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SCORPION DIVERSITY PATTERNS IN THE MISURATA REGION, NORTH LIBYA (ARACHNIDA: SCORPIONES)

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Abstract. The scorpion fauna of Libya is varied and endemic, but little explored. Our work is a contribution to the study into the ecology and distribution patterns of scorpions from the Misurata region (North Libya). Investigations were carried out at 12 sites between June 2019 and December 2020 using ultraviolet light. We sampled 96 adult specimens belonging to nine species: *Androctonus amoreuxi* (relative abundance "RA" = 2.08%), *Androctonus australis* (RA = 31.25%), *Androctonus bicolor* (RA = 9.33%), *Buthacus arenicola, Buthacus* sp. 1 and *Buthacus* sp. 2 (RA = 3.13%), *Buthiscus bicalcaratus* (RA = 10.42%) *Buthus adrianae* (RA = 18.75%) and *Buthus orientalis* (RA = 19.79%). This region is characterized by great scorpion diversity and high community evenness. Among the specimens belonging to the above-mentioned nine species, we noted two species of Egyptian *Buthus*: *B. adrianae* and *B. orientalis,* representing a new record for Libya, and classified as a very accidental species (Occ = 50%). By frequency of occurrence, the other species were assigned to different categories ranging from very accidental to the common ones. The Canonical Correspondence Analysis (CCA) performed to detect gradients in species composition and species-environment relations confirmed the existence of a close relationship between some species and their biotopes, i.e., scorpions of the genus *Buthacus* were associated with sandy habitats, while *A. amoreuxi* and *A. australis* were associated with desert conditions (scarce vegetation, low precipitation and elevation). However, the ecological preferences of *B. bicalcaratus* remain uncertain.

INTRODUCTION

Libya occupies part of northern Africa from 20 to 34° N and from 10 to 25° E. Its strategic location at the midpoint of Africa's northern rim is its important physical asset (Mahklouf and Etayeb 2018). Libya is mostly characterized by arid climatic conditions, except for the coastal strip and the northern hills towards the east and the west, while the rest of the country is located in arid and semiarid conditions (Essghaier et al. 2015). Libya, with its enormous geographical extent and various ecosystems, is inhabited by more than 22 species of scorpions (Dupré 2021) representing more than 0.8% of the global richness of scorpions (Rein 2021). North Africa, including Libya, contains an ancient and endemic scorpion fauna (Vachon 1952; Cloudsley-Thompson 1984), but it is little explored. In his study on scorpions of North Africa, Vachon (1952) listed 18 scorpion species in Libya. This number has increased to 20 species by 1992 (El-Hennawy 1992). A few years later, Fet et al. (2000), listed 21 species. Kaltsas et al. (2008) established the geographical distribution of scorpions in the Mediterranean with a list of 12 species (3 endemic species). Other studies performed on scorpions of Libya, did not add any new species to the fauna of the country (Barbash 1982; Zourgui et al. 2008; Suliman et al. 2013). Recently, a few taxonomic works have added two new species: *Buthus lourencoi* Rossi, Tropea & Yağmur, 2013 and *Cicileus latellai* Lourenço & Rossi, 2015.

Within the project of cooperation between academic scholars from Algeria, Egypt and Libya, methodological field work was performed in the region of Misurata (North Libya). Here, a recently performed study has reported a new locality for *Buthiscus bicalcaratus* and has provided some ecological considerations (Aboshaala et al. 2020). The present work aimed to expand the faunistic knowledge of scorpions in Misurata by focusing on scorpion distribution patterns at 12 stations based on recent fieldwork conducted from June 2019 to December 2020.

MATERIALS AND METHODS

Study area

Our survey was carried out in the Misurata region (Libya), which is situated on the Mediterranean coast in North Africa (Fig. 1). Libya lies between 31° and 33° N and between 14° and 15° E, at an average altitude between 60 and 80 m. The dominant climate conditions are characterized by the Mediterranean hot-summer and hot desert climate (Kottek et al. 2006). It always rains in winter, with annual rainfall ranging from 200 to 300 mm and mean monthly temperatures from 14.8 °C to 25.9 °C (WorldClim 2005).

