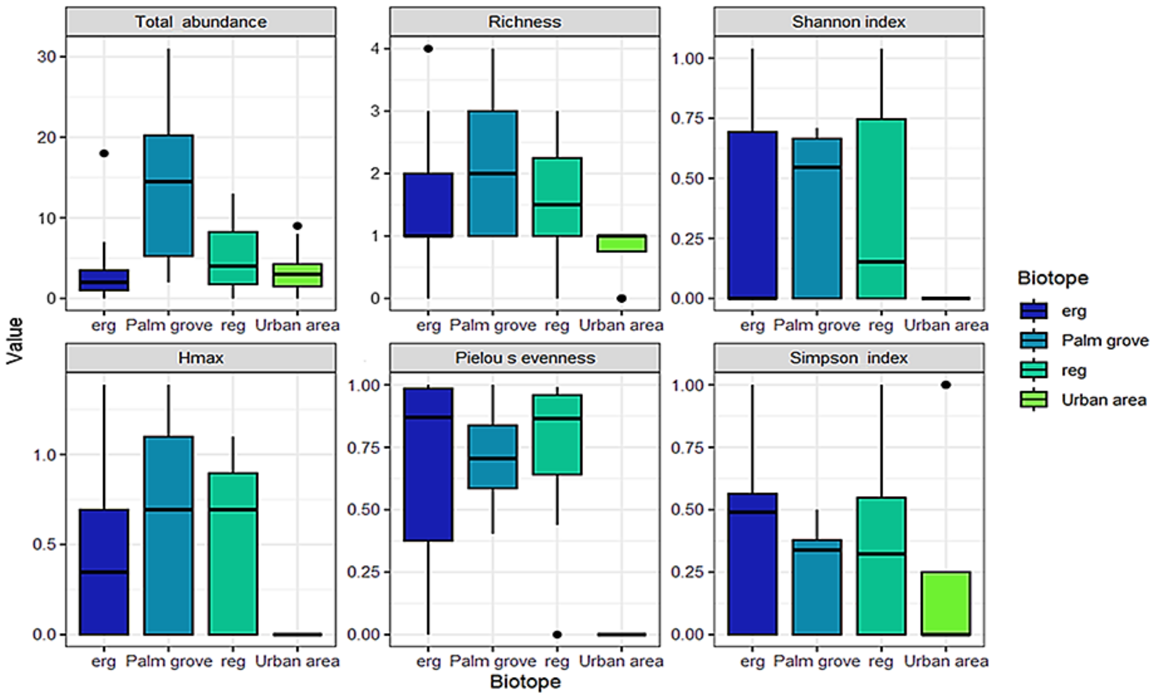

Figure 5. Box-plots representing the different ecological descriptors applied to scorpion species in different biotopes in the central Algerian Sahara.

Distribution analysis of scorpion species according to the biotopes

Table 2 shows that the permutation test for Adonis 2 under the reduced model indicated that scorpion composition varied significantly across biotopes (PERMANOVA: p = 0.001). The pairwise adonis2 (PERMANOVA) test, which analyzed differences in scorpion species composition among the four sampled biotopes, revealed highly significant differences across all pairs (P < 0.001). The results of the distribution analysis of different species and biotopes are illustrated in Figures 6 and 7.

The Venn diagram (Figure 6) shows that 10% of the total scorpion richness was shared across the biotopes, represented by a single species (*A. australis*). 20% of the total richness in the reg biotope was characterized by the two species, *L. chaambi* and *Buthus saharicus*. The palm grove biotope accounted for 20% of the total wealth, with *O. innesi* and *Androctonus aeneas*. In three biotopes (reg, erg, and palm grove), *B. spinatus* and *B. bicalcaratus* represented 20% of the scorpion species in the study region. *Buthacus samiae* accounted for 20% of the species in the area; this percentage is similar between the reg and the erg.

The NMDS diagram in Figure 7 showed that all species were associated with specific biotopes, except *A. amoreuxi*, which was associated with three biotopes: reg, erg, and palm grove. The species related to the reg were *B. samiae* in summer, *B. saharicus* in summer, and *L. chaambi* in winter. The erg hosted *Buthacus deserticus* and *B. bicalcaratus* in autumn and *B. spinatus* in spring and winter. The species associated with the palm grove in summer were *A. aeneas* and *O. innesi*. The only species associated with the urban area was *A. australis*, which occurred in all seasons except winter.

Table 2. Test pairwise. adonis2 (pairwise PERMANOVA) for the difference in scorpion species composition among the four sampled biotopes.

