Annals of Arid Zone 65(1): 115-130, 2026

Structure and Diversity of Earthworm Communities along a Gradient of Aridity in Northeastern Algeria

Karim Bouazdia[1,*] **and Haroun Chenchouni**[2,3]

[1]*Department of Living Beings, Faculty of Exact Sciences and Nature and Life Sciences, University of Tebessa, 12000 Tebessa, Algeria*

[2]*Laboratory of Natural Resources and Management of Sensitive Environments (LRNAMS), University of Oum El Bouaghi, 04000 Oum El Bouaghi, Algeria*

[3]*Department of Ecology & Environment, Faculty of Natural and Life Sciences, University of Batna, 05078 Algeria.*

Received: November 14, 2025 Accepted: March 20, 2026

Abstract: Earthworms are essential soil engineers that contribute to nutrient cycling, organic matter decomposition, and soil fertility. Despite their ecological and agricultural importance, data on earthworm diversity and community structure in Algeria remain scarce, particularly in arid and semi-arid ecosystems. This study aimed to document the abundance, biomass, and diversity of earthworm communities in Tebessa region (northeastern Algeria), and to assess how climate and habitat types influence their distribution. Earthworm sampling was conducted across six sites representing different climatic zones (desert, Thermomediterranean with short dry season [Th.Med–], and Thermomediterranean with long dry season [Th.Med+]) and habitats (field, wadi, and pasture). Soil blocks of 30 × 30 × 30 cm were excavated and earthworms were hand-sorted, counted, and classified into developmental stages. Morphometric traits, abundance, biomass, and diversity indices (species richness, Shannon, evenness, and reciprocal Simpson) were analyzed. A total of 1,575 individuals were collected, of which 395 were adults with a developed clitellum. Six species belonging to Lumbricidae were identified, with *Eisenia tetraedra*, *Octodrilus complanatus*, and *Aporrectodea molleri* recorded for the first time in Tebessa. Species richness and diversity were higher in Th.Med+ and Th.Med– climates than in the desert, while field habitats supported the greatest abundance and biomass. *Aporrectodea caliginosa* dominated in terms of biomass, particularly in Th.Med+ zones. Similarity analyses revealed closer affinities between field and pasture communities. Rarefaction analyses indicated a plateau at six species for Th.Med– and field habitats, whereas desert sites remained depauperate with only two species. Earthworm diversity in arid and semi-arid regions of Algeria is low, reflecting the constraints of arid conditions, yet certain agricultural habitats sustain relatively rich communities. These findings provide baseline knowledge for arid regions

****Correspondence***
Karim Bouazdia
karim.bouazdia@univ-tebessa.dz

Citation
Bouazdia, K. and Chenchouni, H. 2026. Structure and Diversity of Earthworm Communities along a Gradient of Aridity in Northeastern Algeria. Annals of Arid Zone 65(1): 115-130
https://doi.org/10.56093/aaz.v65i1.173264
https://epubs.icar.org.in/index.php/AAZ/article/view/173264

of Algeria and highlight the potential use of earthworms as indicators of soil quality and sustainable land management.

Key words: Algeria, biodiversity, soil biomass, earthworms, similarity analysis, species richness.

Globally, more than 6,000 earthworm species have been described (Csuzdi, 2012; Reynolds and Wetzel, 2022), though the number of valid species is approximately 5,406 (Misirlioğlu *et al.*, 2023). These species are distributed across a wide range of biogeographical regions, from tropical rainforests to temperate grasslands and boreal forests, reflecting both ancient dispersal patterns and recent anthropogenic introductions (Csuzdi, 2012; Reynolds and Wetzel, 2022).

Earthworms constitute a dominant component of terrestrial invertebrate biomass, with mean biomass values reaching up to 39.2 g m^{-2} (Phillips *et al.*, 2021). Their activities are directly linked to the ecological state of soils (Blouin *et al.*, 2013). In areas where earthworms are abundant, nutrient fluxes through their biomass can be substantial; for instance, it has been reported that over 150 kg of nitrogen per hectare per year is cycled through earthworm tissue (Lubbers *et al.*, 2013). Additionally, earthworm biological activity significantly affects soil fertility and plant growth. The density and biomass of earthworms serve as indicators of biological activity and soil quality (FAO, 2017). Enhancing their numbers and biomass is of considerable interest, as it subsequently increases their impact on soil fertility. Studies have indicated that low earthworm densities in conifer stands can be temporarily increased through liming (Vestergård *et al.*, 2015).

While the ecological functions of earthworms have been well-documented in many regions, their diversity and distribution in North Africa remain relatively understudied compared to temperate and tropical areas. North Africa encompasses a range of climates, from Mediterranean coastal zones to the arid and hyper-arid environments of the Sahara. Within this context, Algeria presents a unique ecological spectrum, hosting habitats that range from humid northern forests to southern steppe and desert regions. This variation supports distinct earthworm communities. Recent studies have identified 40 earthworm species in Algeria, with notable endemism in specific mountainous and forested areas (El-Okki *et al.*, 2022; Zerrouki *et al.*, 2022; Chergui *et al.*, 2025).

Recent research indicates that land-use intensity and climatic stressors (notably drought, altered precipitation, and flooding) have a profound impact on earthworm communities. For instance, a Central European field experiment comparing conventional and organic croplands with intensively and extensively managed grasslands under current and future climate scenarios revealed significantly lower earthworm species richness (-26%), abundance (-80%), and biomass (-73%) in croplands compared to grasslands. The declines were particularly severe among juvenile stages (juvenile abundance -83%; juvenile biomass -84%). These negative effects were most pronounced during periods of prolonged drought (Singh *et al.*, 2021; Liu *et al.*, 2025).

However, data on earthworms remains limited, and considerable research is still needed regarding their taxonomy, abundance, and biomass. There has been significantly less focus on the diversity of earthworms in arid and semi-arid ecosystems. These regions, which encompass over 40% of the Earth's land surface (Wang *et al.*, 2023), present challenging environmental conditions, including low moisture availability and high temperatures—factors traditionally believed to constrain earthworm survival and distribution (Singh *et al.*, 2019). Although species richness in arid regions tends to be lower than in mesic environments, endemic and relict taxa are often present, enhancing the overall biodiversity and ecological resilience of these systems (Blakemore, 2010; Misirlioğlu *et al.*, 2023).

Research on earthworm communities is not only of academic significance but also crucial for developing sustainable land use and soil conservation strategies. Additionally, certain species are widespread, representative of native fauna, and easily bred in laboratory settings. Consequently, earthworms are proposed as bioindicators of biodiversity and soil quality (van Gestel, 2012) and the environmental impact of agricultural systems (Bertrand *et al.*, 2015).

The objective of this study is different from the major works realized in Algeria. It provides data related on biodiversity of earthworms in the province of Tebessa (North-eastern Algeria), across various climates and land types. By evaluating earthworm biomass and density, we can gain insights into soil health and ecosystem functionality. Variations in these parameters offer valuable information regarding the impacts of land use, agricultural practices, and climate change on soil ecosystems. Accurate species identification is essential for documenting the diversity of earthworm populations and detecting any endemic or specialized species. This study seeks to explore these dimensions to enhance our understanding of how earthworms interact with their environment and contribute to ecosystem services, ultimately informing sustainable soil management and conservation strategies in the arid regions of North Africa.

Material and Methods

This study was conducted in the province of Tebessa, located in eastern Algeria (Fig. 1). The region is predominantly agro-pastoral, with land use and vegetation patterns closely shaped by climatic and topographic gradients. Its climate extends from Mesomediterranean conditions in the northern parts to desertic in the southernmost areas, with transitional zones characterized by Thermomediterranean stages, including both short (Th.Med–) and long (Th.Med+) dry season regimes (Fatmi *et al.*, 2020). Winters are typically cold and dry, whereas summers are very hot and arid, with pronounced water deficits.