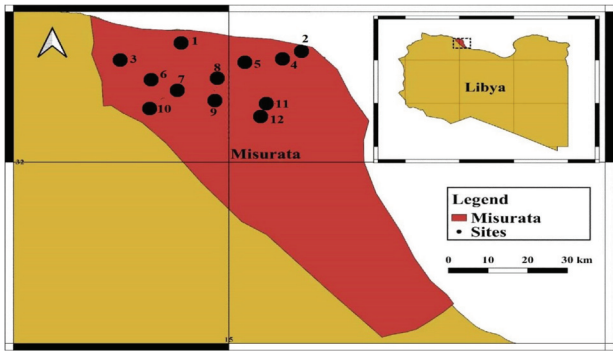


Figure 1. Map of Libya, showing sampling stations. 1 – (Zurayk), 2 – (Gasar Ahmed 2), 3 – (Al Dafiniyah), 4 – (Gasar Ahmed 1), 5 – (Misurata Airport), 6 – (Abu-Kadma), 7 – (Assuita), 8 – (Al Sekat 1), 9 – (Al Sekat 2), 10 – (Saso), 11 – (Tamena), 12 – (Al Krarim).

Sampling and identification of scorpions

Specimens were collected from twelve collecting localities in Misurata city (North Libya) (Fig. 1) from June 2019 to December 2020 during the night using ultraviolet light. The collected specimens were preserved in 75% alcohol. Identification was made using a stereomicroscope following the methodology described by Vachon (1974).

Data Analysis

In our survey, we used the following ecological indices: **Species richness (S)** to explain the composition of the scorpion fauna; **Relative abundance (RA %)** to determine the ratio of the number of individuals of some scorpion species to the total number of the individuals recorded (96); **Occurrence frequency (Occ),** which was calculated for each species by dividing the number of stations whereat the species was recorded by the total number of the stations sampled. By their occurrence frequency, scorpion species were divided into the following four groups (Bigot and Bodot 1973): the group of very accidental species with the frequency of occurrence less than 10%; the group of accidental species with the occurrence frequency varying between 10 and 24%; the group of common species with the occurrence frequency in the range of 25 to 49%; and the group of constant species that are present in 50% or in a higher percentage of the samples. **Shannon's index (H')** was used to evaluate diversity of the scorpion fauna; **Evenness (E)** was used to evaluate the evenness of species in the community (Magurran 2004). The ecological indices were calculated using Microsoft excel 2010. **Canonical correspondence analysis (CCA)** was performed to detect gradients in species composition and species-environment relationships. This analysis is convenient when visualizing dimensional ecological data in a readily interpretable manner without prior transformation (Ter Braak 1986; Palmer 1993). In our survey, we used the CCA which allowed us to relate the abundance of species to environmental variables and thus to highlight the relationships between environmental variables and the distribution of scorpion species. The permutation test was used to test the significance of CCA with 1000 permutations at a significance level of 5%. The CCA was performed using XLSTAT 2014.5.03

RESULTS

Over the period from June 2019 to December 2020, we collected a total of 96 scorpion specimens at 12 different stations.

The systematic list consists of nine species of Buthidae, belonging to four genera: *Androctonus, Buthacus, Buthiscus* and *Buthus* (Table 1). *Androctonus* and *Buthacus* are represented by three species, *Buthus* by two species and *Buthiscus* by one species.

In the Misurata region, the abundance of scorpion species was highly variable. The most abundant species was *A. australis* with the relative abundance of 31.25%. Two species *B. adrianae* and *B. orientalis* were second in abundance, their relative abundance reaching 19.79% and 18.75%, respectively. The relative abundance values of *B. biclacaratus* and *A. bicolor* were very close, i.e., 10.42% and 9.33%, respectively. The relative abundance of other species was less than 3.33%. Furthermore, the relative abundance of dominant genera *Androctonus* and *Buthus* was 41.66% and 38.54, respectively.

