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Effects of Climate on Scorpion Diversity in Arid Ecosystems of the Sahara Desert of Algeria

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Abstract: In desert ecosystems, arthropods such as scorpions are understudied, and sufficient information is still lacking regarding their biodiversity. Specimen collection was carried out over 24 months (2016–2017). This study assessed the phenology, abundance, richness and diversity of scorpion species in arid ecosystems of the Sahara desert of Algeria (Ghardaïa). It examined the potential influence of climate parameters (precipitation, temperature and wind) on activity density, diversity and the phenological distribution of the species among seasons. We identified eight Buthidae species: *Androctonus aeneas*, *Androctonus amoreuxi*, *Androctonus australis*, *Buthacus samiae*, *Buthacus spinatus*, *Buthacus elmenia*, *Buthus saharicus* and *Lissothus chaambi*. *Androctonus amoreuxi* and *Androctonus australis* were the most abundant and omnipresent species, comprising 54.41% and 33.82% of all species found, respectively. Shannon's index and the evenness index demonstrated a very poor diversity of scorpions in this region and a poor balance between the number of sampled species. Seasonal variation and climate parameters, i.e., temperature and wind, influenced the number, distribution, and the diversity of scorpions. The number of species found in Ghardaïa Province represent more than 20% of the scorpion species reported in Algeria.

Keywords: Arachnida; phenology; richness; Ghardaïa; abiotic responses

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1. Introduction

Biodiversity encompasses all aspects of biological variation on a multidimensional level [1]. It refers to the variety of living organisms, from genes and species to habitats and ecosystems, including the critical roles they perform, that make up the intricate web of life. Anthropogenic pressures such as land-use intensification have precipitated a worldwide biodiversity loss [2], particularly among forest and grassland arthropod species [3–5]. In fact, due to their low productivity and diversity [6,7], drylands and deserts have received less scientific attention, despite their critical importance in harboring sensitive endemics and the most endangered species [8,9]. Desert ecosystems are routinely under-documented, and sufficient information and knowledge are still lacking regarding their biodiversity [10,11].

Scorpions are one of the most important taxa for ecological, conservation and biogeographic studies [12,13]. They are among the oldest known Arthropods (more than

450 million years) [14,15]; they have lived through all geological eras and are particularly abundant in deserts and unpopulated areas due to their adaptability and their ecological plasticity [16,17].

To date, zoologists have described more than 2740 species [18], of which more than 50% have been documented from the Neotropical region [19] and over 1000 have been described during the past two decades [20]. Scorpions have radiated into all nonboreal habitats, including deserts, savannas, grasslands, temperate forests, tropical forests, rain forests, the intertidal zone, and snow-covered mountains over 5500 m in altitude [21].

Many environmental factors can influence the diversity and abundance of scorpions in most ecosystems, such as the soil type, topography, hydrology, food resources, and especially, temperature and precipitation [13,22–30], which are the important determinants of the general geographical range of cryptozoic species [12,29,31–34].

Scorpions are primarily solitary and sedentary arthropods and live preferentially in microhabitats [35]. The processes of habitat selection usually involve responses to environmental conditions that promote the growth, survival and reproductive success of this species [36–39].

Scorpion fauna of Algeria are truly native, and the endemic species represent more than 59% [40,41]. More than 49 species can be found [42,43], and the species are assembled in three major groups: scorpions of Algerian–Tunisian compartment (Mediterranean area), those of Saharan sector and scorpions of Saharo-mountainous sector [44]. Nevertheless, scorpion diversity is particularly high in deserts and arid habitats [45,46] because the temperature has an effect on scorpion communities [22,47–49], profoundly modulating several physiological processes such as digestion, oxygen consumption [50,51], growth [52] and movement performance in ectothermic animals such as scorpions [53].

In this context, we performed an ecological study on scorpions in central Algeria. This research used Ghardaïa Province as a study case with the following objectives: (i) to establish a faunistic list of scorpion species; (ii) to determine the phenological pattern of species; (iii) to study the effect of different climate factors in arid ecosystems (temperature, precipitation and wind) on scorpion diversity, distribution and phenology.

2. Materials and Methods

2.1. Study Site

Our study was conducted in the north of the central Algerian Saharan region, specifically in Ghardaïa Province (29°19′ N−32°57′ N, 02°03′ E−04°54′ E) (Figure 1a), which has an area of ca. 86,560 km^2. The average altitude of the main reliefs is 520 m. Geomorphological features constitute wadis and reg formations (Figure 1b,c) [54]. The region is characterized by a dry Saharan climate, with extreme thermal amplitudes between the day and the night that reach 15–16 degrees [55]. The coldest month is January, with a minimum temperature of 6.2 °C, whereas the hottest month is July, with a maximum temperature of 41.8 °C.

Rainfall is extremely low in the region of Ghardaïa, with an average of 80.2 mm per year. Air humidity is rather low, with a maximum humidity of 55.5% in December and a minimum of 21.6% in July [56]. An analysis of dry periods over several years attested that 11 months are dry, ranging from February to December; only a short and slightly more humid period can be experienced in January.