The northern high plains are primarily devoted to rainfed cereal cultivation, where crops such as wheat and barley dominate the agricultural landscape. Toward the mountainous zones, land cover shifts to natural forests and shrublands. These areas are characterized by tree species such as *Pinus halepensis* Mill. (Aleppo pine), and *Quercus ilex* L. (holm oak), accompanied by Mediterranean shrub formations including *Juniperus oxycedrus* L. (prickly juniper), *Juniperus phoenicea* L. (Phoenicean juniper), and *Pistacia lentiscus* L. (mastic tree). In contrast, the vast steppic landscapes of central and southern Tebessa are largely used as rangelands. These

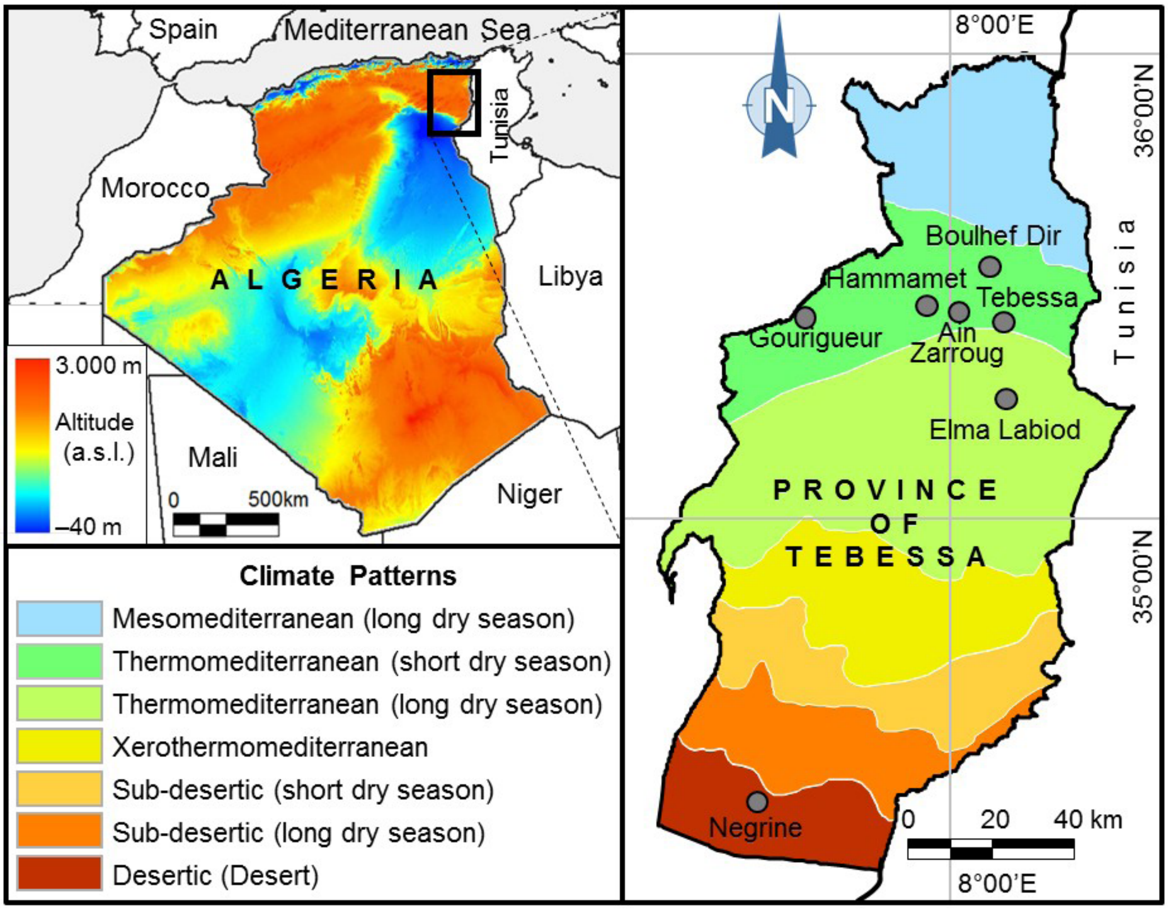

Fig. 1. Map showing studied sites in the province of Tebessa (North-eastern of Algeria).

open ecosystems are dominated by perennial grasses and drought-tolerant shrubs, with *Macrochloa tenacissima* (L.) Kunth syn. *Stipa tenacissima* L. (Halfa grass) and *Artemisia herba-alba* Asso (white wormwood) as the most characteristic species (Macheroum *et al.*, 2025). These rangelands constitute essential grazing resources for local pastoral systems, reflecting the strong agro-pastoral identity of the province. Accordingly, the study sites were selected to represent the dominant bioclimatic zones of Tebessa, which range from semi-arid to arid conditions, thereby encompassing a diversity of land-use types and ecological contexts relevant to earthworm biodiversity.

The sampling of earthworms was conducted by the implementation of a standardized and effective protocol. This sampling protocol represents a critical step for assessing the structure and state of soil communities (Pelosi, 2008). Due to the harsh environmental conditions of Tebessa, where bright sunlight and desiccation during hot summer and autumn, and soil freezing during winter, strongly limit sampling efficiency, fieldwork was conducted during early spring (February-April). This period coincides with more favorable soil moisture and temperature conditions for earthworm activity.

At each study site of the climatic zones (Desert, Th.Med–, and Th.Med+), four replicate samples were collected per year, with sampling conducted monthly between February and April at each study site. Accordingly, for each sampling year (2015, 2016, and 2018), four replicates were obtained following the same sampling design and protocol. Regarding the absence of data for 2017, field sampling could not be carried out during that year due to logistical constraints that prevented access to the study area and the execution of fieldwork within the planned sampling period. This interruption was unrelated to the study design, and sampling resumed in 2018 under the same methodological framework to maintain consistency across years. Earthworms were extracted using a physical method described by Bouché (1972). For each replicate, a soil monolith of 30 × 30 × 30 cm was carefully excavated to capture both surface and sub-surface-dwelling individuals. The anecic worms were found accidentally under large stones. The soil block was manually broken apart, and all visible earthworms were hand-sorted directly in the field. Individuals were immediately placed into labelled plastic containers containing a small amount of soil and plant residues to maintain humidity during transport. Each container was clearly marked with site code, sampling date, and replicate number to ensure traceability.

In the laboratory, specimens were gently rinsed with distilled water to remove adhering soil particles, then blotted dry on absorbent paper. Individuals were classified according to developmental stage (juvenile, sub-adult, or adult with a well-developed clitellum). For accurate identification, adults were preserved in 70% ethanol and examined under a stereomicroscope. Species determination was performed using standard taxonomic keys, namely those of Bouché (1972), Sims and Gerard (1985), and Reynolds (2018). Diagnostic morphological characters such as pigmentation, body size, setae arrangement, and clitellum position were systematically recorded to confirm identification.

Diversity indices were computed using standard ecological formulas: species richness (S) as the total number of species recorded; Shannon index (H), which accounts for both species abundance and evenness; Pielou's evenness index (J), calculated as the ratio of observed diversity to maximum possible diversity; and the reciprocal Simpson index ($1/D$), which gives more weight to dominant species while still reflecting overall community heterogeneity (Chenchouni, 2017).

Diversity analyses were complemented with species richness estimation and rarefaction/extrapolation approaches. Species richness estimators included non-parametric indices such as Chao1, Chao2, first- and second-order Jackknife estimators, and Bootstrap, all computed using EstimateS software version 9.1.0 (Colwell, 2019). Rarefaction and extrapolation curves were generated to assess sampling completeness and to predict asymptotic species richness at standardized sample sizes. Extrapolation curves were generated separately for each climate zone, each habitat type, and for all study sites combined. To account for variability, 95% confidence intervals were estimated based on 100 randomizations without replacement. Since the number of samples differed among climate zones and habitat types, species accumulation was extrapolated to a standardized total of 110 samples, thereby ensuring comparability across groups.

Patterns of similarity among earthworm communities were evaluated using both qualitative (incidence-based) and quantitative (abundance-based) indices (Colwell, 2019). Classic Jaccard and Sørensen indices, as well as their abundance-based and Chao-adjusted variants, were computed alongside Morisita-Horn and Bray-Curtis indices to capture differences in community composition between climates and habitats. These indices provided complementary perspectives on beta diversity and spatial turnover. Three-set Venn diagrams were used to visualize shared and unique species across climates and habitats, separately. This allowed the identification of characteristic species associated with specific environmental contexts and the quantification of species overlap across different ecological gradients.

All statistical analyses and graphical outputs were conducted using R software (R Core Team, 2020). Preliminary data processing included the calculation of descriptive statistics for earthworm morphometric traits (total length, body width, body weight, and total number of segments) as well as population metrics such as abundance, and biomass for different age-class structure (juveniles, sub-adults, and adults).

To examine the influence of environmental factors, two-way analyses of variance (ANOVA) were performed to test the effects of climate zone and land-use type on age-class abundances and biomass parameters (total biomass and biomass per individual), as well as on diversity indices (species richness, Shannon index, evenness, and reciprocal Simpson index 'SRI') (Chao *et al.*, 2006). Climate-habitat interaction is one of the most critical concepts in soil ecology. Habitats often function as environmental filters or thermal buffers against climatic stressors. So, when significant main or interaction effects were detected, Tukey's Honestly Significant Difference (HSD) post hoc tests were applied to identify pairwise differences at $p < 0.05$.