Two species, i.e., *B. adrianae* and *B. orientalis,* were attributed to constant species (Cst = 50%). *Androctonus* (41.66%), *A. bicolor* (Com = 41.67%) and *A. australis* (Com = 33.33%) were assigned to common species. Four species, i.e., *B. bicalcaratus, B. arenicola, Buthacus* sp. 1 *and Buthacus* sp. 2, were attributed to the category of accidental species (Acc = 16.67). *A. amoreuxi*, which was represented by the lowest number of individuals (2 individuals), was considered as an accidental species (Occ = 8.33%).

Table 1. Systematic list, relative abundance and occurrence frequency of scorpion species captured in the Misurata region.

Family	Genus	Species	N	RA (%)	Occ (%)	Scale
Buthidae	*Androctonus* (41.66)	*A. amoreuxi* (Audouin, 1825)	2	2.08	8.33	Vac
		A. australis (Linnaeus, 1758)	30	31.25	33.33	Com
		A. bicolor Ehrenberg, 1828	8	9.33	41.67	Com
	Buthacus (9.38)	*B. arenicola* (Simon, 1885)	3	3.13	16.67	Acc
		Buthacus sp. 1	3	3.13	16.67	Acc
		Buthacus sp. 2	3	3.13	16.67	Acc
	Buthiscus (10.42)	*B. bicalcaratus* Birula, 1905	10	10.42	16.67	Acc
	Buthus (38.54)	*B. adrianae* Rossi, 2013	18	18.75	50.00	Cst
		B. orientalis Lourenço & Simon, 2012	19	19.79	50.00	Cst
Total	4 genera	9 species	96	100%	/	/

N: Number of individuals, RA (%): Relative Abundance, Occ: Occurrence, Cst: Constant species, Com: Common species, Acc: Accidental species, Vac: very accidental species.

Table 2. Shannon's index (H'), evenness (E) and species number (S) of scorpions at each sampling site in the Misurata region.

N	Stations	GPS coordinates	Biotopes	Vegetation cover	H'	S	Hmax	E
1	Zurayk	32°27'N, 14°34'E	Sandy	Very dense	1.91	04	2.00	0.96
2	Gazer Ahmed 2	32°21'N, 15°09'E	Sandy	Very dense	**2.24**	05	2.32	0.96
3	Al Dafiniyah	32°21'N, 14°43'E	Agricultural	Dense	0.99	02	1.00	**0.99**
4	Gazer Ahmed 1	32°37'N, 14°18'E	Sandy	Dense	–	01	–	–
5	Misurata Airport	32°20'N, 15°03'E	Rocky and sandy	Dense	–	01	–	–
6	Abo-Kadma	32°17'N, 14°48'E	Agricultural	Low	–	01	–	–
7	Assuita	32°14'N, 14°59'E	Rocky and sandy	Dense	1.49	04	2.00	0.75
8	Al Sekat 1	32°11'N, 14°48'E	Rocky and sandy	Very low	–	01	–	–
9	Al Sekat 2	32°13'N, 14°58'E	Sandy	Low	0.39	02	1.00	0.39
10	Saso	32°15'N, 14°52'E	Sandy	Dense	1.58	03	1.58	**1.00**
11	Tamena	32°11'N, 15°06'E	Agricultural	Dense	0.81	02	1.00	0.81
12	Al Krarim	32°09'N, 15°05'E	Desert	Dense	1.37	04	2,00	0.69
Misurata region		/	/	/	2.66	9	3.17	0.84

Table 3. Distribution of scorpion species by stations.