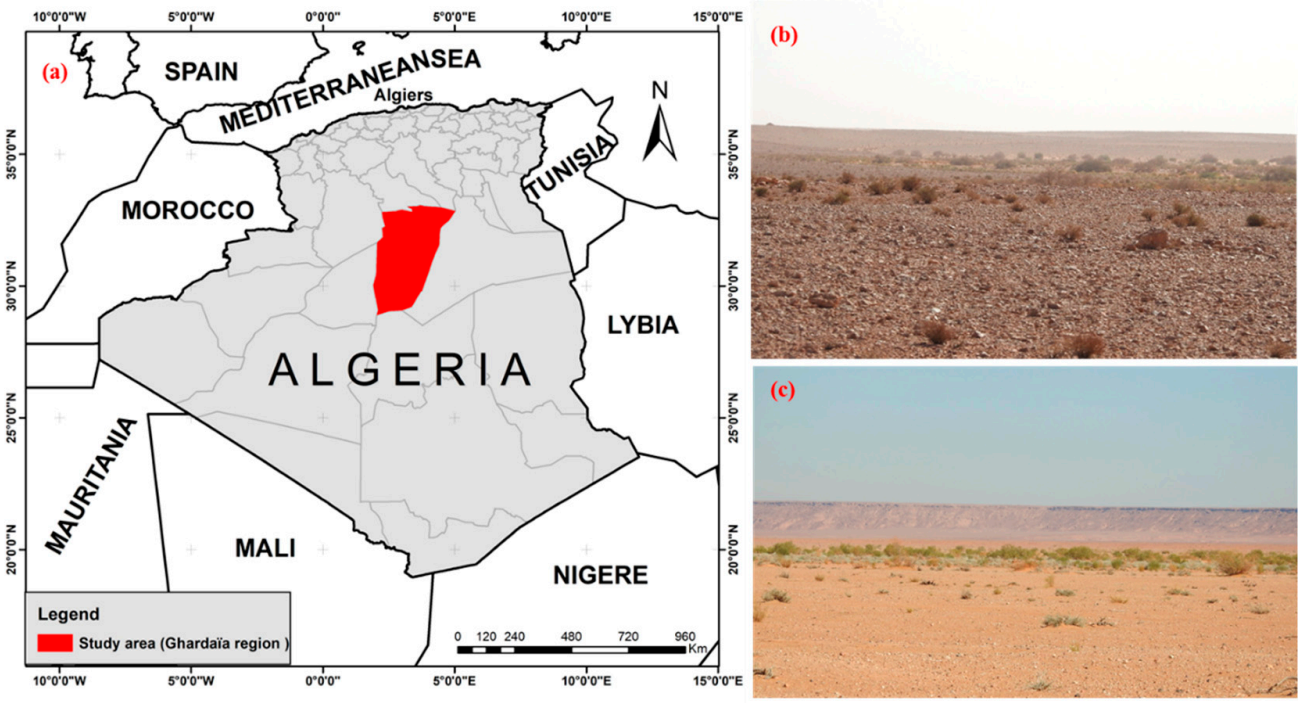

Figure 1. Study area. (**a**) Map of Algeria showing the Ghardaïa region; (**b**) reg formations and "desert pavement"; (**c**) wadi bed.

2.2. Scorpion Sampling

As scorpions are nocturnal predators, preliminary visits to the sites during the nighttime were carried out to confirm the existence of scorpions. However, for practical and security reasons, the collection of scorpions was carried out during the daytime period. Samples were taken monthly over 24 months, between January 2016 and December 2017, and in the same locations. We carried out 24 field trips (each lasting 4 h) during the four seasons, and our capture followed a strategy of systematically searching the shelters, which were chosen at random or were suspected of harboring the scorpions during the visual search in each field trip. All samples were separately preserved in 70° ethanol.

The collected specimens were taken to the Laboratory of Zoology, University of Ghardaïa. They were then identified to their genus and species based on morphological characters, using a binocular magnifying glass. The nomenclature and taxonomy of species were made based on up-to-date references, following measurements [57], Trichobothrial notations [58] and morphological terminology [44,59].

2.3. Data Analysis

Statistical analyses were carried out with R 4.0.2 [60]. Ecological indices were estimated based on the scorpion fauna data to characterize biodiversity in the different sampling season during the study period, which was evaluated by calculating: (i) abundance (Ni), the total number of caught individuals of each species; (ii) the relative abundance (RA%) for each species, which was determined as the ratio of the number of individuals for each species divided over the total number of individuals recorded; (iii) the occurrence frequency©, which was calculated as follows: $C = (p \times 100)/N$, where C represents the constancy % for each species, p represents the number of samples in which the species is present, and N represents the total number of samples [61]. According to their frequency of occurrence, four species groups are distinguished by Bigot and Bodot [62]: very accidental species (Vac), represented by an occurrence of less than 10%; accidental species (Acc), whose occurrence varies between 10 and 24%; common species (Cmt), which are present in 25–49%; constant species (Cst), which are present in 50–57% and omnipresent species (On), whose occurrence is more than 75%. The biodiversity of scorpions was also

assessed by (iv) species richness (S), which represents the total number of species identified. Additionally, (v) Shannon's index ($H' = -\sum(pi \times \log_2 pi)$), the maximum of Shannon index: $Hmax = \log_2(S)$; Ratio N/S; Ratio SRI/S; Simpson reciprocal index: SRI = (1/D), with $D = \Sigma(Ni(Ni - 1)/N(N - 1))$, where (Ni) represents the number of individuals of a given species of rank (i); and (vi) evenness (evenness = $H'/\log_2 Sobs$) were applied for measuring scorpion diversity in each sampled season period, based on the relative density pi of the ith species [61].

The analysis of the similarity between species of scorpions and seasons was carried out by calculating several similarity indices with the software EstimateS [63]. These included qualitative indices (Jaccard and Sørensen) and quantitative indices: the Morisita–Horn index and Bray–Curtis index. Moreover, correlation matrices and a Venn diagram were drawn up in order to illustrate all possible relationships between diversity parameters of scorpions and different scorpion species according to different seasons in the Ghardaïa region.

Generalized linear mixed effect models with Poisson error distribution were applied to assess for the effect of climate variables (T, PP and W) and RA as explanatory variables for the abundance of all species separately, with date and sites taken as random effects (to account for overdispersion). Another generalized linear mixed effect model was conducted to analyze the variation in diversity parameters across the season. The model included the season (cold, pre-hot, hot and post-hot) as explanatory variable, and the number of individuals and diversity index (SR, N:S, Shannon's index, etc.) were included as response variables. All models were fitted using the R package, lme4 [64]. Values presented hereafter are shown as the mean ± SD.