Results and Discussion

Community composition

A total of 1,575 earthworm individuals were collected across the sampling sites in Tebessa. Among these, only 395 specimens were mature adults exhibiting a fully developed clitellum. Taxonomic identification revealed the presence of six species, all belonging to the family Lumbricidae. It is often the most widespread family, particularly in irrigated or cultivated soils within arid regions. Species belonging to this family have the ability to tolerate extreme drought and salinity conditions. Species found were *Aporrectodea caliginosa* (Savigny, 1826), *Aporrectodea rosea* (Savigny, 1826), *Eiseniella tetraedra* (Savigny, 1826), *Eisenia fetida* (Savigny, 1826), *Octodrilus complanatus* (Dugés, 1828), and *Aporrectodea molleri* (Rosa, 1889). Notably, three species (*Ei. tetraedra*, *O. complanatus*, and *A. molleri*) were recorded for the first time in the province of Tebessa, thereby expanding the known distribution range of these taxa within Algeria.

The identified species were classified into distinct ecological categories based on their functional traits. The endogeic group was represented by *A. caliginosa*, *A. rosea*, and *A. molleri*, while the epigeic group comprised *Ei. tetraedra* and *E. fetida*. The anecic category was represented exclusively by *O. complanatus*.

Morphometric of earthworms

Morphometric variations (body length, body width) are critical because they determine the physical limits of an earthworm's interaction with its environment. In soil ecology, these physical traits translate directly into functional performance. Figure 2 indicates significant differences between different earthworm species following total length ($F_{(5,430)} = 75.58$, $p < 0.0001$) and body width ($F_{(5, 430)} = 45.02$, $p < 0.0001$) where the species *O. complanatus* had the highest values followed by *A. caliginosa*. Similarly, body weight ($F_{(5, 430)} = 78.44$, $p < 0.0001$) and total number of segments ($F_{(5, 430)} = 46.87$, $p < 0.0001$) shows that the species *O. complanatus* had the highest values.

Abundance and biomass of the earthworms

There are remarkable differences between the different climates studied in terms of abundance (number of juveniles, adults and total abundance ($p < 0.001$) and sub-adults ($p = 0.028$). Thus, the Th.Med+ climate contained the highest values compared to desert and Th.Med–. Except total abundance ($p = 0.028$), all abundance parameters are comparable in the different habitats selected in this study.

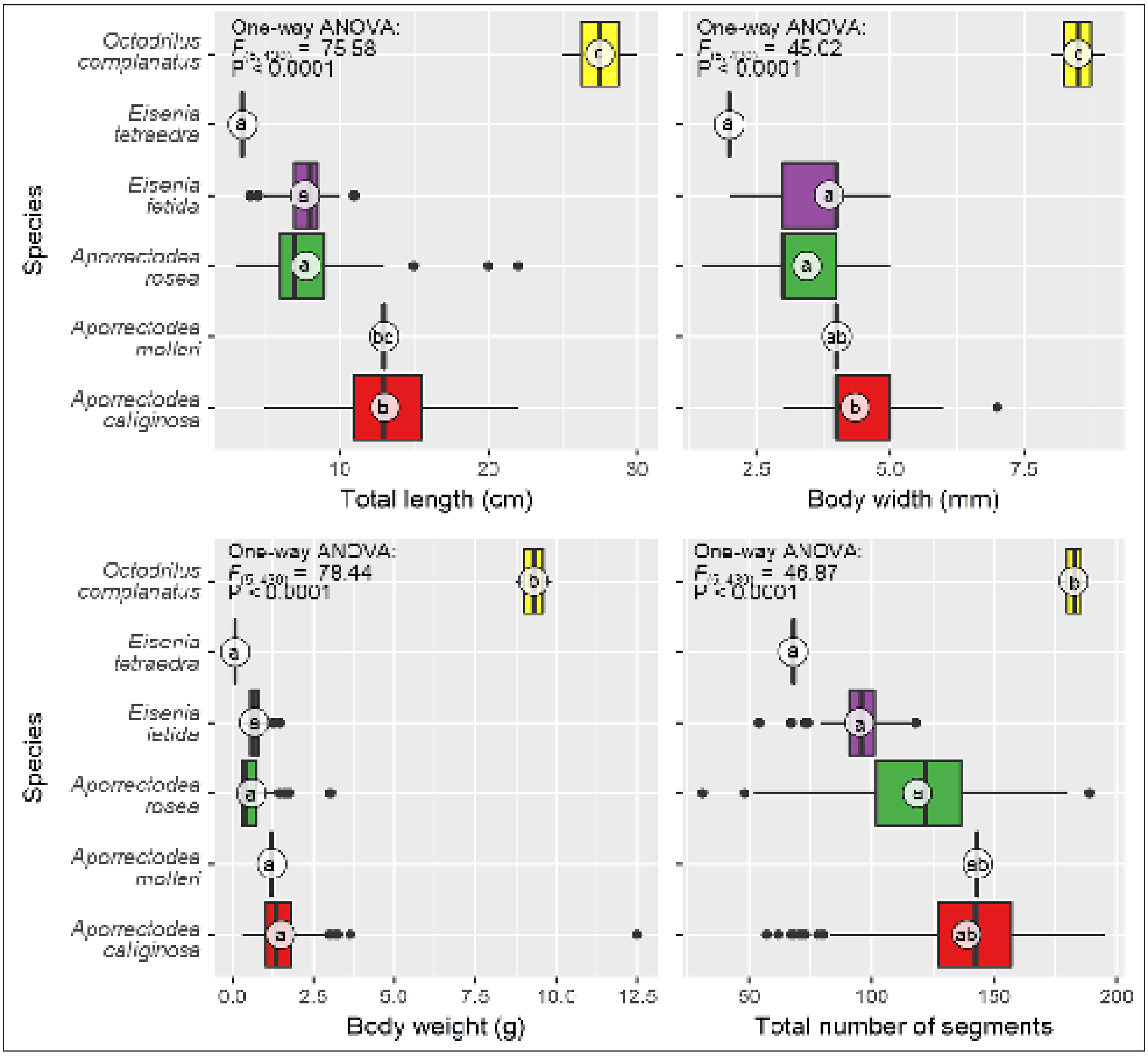

Fig. 2. Variation between different earthworm species following total length, body width, body weight and total number of segments. Lowercase letters displayed within white circles (means) are results of multiple mean comparisons following Tukey's post hoc test (HSD), where different letters are significantly different at p < 0.05.

In comparison to Th.Med- and desert climates, Th.Med+ housed the highest values of total biomass and biomass (p < 0.001). Similarly, field habitats consistently support the highest total biomass of earthworms (p = 0,017) (Fig. 3, Table 1).

Table 1. Effects of climate and land-use on age-class abundance and biomass metrics: ANOVA analysis.

Variable	Statistics	Abundance data				Biomass data	
		Juvenile	Adult	Sub-adult	Total	Total biomass	Biomass/ind
Model	R^2	0.19	0.21	0.06	0.32	0.57	0.31
	F	8.84	9.49	2.14	17.29	48.54	16.23
	P	< 0.001	< 0.001	0.099	< 0.001	< 0.001	< 0.001
Climate	*F*	18.29	23.77	4.97	39.22	105.63	30.01
	P	< 0.001	< 0.001	0.028	< 0.001	< 0.001	< 0.001
Habitat	*F*	2.06	3.32	0.91	4.98	5.83	3.11
	P	0.154	0.071	0.342	0.028	0.017	0.081