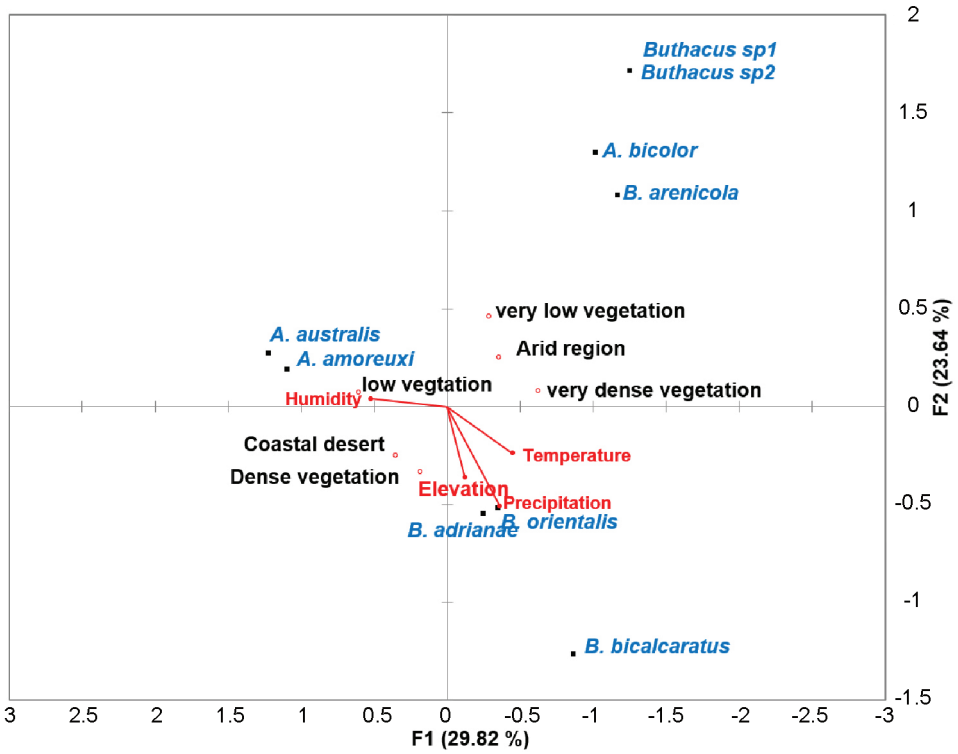
No	Stations	Scorpion species								
		A. amoreuxi	*A. australis*	*A. bicolor*	*B. arenicola*	*Buthacus* sp. 1	*Buthacus* sp. 2	*B. bicalcaratus*	*B. adrianae*	*B. orientalis*
1	Zurayk	–	–	–	+	+	+	–	–	–
2	Gazer Ahmed 2	–	+	–	–	–	–	-	–	–
3	Al Dafiniyah	–	–	–	–	–	–	-	+	+
4	Gazer Ahmed 1	–	–	–	+	+	+	-	+	+
5	Misurata Airport	–	–	+	–	–	–	-	–	–
6	Abo-Kadma	–	–	–	–	–	–	+	+	+
7	Assuita	–	–	+	–	–	–	–	–	–
8	Al Sekat 1	–	–	+	–	–	–	–	–	–
9	Al Sekat 2	–	+	–	–	–	–	-	–	–
10	Saso	–	+	+	–	–	–	+	+	+
11	Tamena	–	–	–	–	–	–	–	+	+
12	Al Krarim	+	+	–	–	–	–	–	+	+

(+) present, (–) absent

Shannon's index (H') and evenness (E) of scorpions in this region are summarized in Table 2. The distribution of species across sampling stations is shown in Table 3.

The value of Shannon's index (H') in the Misurata region is estimated at 2.66, but it is very low at different stations, except in the Gasar Ahmed 2 region, where its value is 2.44. The overall value of evenness (E) for the Misurata region equals 0.84 with the maximum value recorded at the sites of Saso and Al Dafiniyah.

Axis 1 of the CCA analysis showed several factors, i.e., temperature and precipitation of the arid regions



The results of canonical correspondence analysis show that the Eigenvalues of species and environment scores on canonical axis 1 and 2 were 29.82% and 23.64% of the constrained inertia, respectively (Fig. 2). The computed p-value ($p = 0.0001$) was lower than the significance level alpha = 0.05, thus we should accept the hypothesis that the sampled habitats/species abundance data are linearly related to the habitats/variable data.

Figure 2. Canonical Correspondence Analysis (CCA) diagram for habitat traits and scorpion species.

(negatively associated with humidity), that influence 78% (7 species) of scorpions from the Misurata region. However, on Axis 2, the major part of scorpions was positively correlated with arid conditions and sparse vegetation. Meanwhile, *Buthus* species were negatively correlated with height elevation and monthly precipitation.