3. Results

In our survey, a total of 408 scorpions were collected in the Ghardaïa region, during the period from 2016–2017, with 229 and 179 individuals, respectively.

3.1. Taxonomic Composition, Relative Abundance and Occurrence

Based on the identification keys mentioned previously, our study revealed that the scorpion assemblage in Ghardaïa region is composed of eight species. All species belong to four genera in the Buthidae family (Table 1).

Table 1. Species list, abundance and occurrence frequency of scorpion species captured in the Ghardaïa region, Algeria (2016–2017).

Genus (RA in %)	Species	Traits	Seasons				Overall
			Cold	Pre-Hot	Hot	Post-Hot	
Androctonus (91.18)	*A. aeneas* C.L. Koch, 1839	Ni	—	5	6	1	12
		RA [%]	—	1.23	1.47	0.25	2.94
		Occ	—	75	41.7	25	37.5
		Scale	—	Omn	Com	Com	Com
	A. amoreuxi (Audouin, 1826)	Ni	16	57	125	24	222
		RA [%]	3.92	13.97	30.64	5.88	54.41
		Occ	100	100	100	100	100
		Scale	Omn	Omn	Omn	Omn	Omn
	A. australis (Linnaeus, 1758)	Ni	10	15	97	16	138
		RA [%]	2.45	3.68	23.77	3.92	33.82
		Occ	100	100	100	100	100
		Scale	Omn	Omn	Omn	Omn	Omn

Table 1. *Cont.*

Genus (RA in %)	Species	Traits	Seasons				Overall
			Cold	Pre-Hot	Hot	Post-Hot	
Buthacus (2.45)	*B. elmenia* Lourenço and Sadine, 2017	Ni	—	2	—	—	2
		RA [%]	—	0.49	—	—	0.49
		Occ	—	50	—	—	8.3
		Scale	—	Cst	—	—	Vac
	B. samiae Lourenço and Sadine, 2015	Ni	2	4	2	—	8
		RA [%]	0.49	0.98	0.49	—	1.96
		Occ	50	75	16.7	—	29.2
		Scale	Cst	Omn	Acc	—	Com
	B. spinatus Lourenço, Bissati and Sadine, 2016	Ni	—	2	—	—	2
		RA [%]	—	0.49	—	—	0.49
		Occ	—	50	—	—	8.3
		Scale	—	Cst	—	—	Vac
Buthus (1.47)	*B. saharicus* Sadine, Bissati and Lourenço, 2016	Ni	2	1	2	1	6
		RA [%]	0.49	0.25	0.49	0.25	1.47
		Occ	50	25	16.7	25	25
		Scale	Cst	Com	Acc	Com	Com
Lissothus (4.41)	*L. chaambi* Lourenço and Sadine, 2014	Ni	5	1	10	2	18
		RA [%]	1.23	0.25	2.45	0.49	4.41
		Occ	75	25	58.3	50	54.2
		Scale	Cst	Com	Cst	Cst	Cst
	Total	Ni	35	87	242	44	408
		RA [%]	8.58	21.32	59.31	10.78	100

RA, relative abundance (%); Ni—total number of caught individuals; Occ—occurrence frequency; Acc—very accidental species; Com—common species; Cst—constant species; Omn—omnipresent species.

The genus *Androctonus* was represented by three species: *A. aeneas*, *A. amoreuxi* and *A. australis*. The *Buthacus* genus was also presented by three species: *B. elmenia*, *B. samiae* and *B. spinatus*. The genera *Buthus* and *Lissothus* were presented each by a single species, *B. saharicus* and *L. chaambi*, respectively. Among the four genera found in the Ghardaïa region, the *Androctonus* species were the most abundant (RA = 91.18%), while the other genera were represented with a very low abundance (less than 4.4%). *Androctonus* amoreuxi and *A. australis* were the most abundant species with (54.41 and 33.82%), respectively, and they were classified as omnipresent species. The other species are represented with a very low abundance with different occurrences: *Lissothus chaambi* was ranked as a constant species, while *Androctonus* aeneas, *B. samiae* and *B. saharicus* were classified common species. Two species, *B. elmenia* and *B. spinatus*, were classified as very accidental species in our study.

3.2. Species Phenology

The phenogram (Figure 2) shows that the monthly temporal abundance of the scorpion species recorded in Ghardaïa region was very variable during the different months in 2016 and 2017.

In our study, most of the species were present in the pre-hot (21.32%) and hot seasons (59.31%). *Androctonus amoreuxi* and *A. australis* were the dominant species over the 24 months (2016–2017). *Lissothus chaambi* and *B. saharicus* were present throughout the year but demonstrated a low abundance. Similarly, *A. aeneas* was present throughout the year but was absent

the in the cold season. Contrariwise, *B. samiae* was absent in the post-hot season. However, *B. elmenia* and *B. spinatus* were found only in February and March (the pre-hot period) of 2017.