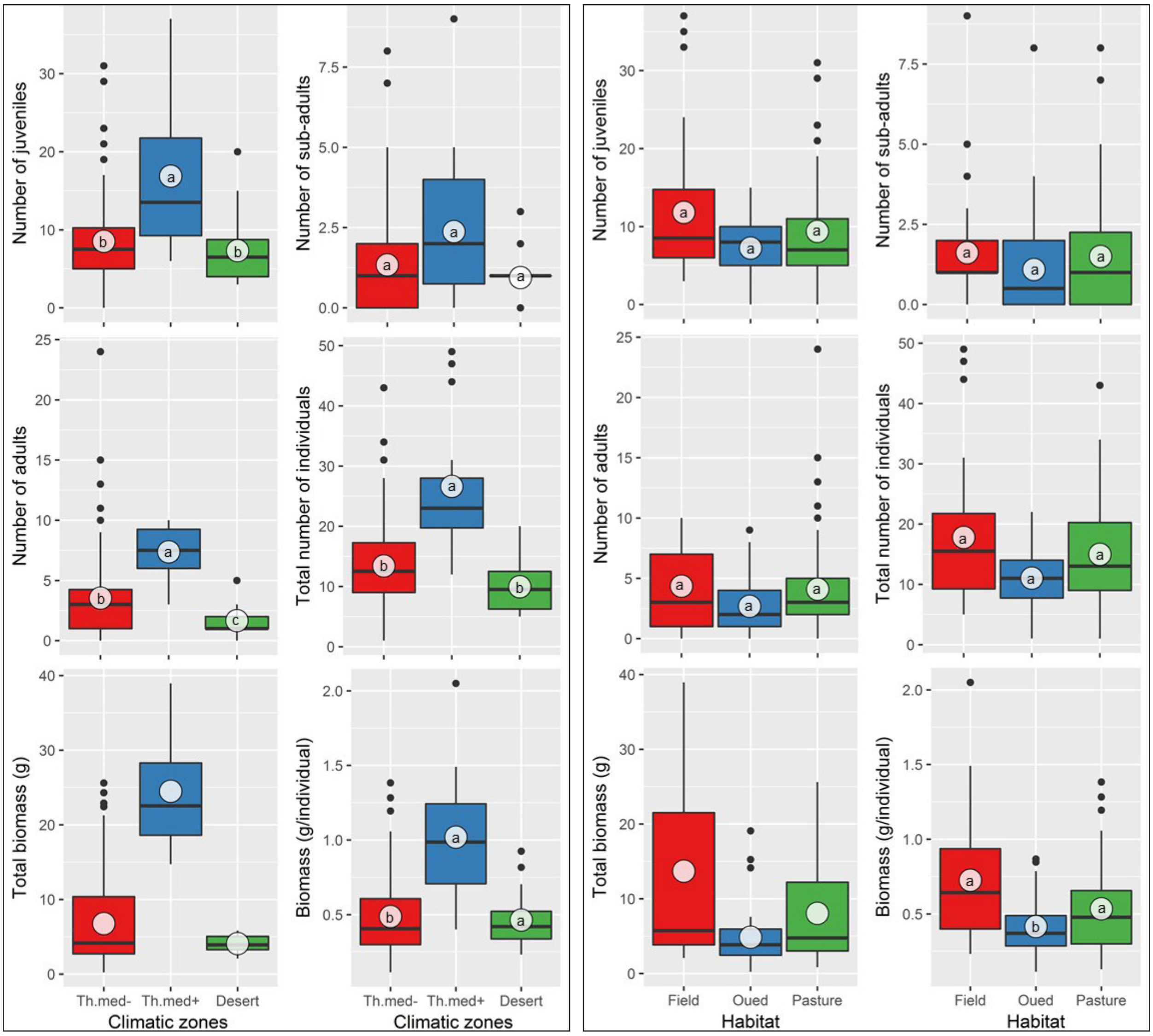

Fig. 3. Abundance, biomass and different developmental stages of earthworms following climatic zones and habitat in Tebessa (Northeastern Algeria). White dots indicate the mean of observed values, whereas the letters within circles are results of multiple mean comparisons following Tukey's post hoc test (HSD), where different letters are significantly different at $p < 0.05$.

Diversity of the earthworm communities

The earthworm species were more diversified in Th.Med+ and Th.Med– climates, compared to desert climate sites. Field communities exhibited higher values of species richness and exponential of Shannon's index, compared to wadi and pasture communities. Earthworm species were equally distributed in the different

Table 2. Variation of diversity indices of earthworm communities sampled in different habitats and climates in Tebessa (Northeastern Algeria)

Variable	Statistics	Species richness	Shannon index	Evenness	Simpson SRI
Model	R^2	0.39	0.45	0.04	0.42
	F	15.20	18.92	1.06	17.22
	P	< 0.001	< 0.001	0.38	< 0.001
Climate	*F*	27.59	35.11	1.47	31.56
	P	< 0.001	< 0.001	0.24	< 0.001
Habitat	*F*	25.15	33.07	0.05	31.51
	P	< 0.001	< 0.001	0.95	< 0.001

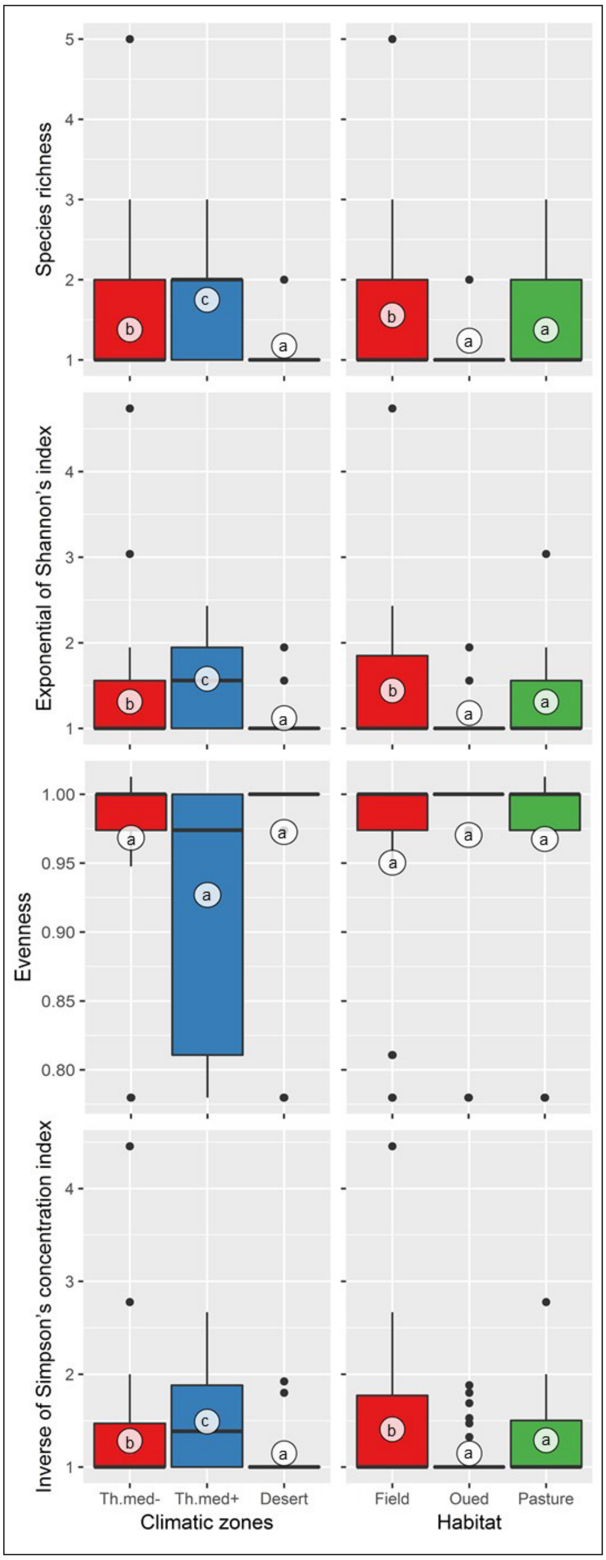

Fig 4. Diversity characteristics of the earthworm communities following climatic zones and habitat in Tebessa (northeastern Algeria). White dots indicate the mean of observed values, whereas the letters within circles are results of multiple mean comparisons following Tukey's post hoc test (HSD), where different letters are significantly different at $p < 0.05$.

habitats, but they were more distributed in Th.Med+ communities compared to Th.Med– and desert communities (Fig. 4, Table 2)

Richness of the earthworms

At the desert and Th.Med+ climate and pasture habitat, the first-order jackknife estimator of species richness $S_{(Jack1)}$ revealed 2.00 ± 0.00, 3.00 ± 0 and 3.00 ± 0 species, respectively, which corresponded to an inventory completeness of 100%. For the Th.Med– climate and the overall, the estimator revealed a completeness of about 66.66%, i.e., $S_{(Jack1)}$ = 9 species based on 6 species observed (Fig. 5, Table 3).

Total earthworm species richness observed was 6 species, while $S_{(Chao2)}$ indicated a value of 8.97 species for the whole study area (Table 3). The first-order Jackknife richness estimator revealed that the earthworm species richness in Th.Med– climate and in field was the highest with the values 8.95 and 7 respectively. The lowest expected earthworm species richness characterized the desert climate and pasture landscape.

Rarefaction of species richness

Based on species richness extrapolation from the specimens of earthworms of each climate zone and habitat to a theoretical sample size of 436 specimens, rarefaction curves revealed that the analytical species richness Sest increased with the number of specimens in communities located in field and wadi habitat and under Th.Med– climate. The earthworm species expected in Th.Med– climates, field habitat as well as in the entire study area reached a plateau, with Sest values of 6 (Fig. 6). The desert climate had the lowest Sest value with 2 species.