All *Buthacus* species were found to be positively correlated with arid habitats, which are negatively associated with precipitation and elevation. Vegetation layers were not shown to have a significant effect on scorpion species. *A. amoreuxi* and *A. australis* were positively correlated with vegetation layers (low vegetation) but negatively with precipitation and elevation. *B. adrianae* and *B. orientalis* were closely associated with elevation, precipitation. Nevertheless, they showed total independence from vegetation cover factors. *B. bicalcaratus* was insulated, showing an apparent independence from the environmental factors under study.

DISCUSSION

Our survey was carried out in the Misurata region (Libya country), which is characterized by the Mediterranean climate with hot summers (Kottek et al. 2006). Over the hot-period from June 2019 to December 2020, at 12 different stations, we collected and examined a set of 96 specimens of scorpions. Below we provide a systematic list along with ecological notes for each species.

Androctonus amoreuxi (Audouin, 1825)

Androctonus amoreuxi has a wide distribution in North Africa (Vachon 1952). In North Libya, this species seems to be rare (2.8%), and in our study, it was grouped with very accidental species (Occ = 8.33%) found only at the Al Krarim station, with rocky habitats in arid regions and a relatively sparse vegetation cover, low precipitation, and low elevation. It is the biggest species that is generally found on sandy, gravelly and stony grounds (Sadine 2012; Sadine et al. 2014). Sadine (2018) reported that this species was very abundant (more than 40%) in central Algeria. According to Zourgui et al. (2008), this species represents the second most abundant species in Libya along with *Leiurus quinquestriatus*. The same situation is noted in Egypt, where two species (*A. amoreuxi* and *L. quinquestriatus*) appear to have high ecological tolerance and have been reported from all Egyptian eco-geographical regions (Saleh et al. 2017) in sandy areas with a shrubby vegetation cover (Badry et al. 2018). In Morocco, this species is omni-

present and non-opportunistic because it is not plastic and environmentally shows strict respect to the nature of substratum requirements (El Hidan et al. 2016).

Androctonus australis (Linnaeus, 1758)

The distribution of *A. australis* is limited to North Africa, in particular, to Algeria, Egypt, Libya, Sudan and Tunisia (Lourenço 2005). Meanwhile, Mirshamsi (2011) reported that this species has a wide general distribution across North Africa and the Middle East. In our study, *A. australis* was found to be an abundant (31.25%) and a very accidental species (Occ = 33.33%). It was found at Al-Krarim, Al Sekat 2, Gasar Ahmed 1, and Saso stations, in rocky habitats in arid regions with a relatively sparse vegetation cover. Zourgui et al. (2008) and Suliman et al. (2013) reported that this species was found in rocky areas of the costal and southern parts of Libya. *A. australis* is an opportunistic species (Sadine 2012), it was reported as the most widespread species in the northern Algerian Sahara (Sadine 2018; Sadine et al. 2020). Also, this species is widespread in different eco-geographical regions in Egypt (Saleh et al. 2017), particularly in rocky habitats with a relatively rich desert vegetation cover (Badry et al. 2018). Nevertheless, in Morocco, the presence of *A. australis* remains unconfirmed (Vachon 1952; Broglio and Goyffon 1980; Lourenço 2005). In 2009, Geniez reported this species in south Morocco. Several studies on scorpions of Morocco that have appeared since then have not mentioned this species again (Touloun et al. 2014a, b; El Hidan et al. 2016; Touloun et al. 2016; El Hidan et al. 2018; Touloun 2019).

Androctonus bicolor Ehrenberg, 1828

A. bicolor is less abundant than in eastern, western, and southern areas of Libya. (Suliman et al. 2013). This species appears to be rare (9.33%) in the Musrata region of North Libya, but previous studies show that it is widespread in eastern, western, and southern parts of Libya (Zourgui et al. 2008; Suliman et al. 2013). *A. bicolor* is classified as a very accidental species (Occ = 41.67%) because it was captured from several localities: the Misurata Airport, Zurayk, Assuita, Al Sekat 1, and Saso stations with rocky and sandy habitats and a very sparse vegetation cover. Similarly, in Egyptian arid regions, this species prefers rocky habitats with patches of sand and the cover of scrub vegetation (Badry et al. 2018). Sadine et al. (2011, 2012), reported that *A. aeneas* C. L. Koch, 1839 (synonym of *A. bicolor* in Algeria) is negatively correlated with the dense forest vegetation and prefers sites with stony substratum. Ouici et al. (2020) reported that this species was found in steppe and forest biotopes at the altitude of 1000–1400 meters, covering less than 50% of stony soil. Vachon (1952) captured individuals of *A. bicolor* in a region with sparse rangeland-floristic compositions.