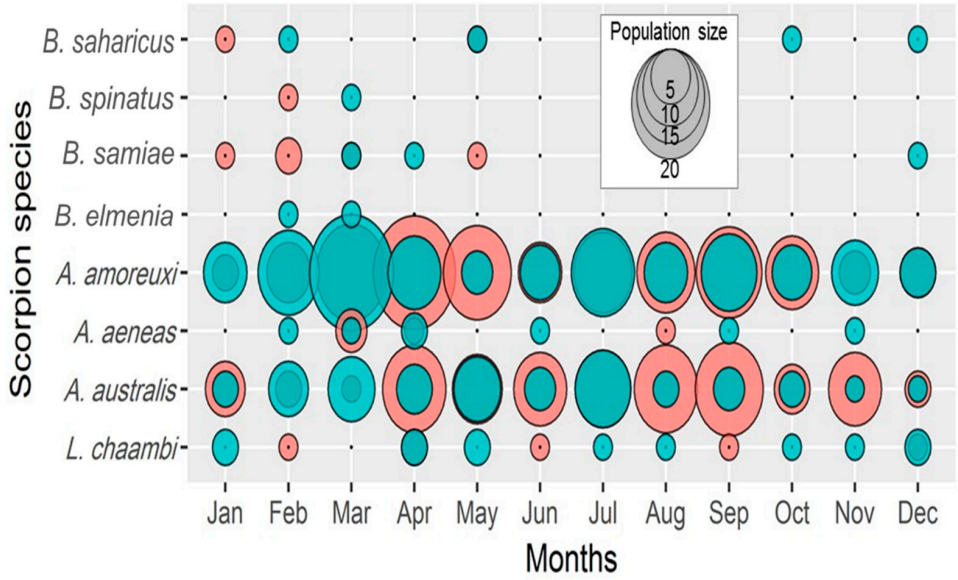

Figure 2. Phenogram representing monthly abundance of scorpions in the Ghardaïa region during the two years of study (red = 2016; green = 2017).

The results of the linear mixed models (GLMM) applied to reveal the effect of the ecological descriptors parameters (temperature, precipitation and wind) on the abundance of each scorpion species separately are represented in Table 2. There was a significant positive relationship between wind and the abundance of the three species *A. amoreuxi*, *A. australis* and *B. elmenia* ($p < 0.05$). Only *A. amoreuxi* showed a potential density-dependent population, which was revealed by the negative relationship between the number of individuals and the relative abundance of the species ($p < 0.05$). There was a significant positive effect of temperature on the abundance of *A. australis* ($p < 0.05$), but with a significant negative relationship with *B. samiae* ($p < 0.05$). Only the number of individuals of *B. saharicus* increased significantly with the increase in precipitation ($p < 0.05$). However, the abundance of *A. aeneas*, *B. spinatus* and *L. chaambi* was independent of these climatic factors ($p > 0.05$).

Table 2. GLMM testing effects of climate on variations of scorpion species abundances in the Sahara Desert of Algeria.

Variables	Estimate	S.E.	z-Value	*p*	Sig.	Estimate	S.E.	z-Value	*p*	Sig.
	A. amoreuxi					*A. australis*				
Intercept	1.605	0.523	3.068	0.002	**	−0.092	0.729	−0.127	0.899	ns
T	−0.008	0.009	−0.843	0.399	ns	0.035	0.012	2.970	0.003	**
PP	−0.026	0.023	−1.106	0.269	ns	−0.055	0.036	−1.526	0.127	ns
W	0.074	0.027	2.690	0.007	**	0.079	0.035	2.245	0.025	*
RA	−0.125	0.054	−2.298	0.022	*	−0.031	0.072	−0.427	0.670	ns
	A. aeneas					*B. elmenia*				
Intercept	−0.481	2.180	−0.221	0.825	ns	−10.691	5.408	−1.977	0.048	*
T	−0.052	0.040	−1.294	0.196	ns	−0.143	0.096	−1.486	0.137	ns
PP	−0.119	0.165	−0.722	0.471	ns	0.006	0.252	0.026	0.980	ns
W	0.096	0.120	0.802	0.423	ns	0.769	0.339	2.267	0.023	*
RA	−0.204	0.236	−0.863	0.388	ns	0.047	0.318	0.147	0.883	ns
	B. samiae					*B. spinatus*				
Intercept	3.752	2.654	1.414	0.158	ns	−3.140	3.332	−0.942	0.346	ns
T	−0.198	0.094	−2.100	0.036	*	−0.103	0.068	−1.502	0.133	ns
PP	0.048	0.144	0.337	0.736	ns	−0.294	0.371	−0.791	0.429	ns
W	−0.039	0.150	−0.258	0.797	ns	0.274	0.192	1.426	0.154	ns
RA	−0.469	0.284	−1.649	0.099	ns	0.085	0.261	0.328	0.743	ns

Table 2. *Cont.*

Variables	Estimate	S.E.	z-Value	*p*	Sig.	Estimate	S.E.	z-Value	*p*	Sig.
	B. saharicus					*L. chaambi*				
Intercept	−3.222	3.643	−0.884	0.377	ns	−0.513	1.802	−0.285	0.776	ns
T	−0.095	0.092	−1.040	0.298	ns	−0.033	0.035	−0.956	0.339	ns
PP	0.240	0.121	1.993	0.046	*	0.068	0.062	1.110	0.267	ns
W	0.164	0.175	0.936	0.349	ns	0.054	0.094	0.576	0.565	ns
RA	0.325	0.340	0.956	0.339	ns	0.024	0.182	0.133	0.894	ns

(T—temperature; PP—precipitation; W—wind; RA—relative abundance (%); **—$p < 0.001$; *—$p \leq 0.05$; ns—$p > 0.05$).

3.3. Variation of Diversity Parameters

3.3.1. Number of Individuals

The number of individuals captured varied depending on the seasons. In fact, the highest number of individuals captured was recorded in the pre-hot and hot seasons, with an average of 21.75± 9.11 and 20.17 ± 8.73 individuals, respectively. The lowest number was recorded in winter, with an average of 8.75 ± 1.26 individuals (Figure 3).