Groups	Df	sum of Sqs	R^2	F	Pr
Biotope	3	6.1957	0.43604	103999	0.001***
Erg_vs_Palm grove	1	1.9169	0.28073	7.806	0.001***
Erg_vs_Reg	1	1.2721	0.17136	3.9291	0.001***
Erg_vs_Urban area	1	2.6454	0.42387	11.772	0.001***
Palm grove_vs_Reg	1	0.7706	0.13499	3.2773	0.022*
Palm grove_vs_Urban area	1	2.6302	0.52479	19.878	0.001***
Reg_vs_Urban area	1	2.5841	0.41640	12.13	0.001***

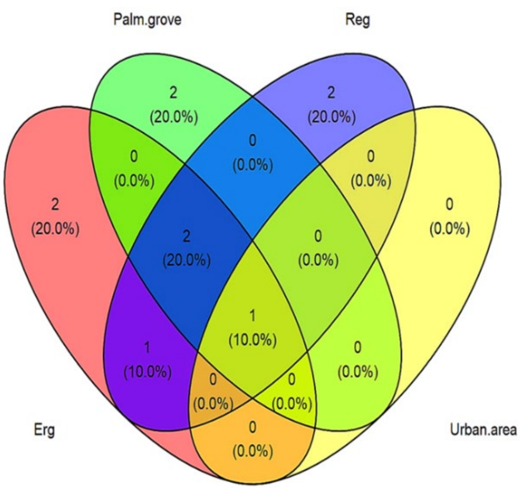

Figure 6. Venn diagram presenting the species distribution of scorpions across different biotopes in the Ghardaïa region of central Algeria.

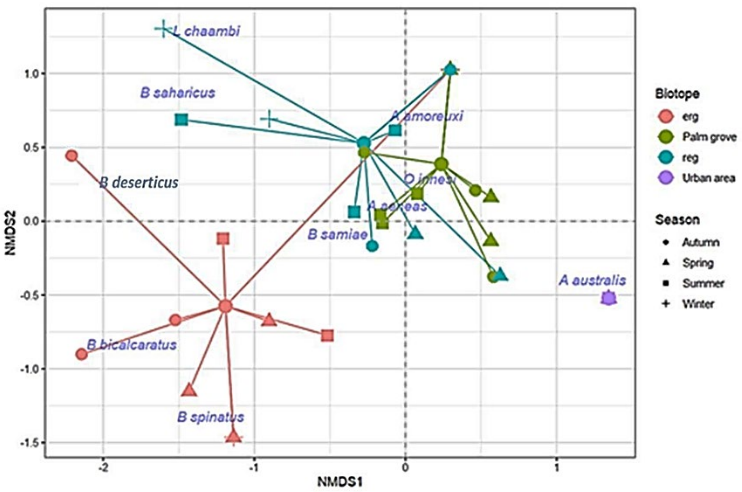

Figure 7. Non-metric multidimensional scaling (NMDS) ordination based on species abundances within different biotopes and seasons.

Discussion

According to Dupré et al. (2023), 54 scorpion species are found in Algeria; thus, the species recorded at Ghardaïa (central part of the Algerian Sahara) represent 18.5% of Algerian scorpions and 67% of the species identified in the northern Algerian Sahara (Sadine 2018). The present survey revealed a wide diversity of scorpion populations in the Ghardaïa region, comprising six genera and ten species within the family Buthidae.

In Algeria, the genus *Androctonus* comprises 6 species (Dupré et al. 2023). We noted the high diversity of this genus in our study; it was the most widespread scorpion genus, with AR around 88%, including three species: *A. amoreuxi*, *A. australis*, and *A. aeneas*. Sadine et al. (2011) reported the occurrence of the same three species in the Souf scorpion, whereas in Ouargla province and northeastern Algeria (Tébessa), only 2 species are found (Mekahlia et al. 2021). Sadine et al. (2012), Hasnaoui et al. (2018), and Ouici et al. (2020) recorded only one species from Belazma (Batna), Khanchla, and Sidi Bel Abbes (*Androctonus aeneas*).

Species occurrence in the genus *Androctonus* varied: *A. amoreuxi* is considered constant, with a dominance of 61%, and *A. australis* is abundant, with an abundance of 25%. This result confirms recent findings (Sadine et al. 2023). Other authors indicate that *A. australis* is the most abundant species in the Ghardaïa region (Lahrech & Souilem 2017, Bengaid 2018) and in the area of Ouargla and Oued (Sadine et al. 2011, 2018). *A. aeneas* has a low abundance of 2% similar to other work in Sidi Belabas and Tebessa.

In our study, the genus *Buthacus* comprises 12 species in Algeria. We identified three species with low abundance (8.5%). This result agrees with the findings of Aboshaala et al. (2022) in the Misurata region of North Libya. Nonetheless, Bengaid et al. (2022) recorded five species in this region. In the El Oued and Ouargla provinces, only two species have been described (Sadine et al. 2011, 2018).

The occurrence of the species of genus *Buthacus*: *B. samiae*, *B. spinatus*, and B. deserticus was accidental, with a high endemism of the region of Ghardaia.

Genus *Buthus* is the most diverse genus in Algeria, with 10 distinct species (Ythier et al. 2021). Recently, 11 species of this genus were reported following the identification of the new species *Buthus goyffoni* (Abidi et al. 2021) in El-Tarf (Northeastern Algeria). In our study, we recorded a low diversity of these genera, with only one species, *Buthus saharicus*, at very low abundance (3%). It is considered highly accidental and is endemic to this region, as confirmed by Sadine et al. (2018) in Ouargla province.