Buthacus arenicola (Simon, 1885)

Scorpions of the genus *Buthacus* are widespread in sandy deserts of the Palearctic region, from the Atlantic coast of West Africa across the Sahara, and throughout the Middle East to India (Vachon 1952; Levy et al. 1973; Levy and Amitai 1980; Fet and Lowe 2000; Lourenço 2004; Lourenço 2006; Lourenço and Qi 2006; Yağmur et al. 2008; Zambre and Lourenço 2010). Zourgui et al. (2008) reported two species from Libya: *B. arenicola* and *B. leptochelys* (Ehrenberg, 1829). In our study, this genus is represented by three species, i.e., by *B. arenicola* and two species that have not been identified yet (specimens are in Egypt with Dr. Ahmed Badry for further examination). Each species is characterized by the low abundance of 3.13% and they are classified as very accidental species (Occ = 16.67%). They were found at Gasar Ahmed 1 and Zurayk stations, which are characterized by sandy habitats. All species of the genus *Buthacus* inhabit sandy substrates (Navidpour et al. 2008; Shehab et al. 2011; Navidpour et al. 2013). Recently, a new species *Buthacus levyi* Cain, Gefen & Prendini, 2021 was described from Egypt, Israel and maybe Libya. This contribution increases the number of *Buthacus* species in Libya to four. However, Algeria can be classified as a diversified area with nine species of *Buthacus* (Lourenço et al. 2017b). In the second position is Morocco with six species and one subspecies (Touloun 2019) and Egypt with two species (Saleh et al. 2017; Badry et al. 2018).

Buthiscus bicalcaratus Birula, 1905

B. bicalcaratus was reported as a desert species (Vachon 1952). It has been recently recorded in the Misurata region (Aboshaala et al. (2020). In the current study, this species is ranked as rare with the rate of 10.42%. It is grouped with very accidental species (Occ = 10.67%) because it was found only at the Assuita station. In Algeria, it is classified as quite rare, limited to "reg" (rock gravel) and palm groves (Sadine et al. 2011; Sadine 2012; Sadine et al. 2020). Its geographical distribution ranges from Central Algeria in the West to northwestern Libya in the East (Lourenço 2002; Goyffon et al. 2012; Sadine 2012; Sadine et al. 2018; Aboshaala et al. 2020). In the Misurata region, we found this species in sandy habitats with a sparse vegetation cover. As noted by many authors, this species is psammophilic and predesertic (Vachon 1942, 1952; Sadine et al. 2011; Sadine 2012), occurring in a variety of climatic conditions but typically in arid, sandy habitats with a variable vegetation cover (Aboshaala et al. 2020).

Buthus adrianae Rossi, 2013

This species was described from northern Egypt, near the Mediterranean coast (Rossi 2013). Badry et

al. (2018) mentioned that it is not unlikely that the species range extends further westwards along the Mediterranean coastal belt in Egypt and possibly to Libya where similar ecological conditions prevail. Our findings confirm its presence with a low abundance (18.75%) in North Libya. It is classified as a constant species (Occ = 50%) because it was found at six stations. In the Misurata region, *B. adrianae* seems to favor mixed habitat with sandy and rocky substrates and a relatively sparse vegetation cover. However, in Egypt, this species prefers sandy habitats in the Western Mediterranean Coastal Desert (Saleh et al. 2017; Badry et al. 2018) with a relatively dense desert scrub vegetation (groves of olive trees) (Badry et al. 2018).