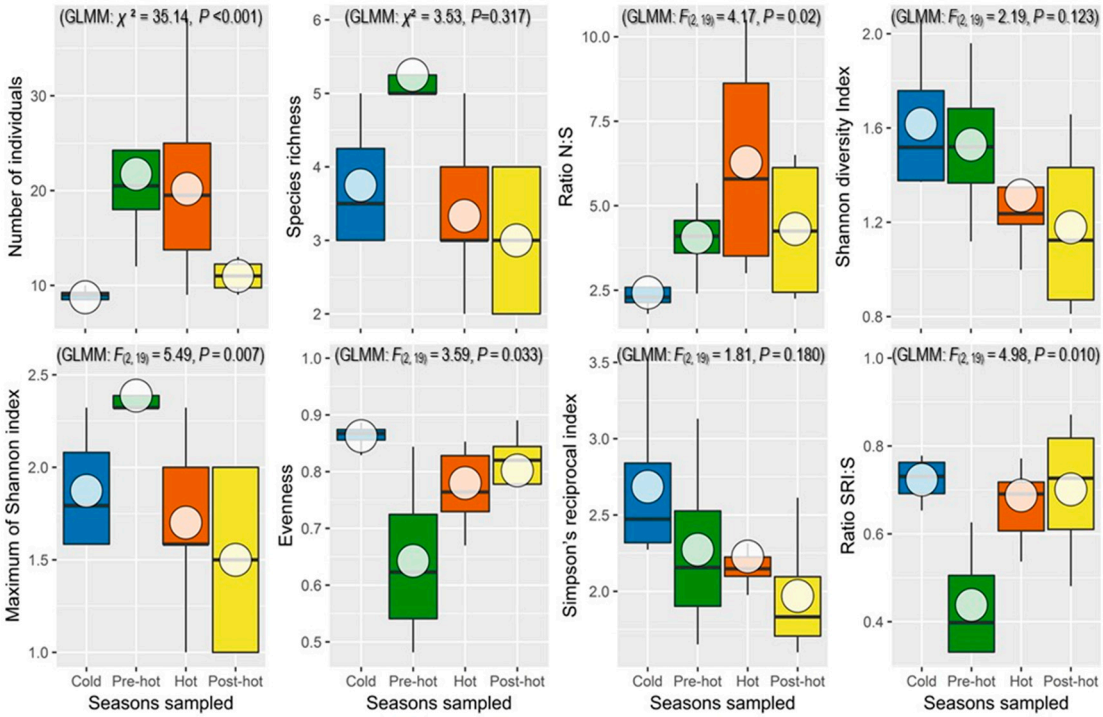

Figure 3. Box plots representing the different ecological indices applied to scorpion assemblages sampled during different seasons.

3.3.2. The Ecological Indices according to Seasons

During the different months (2016–2017), we identified a total of eight species. Figure 3 shows that the specific richness varied according to the seasons. The pre-hot seasons contained five species, while other seasons contained three. We note that the specific richness showed averages ranging from 5.25 ± 0.50, recorded in the pre-hot seasons, to 3.00 ± 1.15, recorded in the post-hot season. The other two seasons (cold and hot) recorded 3.75 ± 0.96 and 3.33 ± 0.78 species, respectively.

During the study period, the most important mean values of the ratio N:S were recorded in the hot seasons (6.29 ± 2.87). The post-hot and pre-hot seasons are represented by 4.31 ± 2.25 and 4.07 ± 1.34, respectively. The lowest value of the ratio N:S was recorded in the cold seasons, with an average of 2.43 ± 0.65 (Figure 3).

In cold seasons, the Shannon diversity index (H′) was mostly recorded with a mean value of 1.62 ± 0.32 bits. The values of this index in the pre-hot, hot and post-hot seasons were 1.53 ± 0.35, 1.31 ± 0.25 and 1.18 ± 0.40, respectively.

The most important value, the average of Shannon's maximum index, was recorded in the pre-hot (2.39 ± 0.13) season, followed by the cold seasons (1.87 ± 0.36) and hot seasons (1.70 ± 0.34). The post-hot seasons are represented by a mean value of 1.50 ± 0.58 (Figure 3).

Evenness recorded an overall average value of 0.77 ± 0.11. The most important evenness value was recorded in the cold (0.86 ± 0.02) and post-hot seasons (0.80 ± 0.09). The hot seasons are represented with an average of 0.78 ± 0.09, while the pre-hot seasons recorded the lowest evenness, with an average of 0.64 ± 0.16 (Figure 3).

The general mean value of SRI during the study period was 2.27 ± 0.47. According to Figure 3, the most important average values were recorded in the cold seasons (2.69 ± 0.58), followed by the pre-hot seasons (2.27 ± 0.63) and the hot seasons (2.23 ± 0.34). The post-hot seasons were represented by the lowest average value of 1.97 ± 0.45 (Figure 3).

The overall mean value of the ratio (SRI:S) recorded a value of 0.65 ± 0.15. We note that the cold and post-hot seasons recorded were almost equal, with 0.72 ± 0.06 and 0.70 ± 0.17, respectively. The value in the hot seasons was 0.69 ± 0.12. The lowest mean value of the ratio was recorded in the pre-hot seasons (0.44 ± 0.14) (Figure 3).

3.4. Relationships between Diversity Parameters

The relationships between the diversity indices are summarize in Figure 4, which shows that there is generally a significant positive correlation (Pearson correlation: $p < 0.05$) between (S) and the other descriptors except (N), and there was a negative relationship between (N:S). A significant positive relationship was detected between N and N:S but was negative with E.