Similarity analysis between climates and habitats

High similarity in earthworm species implies a homogenized soil environment and a dominant, consistent filtering mechanism where species-specific traits, rather than environment, dictate soil structure and nutrient cycling. According to the figure 7, two species out of six are characteristic of the field landscape and another one was found, exclusively, in the wadi habitat. On the other hand, two species are common to all landscapes (*A. caliginosa* and *A. rosea*). Regarding the climate, all the found

Table 3. Diversity indices and estimated total earthworm species richness according to climate regions, landscape types, and the whole study area in Tebessa (Northeastern Algeria)

Diversity metrics	Climatic zones			Habitats			Overall
	Desert	Th.Med-	Th.Med+	Field	Wadi	Pasture	
Sample size	17	66	16	34	25	40	99
Individuals (computed)	31	290	115	153	86	197	436
S(est)	2	6	3	5	3	3	6
S(est) 95% CI lower bound	2	3.24	3	3.23	3	3	3.24
S(est) 95% CI upper bound	2	8.76	3	6.77	3	3	8.76
S(est) SD	0	1.41	0	0.9	0	0	1.41
S Mean (runs)	2	6	3	5	3	3	6
Singletons mean	0	2	0	1	1	0	2
Doubletons mean	0	1	0	1	0	0	1
Uniques mean	0	3	0	2	1	0	3
Duplicates mean	0	0	0	0	0	0	0
ACE mean	2	9	3	6	3	3	9
ICE mean	2	14.44	3	8.48	3.99	3	8.97
S (Chao 1)	2	7.99	3	5.5	3	3	8
Chao 1 95% CI lower bound	2	6.18	3	5.03	3	3	6.18
Chao 1 95% CI Upper Bound	2	28.06	3	13.4	4.49	3	28.08
Chao 1 SD (analytical)	0	3.73	0	1.32	0.48	0	3.73
S (Chao 2)	2.0	9.0	3	5.97	3	3	8.97
Chao 2 95% CI lower bound	2	6.36	3	5.07	3	3	6.36
Chao 2 95% CI upper bound	2.06	30.26	3.28	18.15	4.49	3.04	30.37
Chao 2 SD (analytical)	0.03	2.35	0.13	2.14	0.48	0.02	4.37
S (Jack 1)	2	8.95	3	7	4	3	9
Jack 1 SD (analytical)	0	2.19	0	1.94	0.96	0	2.2
S (Jack 2)	2.0	11.9	3	8.82	4.88	3	11.91
Bootstrap mean	2	7.1	3.01	5.73	3.36	3	7.1
MMRuns mean	2.15	5.36	3.28	4.89	2.98	3.15	5.17
MMMeans (1 run)	2.15	5.34	3.22	4.78	2.92	3.16	5.12
Cole Rarefaction	0	6	3	5	3	3	6
Alpha mean	0.48	1.07	0.56	0.99	0.6	0.5	0.98
Alpha SD (analytical)	0.18	0.19	0.14	0.2	0.16	0.12	0.16
Shannon mean	0.68	1.08	0.87	0.96	0.47	1.06	1.03
Shannon exponential mean	1.97	2.94	2.38	2.62	1.59	2.9	2.8
Simpson SRI mean	1.95	2.57	2.01	2.14	1.35	2.82	2.42

species exist in the Th.Med– climate where two of them are common to all the studied climates. However, desert and Th.Med+ climates (twice with field habitats) have no characteristic species.

Spatial similarities of the earthworm species

Earthworm species compositions assessed between the climatic regions and landscapes of the studied communities indicated high similarity based on qualitative (Classic Jaccard and Sørensen similarity indices) or abundance-based indices. Considering habitats, all indices revealed that the highest similarity in earthworms is between field and pasture. Chao's Sørensen indices applied using raw and estimated data showed higher similarity values (≥75.8) than Chao's Jaccard among climates and habitats (Table 4).

Six species of earthworms were identified in the study area. The results of earthworm's identification from the sites of Tebessa,

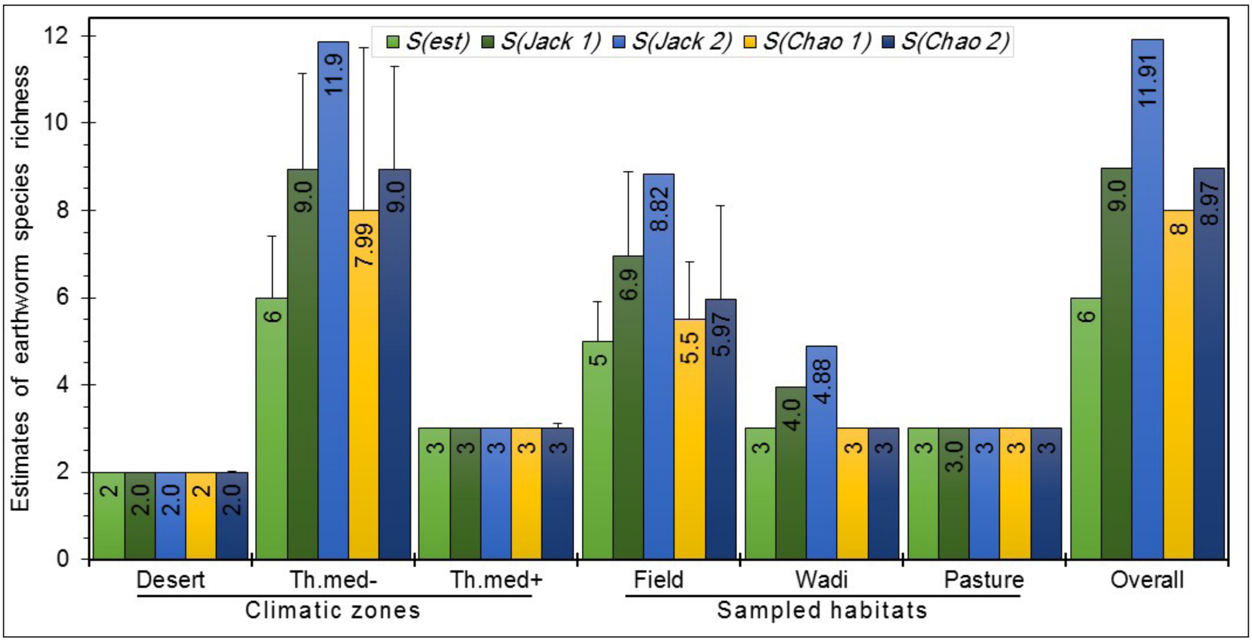

Fig. 5. Estimates of earthworm species richness following climatic zones, sampled habitats and overall.

Hammamet, and Elma Labiod are consistent with the study conducted by Bouazdia and Habes (2017). Thus, it is noteworthy that semi-arid to arid areas typically exhibit low earthworm species diversity. In Algeria, a total of 40 earthworm species were documented across 24 studies and 346 sampling sites (Chergui *et al.*, 2025).

Soil moisture functions as the principal ecological constraint in dryland ecosystems. Because earthworms respire through their skin and are highly vulnerable to desiccation, reduced soil water directly limits survival, cocoon viability, reproductive timing, and mobility. Moisture availability also regulates microbial activity, which determines the quality and palatability of organic matter resources. Under dry conditions, decomposition slows, nutrient diffusion declines, and thermal stress intensifies, narrowing the range of species capable of persistence. Global analyses confirm that earthworm richness increases with soil moisture and favorable soil nutrient balance (Phillips *et al.*, 2019; Phillips *et al.*, 2021). In arid systems, therefore, moisture acts as a primary

Table 4. Spatial incidence-based (qualitative) and abundance-based similarities in earthworm species between climates and habitats

Similarity estimators		Climatic zones			Habitats		
	First sample	Desert	Desert	Th.Med–	Field	Field	Wadi
	Second sample	Th.Med–	Th.Med+	Th.Med+	wadi	pasture	pasture
Sobs first sample		2	2	5	4	4	3
Sobs second sample		5	3	3	3	3	3
Shared species observed		2	2	3	2	3	2
ACE first sample		2	2	6	4	4	3
ACE second sample		6	3	3	3	3	3
Classic Jaccard index [%]		40.0	66.7	60.0	40.0	75.0	50.0
Classic Sørensen index [%]		57.1	80.0	75.0	57.1	85.7	66.7
Raw Chao-Jaccard index [%]		72.6	87.0	99.3	87.8	99.3	61.0
Estimated Chao-Jaccard index [%]		72.6	87.0	99.3	87.8	99.3	61.0
Raw Chao-Sørensen index [%]		84.1	93.0	99.7	93.5	99.7	75.8
Estimated Chao-Sørensen index [%]		84.1	93.0	99.7	93.5	99.7	75.8
Morisita-Horn index [%]		86.1	93.3	96.1	94.3	83.8	67.6
Bray-Curtis index [%]		19.4	42.5	57.1	71.7	76.4	60.1

