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Oak heterogeneity shaping arthropod diversity and ecological dynamics in Boumezrane forest (Souk Ahras, Algeria)

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ABSTRACT. The Boumezrane Forest in northeastern Algeria is a biodiversity hotspot characterized by a mosaic of oak species and varied habitats. This study examined how habitat heterogeneity influences arthropod diversity across five forest habitats: Cork Oak, Zeen Oak, Mixed Oak formations, Afares Oak, and Low Scrubland. A total of 116 arthropod taxa, spanning 44 families and nine orders, were recorded, with Coleoptera emerging as the most diverse group. Results revealed that habitat structure significantly influenced arthropod assemblages, with Low Scrubland hosting the highest diversity, and Cork Oak forests showing the lowest. Unique taxa were most prevalent in transitional habitats, while shared species highlighted ecological connectivity between habitats. Non-metric multi-dimensional scaling (NMDS) and Jaccard index analyses demonstrated distinct taxa compositions across habitats and vegetation strata. These findings highlight the critical role of habitat heterogeneity in shaping biodiversity and emphasize the need for conservation efforts tailored to the unique ecological features of oak-dominated landscapes.

Keywords: Coleoptera, conservation, entomofauna, forests, Landscape, Northeastern Algeria

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INTRODUCTION

Forest ecosystems are dynamic communities of trees, plants, animals, and microorganisms interacting with their environment (Perry et al., 2008). It maintains biodiversity, regulates climate, cycles nutrients, and provides habitats (Brockerhoff et al., 2017). Forests also support human well-being by offering resources like timber, clean air, and water, as well as recreation and cultural value (Hallaj et al., 2024). A significant portion of the biodiversity found in forests lies within floristic assemblages, which refer to the various plant communities that inhabit these ecosystems and directly support insect and bird fauna (Wenninger & Inouye, 2008). The habitat structure of these forests, shaped by variations in characteristics such as tree height, species composition, and canopy structure, further influences species richness across different taxonomic groups, highlighting the interplay between plant communities and broader biodiversity patterns (Gardner et al., 1995; Díaz, 2006; Carroll et al., 2023). Insects are essential to forest ecosystems as they pollinate plants, decompose organic matter, recycle nutrients, aerate the soil, and serve as food for wildlife, all of which support healthy plant growth (Battisti, 2015; Habbachi et al., 2016). They also provide essential food for birds and mammals, control pests naturally, and help disperse seeds, promoting biodiversity. Furthermore, insects make a significant contribution to forest biodiversity, representing more than half of all species, far exceeding fungi and other invertebrates (Gosselin et al., 2004). The conservation of forest ecosystems relies primarily on biodiversity inventory (Corona et al., 2011), as well as a better understanding of the factors that could alter their composition and ecological characteristics. These inventories help to assess species richness, identify rare or threatened species, and track changes in community structure over time. Insects' inventory is vital for forest ecosystems, as it not only enhances our understanding of biodiversity but also in monitoring ecological health, supporting species interactions, and informing conservation efforts to maintain the balance of these complex environments (Brown, 1997).

The Boumezrane Forest, part of the Majerda Mountains and covering an area of 3,900 hectares (Chenoune, 2011), is a natural extension of the El Feidja National Park in Tunisia, which serves as the last sanctuary for the Barbary deer in its western region. It is considered an important area for biodiversity. A project to establish a natural park was initiated in 2006, yet today, this forest faces various threats related to human activities, particularly large-scale wildfires (Djema & Messaoudene, 2009). In the Boumezrane forest, there have been only a handful of studies conducted in this area, and the available research primarily centers on the inventory of forest birds and their association with forest habitats (Menaa et al., 2016). Habitat heterogeneity theory suggests that environments with diverse structures and resources can sustain more varied biological communities and greater species coexistence (Staudacher et al., 2018); Hence, this study investigates how variations in tree species, understory density, and microhabitats influence insect diversity across five distinct forest habitats: cork oak forest, zeen oak forest, a mixed formation of cork and zeen oaks, afares oak forest, and low scrubland. Specifically, it aims to (1) establish an entomofaunal inventory of the Boumezrane Forest and (2) examine the effect of habitat heterogeneity on insect assemblages and its role in shaping biodiversity patterns within forest ecosystems.

MATERIAL AND METHODS

Study area. The study was conducted in the Boumezrane forest (36°24'58.4"N, 8°11'46.2"E), located in northeastern Algeria, about 40 km east of Souk Ahras. It lies within the northeastern region of the Ain Zana municipality, near the border with Tunisia (Fig. 1). The forest spans 7,428.8 hectares and includes species such as cork oak *Quercus suber*, Zean oak *Quercus canariensis*, African oak *Quercus afares*, and *Olea europaea*. The climate of the region is categorized as subhumid, characterized by annual precipitation levels between 600 and 900 mm, and average monthly temperatures that vary from 3°C in January to 33°C in August.