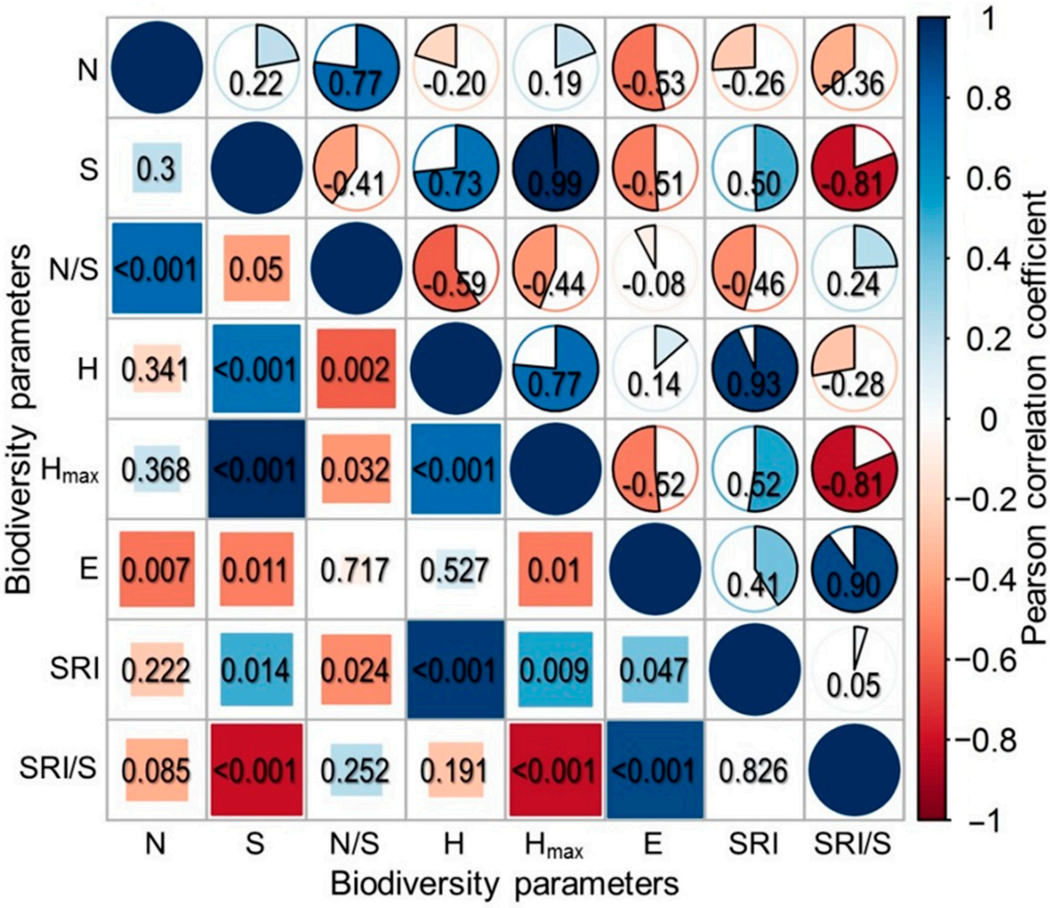

Figure 4. Correlation matrix between diversity indices of scorpions in the Sahara Desert of Algeria (Values above diagonal are Pearson's correlation coefficients, and figures below diagonal represent *p*-values).

3.5. Effects of Climate on Variations of Biodiversity Parameters

The linear mixed models (GLMM) applied for the effects of climate on variations of the biodiversity parameters in the scorpions of the Algerian Sahara are represented in Table 3.

Our GLMM models showed that there was a highly significant effect of temperature on diversity indices H and H_{max} in which the values decreased with the increase in the latter (Table 3). A significant positive relationship was detected between the number of scorpion individuals and the speed of the wind. Moreover, the ratios N:S and SRI:S varied significantly with temperature, and they increased with the increase in temperature. For the rest of the parameters, no effect was revealed ($p > 0.05$) (Table 3).

Table 3. GLMM testing effects of climate on variations of biodiversity parameters in scorpions of the Algerian Sahara.

N	**Estimate**	**S.E.**	**z-Value**	***p***	**Sig.**	**S**	**Estimate**	**S.E.**	**z-Value**	***p***	**Sig.**
Intercept	2.163	0.388	5.579	<0.001	***	Intercept	1.785	0.791	2.257	0.024	*
T	−0.001	0.007	−0.176	0.861	ns	T	−0.029	0.015	−1.925	0.054	ns
PP	−0.033	0.017	−1.861	0.063	ns	PP	0.015	0.031	0.477	0.633	ns
W	0.066	0.020	3.251	0.001	**	W	0.014	0.042	0.330	0.742	ns
RA	−0.104	0.040	−2.616	0.009	**	RA	−0.046	0.083	−0.556	0.578	ns
N:S	Estimate	S.E.	t-value	*p*	Sig.	**H**	Estimate	S.E.	t-value	*p*	Sig.
Intercept	−1.087	3.418	−0.318	0.758	ns	Intercept	2.087	0.417	5.001	<0.001	***
T	0.149	0.057	2.600	0.018	*	T	−0.025	0.007	−3.554	0.002	**
PP	−0.131	0.131	−1.004	0.345	ns	PP	0.013	0.016	0.841	0.429	ns
W	0.222	0.172	1.293	0.217	ns	W	−0.007	0.021	−0.318	0.757	ns
RA	−0.073	0.340	−0.214	0.839	ns	RA	−0.045	0.042	−1.068	0.318	ns
Hmax	Estimate	S.E.	t-value	*p*	Sig.	**E**	Estimate	S.E.	t-value	*p*	Sig.
Intercept	2.734	0.494	5.534	<0.001	***	Intercept	0.763	0.180	4.236	<0.001	**
T	−0.041	0.008	−5.074	<0.001	***	T	0.004	0.003	1.150	0.271	ns
PP	0.011	0.019	0.584	0.577	ns	PP	0.000	0.007	0.056	0.963	ns
W	0.013	0.024	0.511	0.618	ns	W	−0.008	0.009	−0.791	0.461	ns
RA	−0.100	0.049	−2.071	0.059	ns	RA	0.017	0.018	0.932	0.441	ns
SRI	Estimate	S.E.	t-value	*p*	Sig.	**SRI:S**	Estimate	S.E.	t-value	*p*	Sig.
Intercept	3.042	0.717	4.240	<0.001	***	Intercept	0.489	0.223	2.199	0.050	*
T	−0.026	0.013	−2.099	0.052	ns	T	0.010	0.004	2.640	0.017	*
PP	0.022	0.028	0.799	0.490	ns	PP	−0.003	0.009	−0.294	0.790	ns
W	−0.010	0.038	−0.267	0.800	ns	W	−0.007	0.012	−0.640	0.540	ns
RA	−0.048	0.073	−0.653	0.573	ns	RA	0.022	0.023	0.992	0.375	ns

T—temperature; PP—precipitation; W—wind; RA—relative abundance (%); Sig.—probability significance; ***—$p < 0.001$; **—$p < 0.01$; *—$p \leq 0.05$; ns—$p > 0.05$.