In our fieldwork, the genus *Orthochirus* was represented by a single low-abundance species (0.3%), whereas in Algeria, three species were documented (Lourenço & Sadine 2021, Dupré et al. 2023).

In Algeria, the genera *Buthiscus* and *Lissothus* were represented by only one species each in our study. We recorded them at low abundance (0.3%), which is rare in our study. *Lissothus chaambi* is endemic to the Ghardaïa region, while *B. bicalcaratus* in the works of Sadine was limited to the El-Oued region (Sadine et al. 2011).

The use of diversity indices is essential for assessing diversity in community studies (Van Strien et al. 2012). In arid ecosystems, scorpion assemblages often exhibit greater species diversity and serve as useful indicators (Lira et al. 2023). Relative abundance, species richness, and species diversity of scorpions in the central Algerian Sahara were, on average, higher in the palm grove than in the reg biotope; the two other biotopes have a low abundance. On the other hand, species richness was higher in the reg and erg biotopes than in the palm grove, and the urban area had the lowest, with only one species. Species diversity was higher in the palm grove than in other biotopes. However, there was no equilibrium between the numbers of species harvested only in the palm grove and reg. This result agrees with the field study of several others in different biotopes in this region (Lahrech & Souilem 2017, Bengaid 2018, Sadine et al. 2011).

However, Sadine (2018) reported that the palm grove of El Oued has a higher species richness than other biotopes. The forest of Khanchla was the most abundant biotope both quantitatively (accounting for almost 50% of the individuals collected) and qualitatively (supporting four species). Similar findings were reported for certain deserts and semi-arid savannahs, where scorpion abundance increased with the presence of shrubs (Polis & McCormick 1987, Blaum et al. 2009).

Our study revealed a strong spatial dissimilarity in the distribution of scorpion communities across biotopes in the Ghardaïa region. Except for the dominant species, A. amoreuxi, the affinity of the other nine species for the habitat can be explained by the biotope's heterogeneity and structure. Several others indicate that the dominant rainforest species were found in most litter microhabitats, as noted by Lira et al. (2013), and that the dominant dry forest species also occurred in the highest proportion of terrestrial microhabitats. Similarly, in the desert of California's Coachella Valley, the dominant scorpion (approximately 95% of the total) accounted for the most significant proportion of available terrestrial animals (Polis & McCormick 1987, Lira et al. 2013).

Our study shows that variation in scorpion species composition, richness, and diversity is explained by biotope heterogeneity and structure, indicating that the principal determinants of scorpion distribution are elevation and soil type, whereas plant cover is an auxiliary factor. In addition, greater habitat heterogeneity indicates greater availability of shelter, an important feature for scorpions. Scorpions are considered generalist predators and are known to be aggressive towards other scorpions (Polis 1990, Smith & Pettorelli 1995). Diversity of scorpions in the Brazilian Atlantic Forest, Lira et al. (2016), documented that species composition is related to area and habitat structure of forest remnants. Scorpion species in the Atlantic Forest are dependent on forested habitats and avoid modified habitats, such as agricultural and grazing lands (Porto et al. 2018). Tabarelli et al. (2010) and Lira et al. (2018) report that scorpion diversity in the Atlantic Forest is relatively low, likely due to the highly fragmented landscape of this ecosystem.

This study on the diversity of scorpion populations in the Ghardaïa region highlights remarkable species richness, with six genera and ten identified species. The area is characterized by unique diversity, dominated by species of the genus *Androctonus*. The study reveals significant spatial distribution differences among scorpion species across biotopes, reflecting variability in habitat and ecological structure. The findings emphasize the crucial importance of preserving natural habitats, especially in fragile ecosystems such as the Sahara. Any disturbance or alteration of these environments could lead to notable changes in the composition of faunal communities, including scorpions, thereby disrupting the ecological balance of these already vulnerable ecosystems.

The geographical distribution of scorpions, as well as their species diversity, is closely linked to various environmental factors (Bobka et al. 1981, Zhang & Ji 2004, Angilletta et al. 2004, Sadine et al. 2012, 2023). These include soil type, vegetation cover, temperature variations, humidity levels, and most importantly, the type of habitat in which they live (Polis 1990, Yamaguti & Pinto-da-Rocha 2006, Araújo et al. 2010, Sadine et al. 2012). Any modification of their natural habitat leads to a significant alteration of local ecological conditions. Such changes can disrupt the balance of key parameters essential to scorpions' survival. Habitat change thus acts as an important environmental disruptor, influencing the spatial distribution of scorpions.

Ultimately, the Sahara offers a particularly favorable environment for studying scorpion biological adaptations. Indeed, the desert ecosystems of Algeria are home to a wide variety of scorpion species, thanks to the diversity of their habitats, which offer ideal conditions for their development. The high temperatures and extreme climatic conditions typical of desert regions play an important role in the proliferation of these arthropods. These conditions promote diversity and significantly increase scorpion richness, thereby enabling close observation of their adaptation strategies.

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