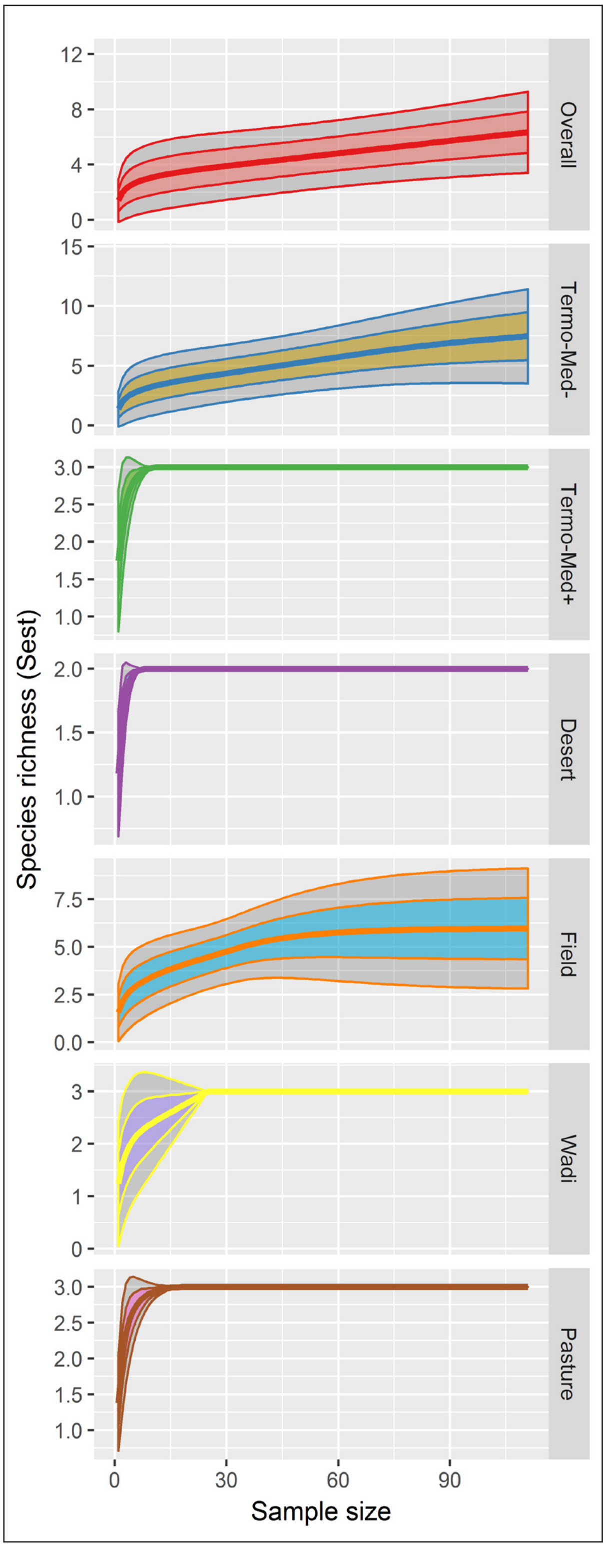

Fig. 6. Climatic zones and habitat-based extrapolation curves of species richness estimated for earthworm communities living in the studied climate zone and habitat (Northeastern Algeria). Light grey shaded areas represent lower and upper bounds of 95% confidence intervals for the S(est). Colored-shaded areas indicate ± standard deviation.

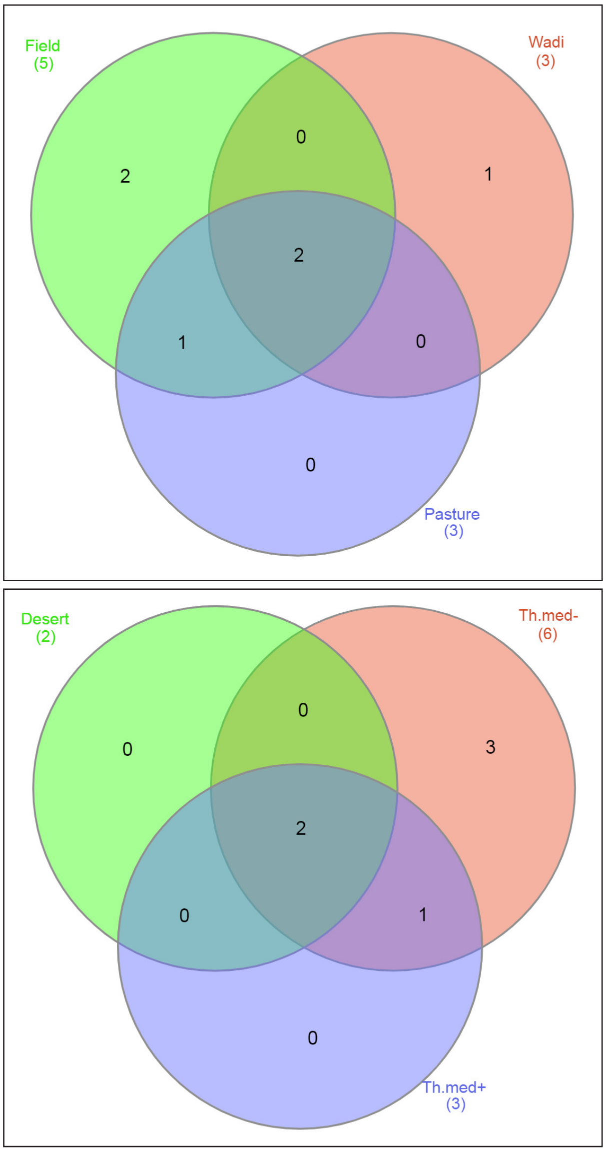

Fig 7. Three-set Venn diagram displaying earthworm species richness (S) recorded at various habitats and climates of Tebessa. Values reported between brackets represent the total number of species in each climate zone and habitat, whereas numbers within the diagram are species shared exclusively between the corresponding sites.

environmental filter, explaining the reduced diversity typically observed in desert climates and the comparatively higher richness under Mediterranean conditions. Similar patterns in North African drylands were documented by Ababsa *et al.* (2017), who reported inherently low richness but persistence of drought-tolerant taxa.

Land-use disturbance interacts with climatic stress by modifying soil structure, compaction, hydrology, and organic matter inputs.

Agricultural systems can either exacerbate or buffer climatic constraints depending on management intensity. Intensive tillage, heavy machinery, and chemical inputs reduce soil porosity and disrupt habitat continuity, negatively affecting earthworm populations (Pelosi *et al.*, 2013; Beaumelle *et al.*, 2023). Conversely, moderate management, crop residue retention, and organic amendments enhance soil carbon content and water-holding capacity, creating microhabitats that partially mitigate moisture stress. Spurgeon *et al.* (2013) demonstrated that land management intensity is a key determinant of soil invertebrate community structure, while Zeiss *et al.* (2024) and Hassan (2025) confirmed strong correlations between agricultural land cover, soil texture, phosphorus content, and earthworm species richness. Thus, land use does not operate independently of climate; rather, it modulates the severity of water limitation through its effects on soil physical and chemical properties.

Resource availability constitutes a third critical constraint. In arid and semi-arid environments, primary productivity is low and litter inputs are often episodic. Earthworms depend not only on organic matter quantity but also on its microbial conditioning, which enhances nutrient accessibility. Reduced vegetation cover limits carbon inputs, weakens soil aggregation, and restricts habitat buffering against temperature extremes. Our results significantly exceed those reported by Ghanem *et al.* (2017) in Batna. The study of Bazri *et al.* (2013) recorded earthworm biomass and density in eastern Algeria from desert to coastal regions, ranging from 0.28 ± 0.39 to 13.13 ± 7.94 g m^{-2} and 6.00 ± 1.41 to 29.60 ± 11.83 ind m^{-2}, respectively. Similarly, Omodeo and Martinucci (1987) observed earthworm densities ranging from 11.0 to 12.7 ind m^{-2} and biomass from 1.25 to 3.0 g m^{-2}. The dominance of a particular species at a site will invariably impact biomass values. Thus, the high biomass recorded in field landscapes and Th.Med+ climate may be attributed to the predominance of *A. caliginosa*, which is characterized by its relatively high weight. Tripathi and Bhardwaj (2004) showed that declines in moisture and food palatability are directly associated with reduced abundance and biomass in arid agroecosystems. At broader scales, soil organic matter has been identified as one of the most consistent predictors of earthworm richness and abundance (Phillips *et al.*, 2021). Biomass patterns, therefore, should be interpreted as integrative indicators of energy flow and soil functional capacity rather than simple numerical measures.