3.6. Distribution and Similarity Analysis of Scorpions According to the Seasons

According to the Venn diagram (Figure 5), four species were common between seasons, i.e., *A. amoreuxi*, *A. australis*, *B. saharicus* and *L. chaambi*. The *B. elmenia* and *B. spinatus* were characteristic of the pre-hot season. *B. samiae* was found in all three seasons (cold, pre-hot and hot seasons), while *A. aeneas* was common between the three hot seasons (pre-hot, hot and post-hot seasons).

The similarity calculation between the different seasons (Table 4) showed that the most important similarity was found between the cold and hot seasons, with a 83.3 and 90.9% similarity for the Jaccard and Sorensen, respectively, whereas the Morisita–Horn index showed a 99.4% similarity between the hot and post-hot seasons. The Bray–Curtis dissimilarity index showed that the greatest dissimilarity existed between the cold and post-hot (70.1%) seasons, while the least significant dissimilarity exists between the cold and hot (25.3%) seasons (Table 4).

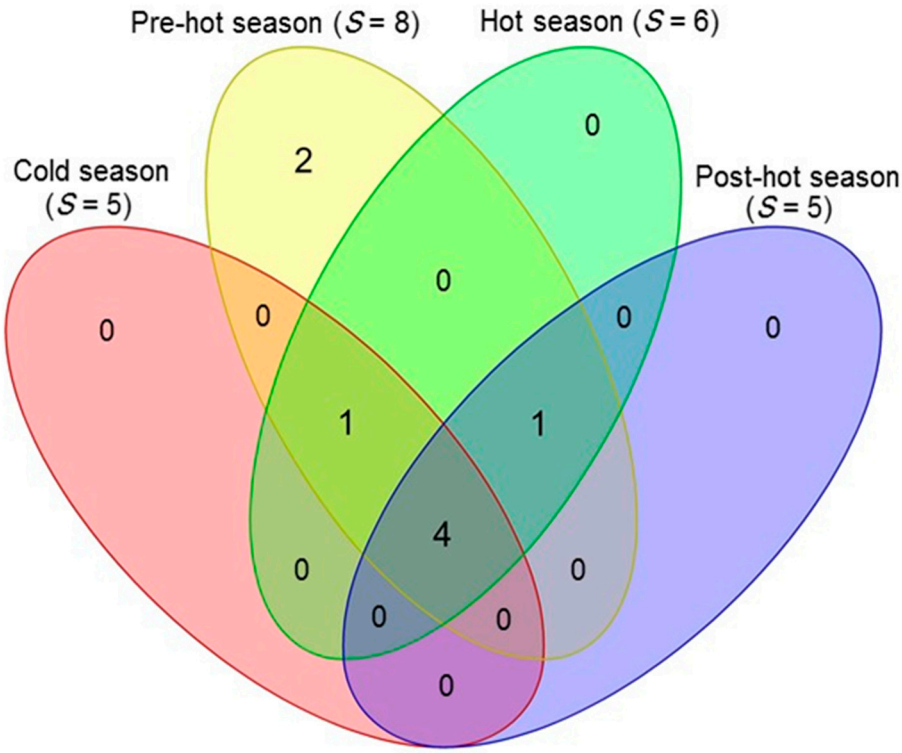

Figure 5. Venn diagram explaining the distribution of number of scorpion species according to seasons in the Ghardaïa region, Sahara Desert of Algeria.

Table 4. Similarity analysis (in %) between number of scorpions and seasons in the region of Ghardaïa, Algeria.

First Sample	Second Sample	Jaccard Classic	Sorensen Classic	Morisita–Horn	Bray–Curtis
Cold	Pre-hot	62.5	76.9	90.3	49.2
Cold	Hot	83.3	90.9	95.7	25.3
Cold	Post-hot	50	66.7	94	70.1
Pre-hot	Hot	75	85.7	91.5	49.2
Pre-hot	Post-hot	50	66.7	94.1	63.6
Hot	Post-hot	66.7	80	99.4	29.6

4. Discussion

Our survey is the first of its kind on scorpions in Algeria's arid ecosystem (Ghardaïa), which is characterized by an arid climate with hot summers. During the study period, we documented eight scorpion species, accounting for more than half of the scorpions in the northern Algerian Sahara [65], with good congeneric coexistence [66–70].

Most of those species are recorded as Saharan endemic scorpions [40,44,71]. In neighboring regions of Ghardaïa, [72] identified eight scorpions species in El-Oued and nine scorpion species in Ouargla, [40]. In the Algerian forest and mountainous ecosystems, up to ten scorpion species were identified in Sidi Bel Abbes, northwest Algeria [73] and eight scorpion species were identified in the Ouarsenis massif of Tissemsilt, northwest Algeria [23]. However, it seems that the species richness of scorpions was lower in other regions, such as the Khenchela region [74] and Tebessa region [42], with only five species identified. During the study period, five new records of species were discovered for the region, i.e., *B. elmenia*, *B. samiae*, *B. spinatus*, *B. saharicus* and *L. chaambi*, reflecting an important endemism for this region. Lourenço et al. [75] suggested in particular the presence of micro endemic populations of scorpions in Ghardaïa deserts.