Buthus orientalis Lourenço & Simon, 2012

B. orientalis was described from Alexandria (North Egypt), very close to the locality of *B. adrianae* (Lourenço and Simon 2012). In the present investigation, a new record of this species was reported from Libya. Despite the fact that this species seems to be rare (19.79%), it was collected from several localities: Assuita, Al Sekat 2, Tamena, Al Krarim, Gasar Ahmed 2 and Al Dafiniyah. All these localities are sandy and rocky habitats with a relatively sparse vegetation cover. The situation was reported from Egypt (Badry et al. 2018).

The value of Shannon's index (H') in the Misurata region was estimated at 2.66 bits, indicating that this region can be rated as diverse, which is due to the arid climate and sandy/rocky substrate. Many authors (Polis 1990; Prendini 2005; Dias et al. 2006; Araújo et al. 2010; Sadine et al. 2012; Nime et al. 2013, 2014; Pizarro-Araya et al. 2014) have presumed that such environmental factors as soil type, topography, hydrology, food resources, and especially, temperature and precipitation can affect the diversity and abundance of scorpions in most ecosystems. Also, Badry et al. (2018) mentioned that rocky habitats in arid regions with a relatively rich desert vegetation cover are important for scorpion diversity. The significant value of this index at Gasar Ahmed 2 (H' = 2.44 bits) with 5 species recorded can be explained not only by the physiognomy of the soil (sandy habitat) but also by its location in the Mediterranean coastal desert with a very dense vegetation cover. The value of evenness (E) equaling to 0.84 reflects the equilibrium between the effectiveness of sampled species. As all of the sampled scorpions are thermophilic, they are the best adapted scorpions to this arid climate (Sadine et al. 2018).

The CCA revealed that the distribution of scorpion species in the Misurata region is influenced by several factors because scorpions are very attached to preferential biotopes (Vachon 1952). We consider below four groups.

Group 1: contains three species of *Buthacus* ranked as psammophilic. Cain et al. (2021) reported that scorpions of the genus *Buthacus* are commonly known as "sand scorpions". In central Algeria, all *Buthacus* species were captured in Erg biotopes (Lourenço and Sadine 2015; Lourenço et al. 2016, 2017a; Sadine et al. 2018) or in sand deposits (Lourenço et al. 2017b). We note here that vegetation cover, precipitation and elevation apparently have no effect on *Buthacus* species.

Group 2: contains two species of the genus *Androctonus* (*A. amoreuxi* and *A. australis*) classified as deserticolous scorpions associated with sparse vegetation, low precipitation and elevation.

Group 3: is composed of two *Buthus* species (*B. adrianae* and *B. orientalis*) that are closely correlated with elevation and precipitation. However, they show a total independence from vegetation cover factors. Vachon (1952), indicated that *Buthus* species occupy various types of environments; low altitude, under stones, in sand, in forests as well as in the mountains, even near the snow line. For example, *B. tunetanus* can populate the habitats of high mountains (El-Hennawy 1992; Sadine et al. 2012).

Group 4: is represented by *B. bicalcaratus*, which was reported as a desert species (Vachon 1952). Although this species occurs in conditions of arid climate and in sandy habitats with a variable vegetation cover (Aboshaala et al. 2020), in the present study we have established that it is not influenced by these factors.

CONCLUSION

This study is the first one to highlight the ecological and distribution patterns of scorpions from the Misurata region (North Libya). The recent investigations were carried out at 12 stations from June 2019 to December 2020. We identified nine species of scorpion belonging to the Buthidae family and distributed among 4 genera: *Androctonus* (3 species), *Buthacus* (3 species), *Buthiscus* (1 species) and *Buthus* (2 species). Among nine species of *Buthus*, we have noted a new record of two species of Egyptian *Buthus*, i.e., *B. adrianae* and *B. orientalis*, in Libya and an important relationship between some species and their biotopes. *Buthacus* is classified as psammophilic because of their strong attachment to sandy habitats. *A. amoreuxi* and *A. australis* were shown to be associated with desert conditions (sparse vegetation, low precipitation and elevation). However, *B. bicalcaratus* was isolated and apparently not influenced by the studied environmental factors.

CONFLICTS OF INTEREST

The authors declare not to have conflicts of interest.

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