Functional composition provides further ecological insight beyond species counts. Earthworms are commonly classified into epigeic, endogeic, and anecic functional groups, each contributing differently to soil processes (Edwards and Arancon, 2022). In arid and semi-arid systems, endogeic species frequently dominate because they inhabit mineral soil layers and feed on soil organic matter rather than relying on surface litter. The predominance of endogeic taxa such as *A. caliginosa* and *A. rosea* indicates adaptation to subsurface feeding and fluctuating moisture conditions. Studies linking functional diversity to ecosystem processes have shown that community composition directly influences decomposition dynamics, nutrient redistribution, and soil aggregation (Mathieu and Davies, 2014). The relative scarcity of epigeic and anecic groups in dry climates reflects structural simplification of soil food webs under moisture stress, as surface litter layers are often sparse and unstable.

Resilience strategies are central to persistence in arid environments. Many drought-tolerant earthworms exhibit vertical migration to deeper, moister soil horizons during dry periods, temporary aestivation with reduced metabolic activity, and production of desiccation-resistant cocoons. The broad Holarctic distribution of *A. caliginosa* and *A. rosea* suggests high ecological plasticity and tolerance to wide climatic gradients (Pérez *et al.*, 2009; Fernandez *et al.*, 2016). However, resilience is not unlimited. Increasing aridity, soil degradation, and intensified chemical disturbance may exceed physiological thresholds, leading to community simplification and functional loss.

When synthesized hierarchically, the structuring mechanisms become clearer. Climate-particularly moisture availability-sets the fundamental physiological limits. Land use modifies these limits by altering soil hydrology, disturbance regimes, and organic inputs. Resource quality determines trophic support and biomass accumulation. Finally, species-specific functional traits govern persistence and ecosystem contribution. Similar conclusions were reached in dryland studies by Tripathi and Panwar (2012) and Ababsa *et al.* (2023), who observed low richness but persistence of functionally tolerant taxa in arid environments. Thus, a review of 113 publications across 44 countries by Betancur-Corredor *et* al. (2024) noted higher earthworm species richness in pastures. Conversely, Karimifard *et al.* (2024) found that while pastures had a higher overall abundance of earthworms, farmlands actually exhibited greater species diversity. The similarity between field and pasture observed in our study may be attributed to the limited use of pesticides by farmers, as earthworm abundance has been shown to increase with reduced pesticide application (Pelosi *et al.*, 2013; Beaumelle *et al.*, 2023).

Overall, earthworm communities in drylands are not simply depauperate versions of temperate assemblages. They are environmentally filtered systems structured by interacting climatic and anthropogenic pressures. Although species richness may remain low, functional stability can be maintained by drought-adapted endogeic taxa. Understanding these mechanistic relationships is essential for predicting how increasing aridity and land-use intensification under global change will influence soil biodiversity and ecosystem functioning.

Conclusions

Earthworms play a pivotal role in ecosystem functioning and soil fertility, making their study essential not only for ecological understanding but also for sustainable agricultural management. The present investigation provides one of the few records of earthworm diversity in the largely unexplored arid zones of northeastern Algeria (Tebessa). The limited diversity found in the studied area likely reflects both the inherently low biodiversity of arid environments and the scarcity of systematic monitoring programs in the region. These findings underscore the urgent need for expanded surveys across other poorly studied arid and semi-arid areas in order to establish a comprehensive national inventory of earthworm fauna in Algeria.

Beyond simple biodiversity documentation, such baseline data represent a crucial first step toward the development of long-term biological monitoring frameworks for soil health. Earthworms are widely recognized as sensitive bioindicators of soil condition, responding to changes in moisture availability, organic matter inputs, and land-use practices. Establishing reference datasets for their distribution and abundance in arid landscapes will enable future assessments of ecological change and provide measurable indicators for evaluating the effectiveness of soil conservation and sustainable land management strategies.

The importance of such monitoring is likely to increase under projected climate change scenarios, which are expected to intensify drought frequency, alter precipitation regimes, and exacerbate land degradation in North African drylands. Under these conditions, earthworm communities may serve as early warning indicators of declining soil resilience and ecosystem functionality. Integrating earthworm-based indicators into regional soil monitoring programs could therefore support adaptive management approaches aimed at maintaining soil fertility, enhancing carbon sequestration, and improving agricultural sustainability in water-limited environments.

Given the accelerating pace of global environmental change—including climate alteration and land-use intensification—proactive efforts to document, monitor, and conserve earthworm biodiversity are essenti*al.* Protecting these key soil engineers will be critical for sustaining ecosystem services, preserving soil structure and nutrient cycling, and safeguarding the long-term productivity and ecological stability of arid and semi-arid agroecosystems.

Credit Authors' Contributions

Karim Bouazdia (Conceptualization, Methodology, Resources, Investigation, Writing – Original Draft, Writing – Review & Editing). Haroun Chenchouni (Formal Analysis, Visualization, Writing – Original Draft, Writing – Review & Editing).

Funding

This study was not funded by any source.

Competing Interests

The authors declare that they have no competing interest.

Availability of Data

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Ababsa, N., Fellah, S., Chenchouni, H., Lallaouna, R., Bouchama, K., Baha, M. and Kribaa, M. 2023. Structure and diversity of earthworm communities in long-term irrigated soils with raw effluent and treated wastewater. *Water Science & Technology* 88(9): 2473-2489. https://doi.org/10.2166/wst.2023.345

Ababsa, N., Laiche, A. and Djabbar, F. 2017. Abundance and species richness of lombric macrofauna in a semi-arid forest ecosystem. *Journal of Fundamental and Applied Sciences* 9(3): 1634-1643. https://doi.org/10.4314/jfas.v9i3.24

Bazri, K., Ouahrani, G., Prigo, D. and Cosin, D. 2013. Soil factors and earthworms in Eastern Algeria. *Sciences & Technologie. C, Biotechnologies* (37): 22-31.

Beaumelle, L., Tison, L., Eisenhauer, N., *et al*. 2023. Pesticide effects on soil fauna communities-A meta-analysis. *Journal of Applied Ecology* 60(7): 1239-1253. https://doi.org/10.1111/1365-2664.14437

Bertrand, M., Barot, S., Blouin, M., Whalen, J., de Oliveira, T. and Roger-Estrade, J. 2015. Earthworm services for cropping systems. A review. *Agronomy for Sustainable Development* 35(2): 553-567. https://doi.org/10.1007/s13593-014-0269-7

Betancur-Corredor, B., Zaitsev, A. and Russell, D.J. 2024. The impact of multiple agricultural land uses in sustaining earthworm communities in agroecosystems-A global meta-analysis. *Scientific Reports* 14(1): 30160. https://doi.org/10.1038/s41598-024-81676-5

Blakemore, R.J., Kupriyanova, E. and Grygier, M.J. 2010. Neotypification of *Drawida hattamimizu* Hatai, 1930 (Annelida, Oligochaeta, Megadrili, Moniligastridae) as a model linking mtDNA (COI) sequences to an earthworm type, with a response to the 'Can of Worms' theory of cryptic species. *ZooKeys* 41: 1-29. https://doi.org/10.3897/zookeys.41.374

Blouin, M., Hodson, M.E., Delgado, E.A., *et al*. 2013. A review of earthworm impact on soil function and ecosystem services. *European Journal of Soil Science* 64(2): 161-182. https://doi.org/10.1111/ejss.12025

Bouazdia, K. and Habes, D. 2017. Earthworm Species Identified in the Region of Tebessa (Eastern Algeria). *International Journal of Zoological Research* 13: 38-44. https://doi.org/10.3923/ijzr.2017.38.44

Bouché, M.B. 1972. Lombriciens de France, Ecologie et systématique. Inst. Nat. Rech. Agronomique, Paris, pp. 671.

Chao, A., Chazdon, R.L., Colwell, R.K. and Shen, T.J. 2006. Abundance-based similarity indices and their estimation when there are unseen species in samples. *Biometrics* 62(2): 361-371.

Chenchouni, H. 2017. Variation in white stork (*Ciconia ciconia*) diet along a climatic gradient and across rural-to-urban landscapes in North Africa. *International Journal of Biometeorology* 61: 549–564.

Chergui, C. N., Ouahrani, N.S. and Pelosi, C. 2025. Checklist of earthworm species Annelida, Oligochaeta in Algeria. *Zootaxa* 5686(2): 277-293. https://doi.org/10.11646/zootaxa.5686.2.7

Colwell, R.K. 2019. Estimates: Statistical estimation of species richness and shared species from samples. Version 9.1.0. User's Guide and Application published at: http://purl.oclc.org/estimates.