Among the eight species found in the Ghardaïa region, *A. amoreuxi* is the most abundant species, followed by *A. australis*. Similar results were indicated in Sadine [40], with a rate of 42% for these two species. However, many other authors mentioned that *A. australis* is the most abundant and the most widespread species in the Algerian Sahara [40,43,71,76,77]. As *Androctonus australis* is limited to North Africa, in particular to Algeria, Egypt, Libya, Sudan and Tunisia [78], this species remained the most abundant (RA = 31.25%) in the Misurata region, North Libya [79]. This species is also widespread in different eco-geographical regions in Egypt [80]. The other species, i.e., *A. aeneas*, *B. elmenia*, *B. samiae*, *B. saharicus*, *B. spinatus* and *L. chaambi*, ranked as rare species and are represented by ratios of less than 0.5%. The same results were reported in previous studies with less than 3% [40,76,77].

The relative abundance of Ghardaïa scorpions is variable in months and shows an annual activity with a potential dynamic observed in some months (the hot period). However, they have a slight presence in the cold period. According to Sadine [81], scorpions in Ouargla (Algerian Sahara) are active in the spring and summer, and they begin their winter diapause (hibernation under shelters) at the beginning of autumn. While some species may retain their ability to be active during the cold season, this only justifies a minor presence during the cold season [82].

Nonetheless, some scorpions undergo semi-hibernation; if disturbed, they maintain the whole of their resources, which they demonstrate by being alert [83,84].

Furthermore, the abundance of certain species, such as *A. australis* and *A. amoreuxi*, can be deduced from average number of offspring for these scorpions; for example, *A. australis* can produce more than 130 offspring [71]. While, in Morocco, *Lissothus occidentalis* produces 2 to 14 pullus (offspring) [85].

Both *A. amoreuxi* and *A. australis* were classified as omnipresent species during the study period. The former was also reported as omnipresent in Morocco [86] and Egypt [80,87], but it was ranked as very accidental species (Occ = 8.33%) in the North of Libya [88]. The second species was as omnipresent in all previous countries. The constant species category is represented by *L. chaambi*. *A. aeneas*, *B. samiae* and *B. saharicus*, which were classified as common species. Two species, *B. elmenia* and *B. spinatus*, were classified as very accidental species in our study.

Only three species (*A. amoreuxi*, *A. australis* and *L. chaambi*) showed annual activity in our study area, with a potential dynamic between May and August and a slight absence during the cold periods. This significant increase in population can be attributed to an increase in the number of males preparing for mating [40,84]. Buthidae, like southern hemisphere scorpions, mate in the autumn and begin their gestation period from November to April, lasting 5.2 ± 2.3 months [13,89]. The mating behavior of *A. australis* in the Ouargla region begins in late August and lasts until mid-October, when the climate conditions are characterized by relatively low nighttime temperatures, ranging from 18 to 20 °C, and frequent winds with high humidity [84]. Sadine et al [40] reported that the phenological cycle of *A. amoreuxi* is nearly identical to that of *A. australis*, with a minor difference in the favorable period for mating (coupling).

Many environmental factors may influence scorpion activity in arid ecosystems [26]. In ectothermic animals such as scorpions, temperature profoundly modulates several physiological processes including, but not limited to, digestion, oxygen consumption [50,51], growth [52] and movement performance [53]. The temporal distribution of the species reveals that the pre-hot and hot seasons are the best time to collect scorpions. This can be explained by the fact that scorpion activity begins during this season, which corresponds to scorpion reproduction and an increase in their locomotor activity [90]. The number of individuals harvested in winter was very low (an average of 8.75 ± 1.26 individuals), which is explained by the fact that this season corresponds to the scorpions' lowest activity [37].

Hotspots of scorpion species richness at continental or regional scales are associated with areas of climatic, topographic and geological complexity [29]. Climate factors, substrate (soil hardness and texture; amount of stone or litter cover), and vegetation

physiognomy all influence scorpion assemblages and their feeding resources at the local scale [29,91,92]. Indeed, Haghani et al. [93] discovered that ecological factors have a significant impact on the families Buthidae and Scorpionidae.

The results obtained regarding species diversity show that climate variables have an effect on scorpion biodiversity. Previous research indicated that temperature and precipitation play an important role in the distribution and beta diversity of scorpion species assemblages [13,25,29,92,94,95]. Algeria, for example, with its vast geographical extent and diverse ecosystems, attests to a high level of diversity, with more than 49 species of scorpions [42,43].

This study allowed us to explore this region in order to better direct our efforts in the management and conservation of scorpion populations. We hope that this pioneer study will inspire scientists in North Africa to use this fascinating biological system in future research because this taxon, with its relatively limited dispersion and long life cycles, is an excellent tool for studying patterns and processes related to biological gradient diversity [29,92,94,96–98].

5. Conclusions

This study focused on scorpion diversity in arid ecosystems of Algeria's Sahara Desert. Despite the conditions of this region, we documented eight species during our survey over the two years of the study (2016–2017). Our findings demonstrate a modest level of diversity of scorpions in the Algerian Sahara compared to other regions in the world [99,100]. The study revealed temporal variations in scorpion biodiversity and demonstrated that several parameters influence the distribution of the scorpion fauna. Indeed, seasonal changes may cause variations in feeding resources which affect the temporal distribution and abundance of scorpion species. *Orthochirus innesi*, the ninth scorpion species, was recently recorded in central Algeria [101], with a new locality in Ghardaïa palm groves. It would be preferable to increase the number of studies that could lead to new discoveries regarding scorpion biodiversity in this understudied area.

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