Csuzdi, C. 2012. Earthworm species, a searchable database. *Opuscula Zoologica* 43(1): 97-99. https://doi.org/10.5281/zenodo.1045525

Edwards, C.A. and Arancon, N. 2022. *Biology and Ecology of Earthworms*. 4th edition, Springer New York, NY. https://doi.org/10.1007/978-0-387-74943-3

El-Okki, M.E.H., Khelfaoui, F. and Sahli, L. 2022. New distribution record of *Hormogaster redii* (Rosa, 1887) and *Octodrilus maghrebinus* (Omodeo and Martinnucci, 1987) in the south integral reserve of El-Kala National Park (Algeria). *Ukrainian Journal of Ecology* 12(12): 24-29.

FAO - Food and Agriculture Organization of the United Nations 2017. Soil Organic Carbon: The Hidden Potential. FAO, Rome. URL: https://openknowledge.fao.org/items/a9260c9f-71e8-46fa-a853-0d18f0de3bda

Fatmi, H., Mâalem, S., Harsa, B., Dekak, A. and Chenchouni, H. 2020. Pollen morphological variability correlates with a large-scale gradient of aridity. *Web Ecology* 20: 19-32. https://doi.org/10.5194/we-20-19-2020

Fernandez, R., Novo, M., Marchan, D.F. and Cosín, D.J.D. 2016. Diversification patterns in cosmopolitan earthworms: similar mode but different tempo. *Molecular Phylogenetics and Evolution* 94: 701-708. https://doi.org/10.1016/j.ympev.2015.07.017

Ghanem, N.K., Kribaa, M. and El-Okki, M.E.H. 2017. Interaction between soil physicochemical parameters and earthworm communities in irrigated areas with natural water and wastewaters. *Applied and Environmental Soil Science* 2017(1): 5808945. https://doi.org/10.1155/2017/5808945

Hassan, M. 2025. Distribution, diversity, and ecological traits of earthworms in different habitats: Implications for conservation and management practices in Jammu, India. *Science Reviews - Biology* 4(1): 15-35. https://doi.org/10.57098/SciRevs.Biology.4.1.3

Karimifard, S., Saberi-Pirooz, R., Ahmadzadeh, F. and Aghamir, F. 2024. Investigating the impacts of agricultural land use on soil earthworm communities: A case study of northern Zagros Mountains of Iran. *Heliyon* 10: e23523. https://doi.org/10.1016/j.heliyon.2023.e23523

Liu, Q., Eisenhauer, N., Scheu, S., Reitz, T. and Schädler, M. 2025. Grasslands support more diverse and resilient earthworm communities to climate change than croplands in Central Europe. *Agriculture, Ecosystems & Environment* 377: 109259. https://doi.org/10.1016/j.agee.2024.109259

Lubbers, I.M., van Groenigen, K.J., Fonte, S.J., Six, J., Brussaard, L. and van Groenigen, J.W. 2013. Greenhouse-gas emissions from soils increased by earthworms. *Nature Climate Change* 3(3): 187-194. https://doi.org/10.1038/nclimate1692

Macheroum, A., Sayada, N. and Chenchouni, H. 2025. Restoration of soil quality and improvement of physicochemical properties through grazing exclusion in arid and semi-arid rangelands. *Catena* 249: 108646. https://doi.org/10.1016/j.catena.2024.108646

Mathieu, J. and Davies, T.J. 2014. Glaciation as an historical filter of below-ground biodiversity. *Journal of Biogeography* 41(6): 1204-1214. https://doi.org/10.1111/jbi.12284

Misirlioğlu, M., Reynolds, J.W., Stojanović, M., *et al.* 2023. Earthworms (Clitellata, Megadrili) of the world: an updated checklist of valid species and families, with notes on their distribution', *Zootaxa* 5255(1): 417-438. https://doi.org/10.11646/zootaxa.5255.1.33

Omodeo, P. and Martinucci, G.B. 1987. Earthworms of Maghreb. In: *Selected Symposia and Monographs on Earthworms* (Eds. A.M. Bonvicini, I. Paglia and P. Omodeo), pp. 235-250. U.Z.I., 2, Mucchi, Modena

Pelosi, C. 2008. Modélisation de la dynamique d'une population de vers de terre *Lumbricus terrestris* au champ. Contribution à l'étude de l'impact des systèmes de culture sur les communautés lombriciennes. Sciences de la Terre. AgroParisTech, Francais. URL: https://pastel.h*al*.science/tel-00336523

Pelosi, C., Joimel, S. and Makowski, D. 2013. Searching for a more sensitive earthworm species to be used in pesticide homologation tests – a meta-analysis. *Chemosphere* 90: 895-900. https://doi.org/10.1016/j.chemosphere.2012.09.034

Pérez-Losada, M., Ricoy, M., Marshall, J.C. and Domínguez, J. 2009. Phylogenetic assessment of the earthworm *Aporrectodea caliginosa* species complex (Oligochaeta: Lumbricidae) based on mitochondrial and nuclear DNA sequences. *Molecular Phylogenetics and Evolution* 52(2): 293-302. https://doi.org/10.1016/j.ympev.2009.04.003

Phillips, H.R., Bach, E.M., Bartz, M.L. *et al.* 2021. Global data on earthworm abundance, biomass, diversity and corresponding environmental properties. *Scientific data* 8(1): 136. https://doi.org/10.1038/s41597-021-00912-z

Phillips, H.R., Guerra, C.A., Bartz, M.L. *et al.* 2019. Global distribution of earthworm diversity. *Science* 366(6464): 480-485. https://doi.org/10.1126/science.aax4851

R Core Team 2020. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.r-project.org/index.html

Reynolds, J.W. 2018. Preliminary Key to Algerian Megadriles (Annelida, Clitellata, Oligochaeta), based on external characters, insofar as possible. *Megadrilogica* 24(1): 1-16.

Reynolds, J.W. and Wetzel, M.J. 2022. Nomenclatura Oligochaetologica – A catalogue of names, descriptions and type localities of earthworms. Online Edition. Available at: https://www.inhs.illinois.edu/people-programs/oligochaetology/nomenclatura

Sims, R.W and Gerard, B.M. 1985. Earthworms: Keys and Notes for the Identification and Study of the Species. In: *Synopses of the British Fauna* (New Series) Published for The Linnean Society of London and The Estuarine and Brackish Water Sciences Association (Eds. E.J. Brill, W. Backhuys and E.J. Brill) Publishing Company, Leiden, The Netherlands, 171 p.

Singh, J., Eisenhauer, N., Schädler, M. and Cesarz, S. 2021. Earthworm gut passage reinforces land-use effects on soil microbial communities across climate treatments. *Applied Soil Ecology* 164: 103919. https://doi.org/10.1016/j.apsoil.2021.103919

Singh, J., Schädler, M., Demetrio, W., Brown, G.G. and Eisenhauer, N. 2019. Climate change effects on earthworms-a review. *Soil Organisms* 91(3): 114. https://doi.org/10.25674/so91iss3pp114

Spurgeon, D.J., Keith, A.M., Schmidt, O., Lammertsma, D.R. and Faber, J.H. 2013. Land-use and land-management change: Relationships with earthworm and fungi communities and soil structural properties. *BMC Ecology* 13(1): 46. https://doi.org/10.1186/1472-6785-13-46

Tripathi, G. and Bhardwaj, P. 2004. Earthworm diversity and habitat preferences in arid regions of Rajasthan. *Zoo's Print Journal* 19(7): 1515-1519. https://doi.org/10.11609/jott.zpj.1074.1515-9

Tripathi, G. and Panwar, K.R. 2012. Earthworm fauna of Indian Thar Desert: (Oligochaeta). *Zoology in the Middle East* 58(sup4):133-140. https://doi.org/10.1080/09397140.2012.10648995

van Gestel, C.A. 2012. Soil ecotoxicology: State of the art and future directions. *ZooKeys* 176: 275. https://doi.org/10.3897/zookeys.176.2275

Vestergård, M., Dyrnum, K., Michelsen, A., Damgaard, C. and Holmstrup, M. 2015. Long-term manipulation of the microbes and microfauna of two subarctic heaths by addition of fungicide, bactericide, carbon and fertilizer. *Soil Biology and Biochemistry* 81: 53-64. https://doi.org/10.1016/j.soilbio.2014.11.008

Wang, X., Zhang, M., Li, Y., Liu, H., Chen, X. and Yang, L. 2023. Research on the coordinated relationship between human activities and ecological environment in arid and semi-arid regions. *Frontiers in Ecology and Evolution* 11:1307274. https://doi.org/10.3389/fevo.2023.1307274

Zeiss, R., Briones, M.J.I., Mathieu, J. *et al.* 2024. Effects of climate on the distribution and conservation of commonly observed European earthworms. *Conservation Biology* 38:14187.

Zerrouki, H., Hamil, S., Alili, M., Isserhane, W. and Baha, M. 2022. Contribution to the knowledge of earthworm fauna of Chrea National Park (Algeria). *Ukrainian Journal of Ecology* 12(3): 1-10.

Printed in March 2026