Habitat heterogeneity. Using Google Earth Engine, we calculated the Normalized Difference Vegetation Index (NDVI) from Sentinel data for the period from January 1, 2018, to December 31, 2018, using the formula: NDVI = (NIR - R) / (NIR + R), where NIR represents the near-infrared band and R represents the red band of the satellite imagery. NDVI values range from -1 to +1, with lower values indicating water bodies, barren land, non-vegetated areas, or sparse vegetation, while positive values represent varying levels of vegetation density (Amiri & Pourghasemi, 2022).

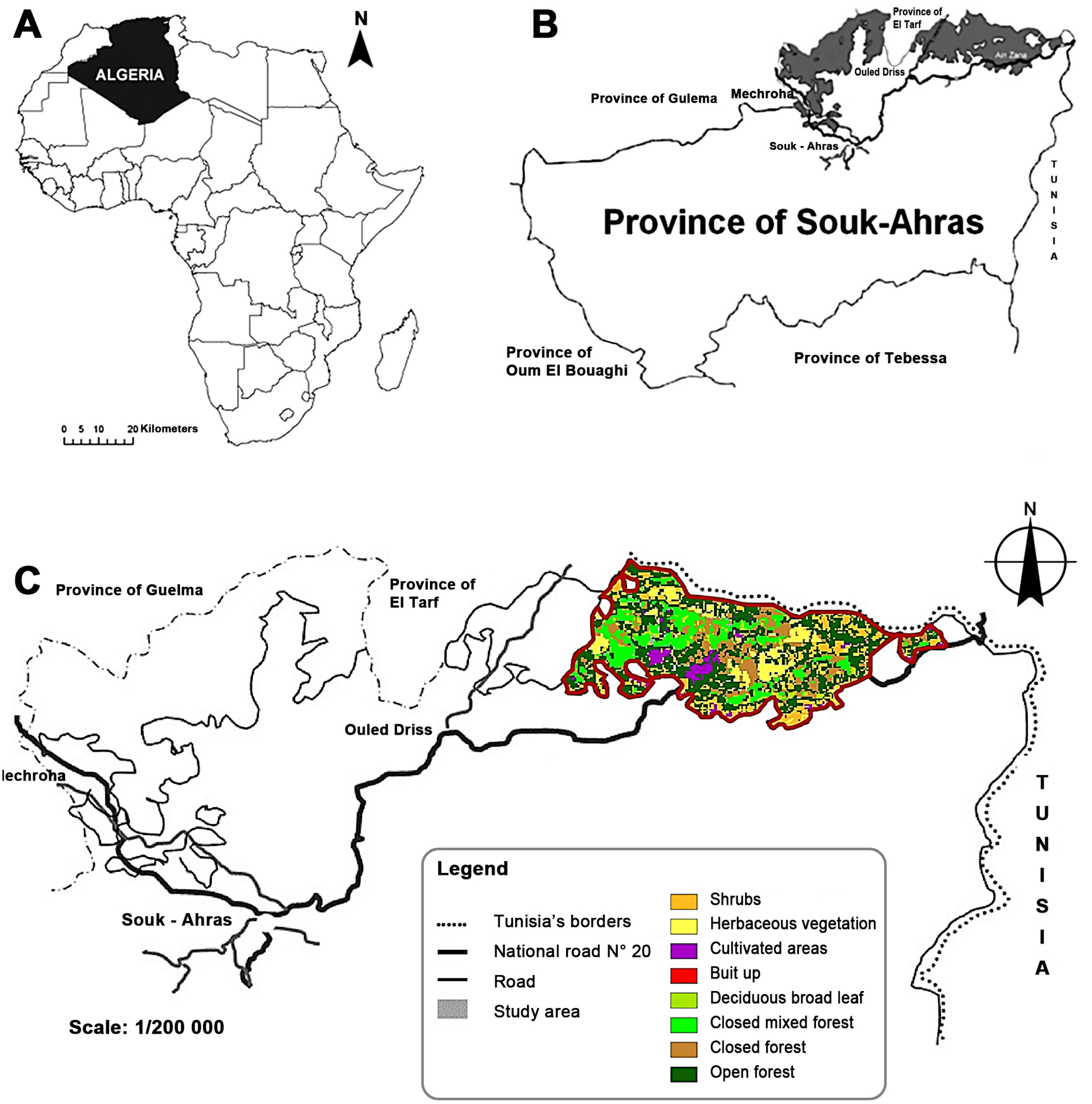

Figure 1. Geographic location of the Boumezrane Forest. **A.** Algeria's location in North Africa; **B.** The position of Boumezrane within Souk Ahras Province; **C.** Land use and land cover characteristics of Boumezrane Forest, obtained from The Copernicus Global Land Service (CGLS) (Buchhorn, 2020).

To assess landscape complexity and heterogeneity, the NDVI values in these plots were summarized using several statistical measures, including the average, standard deviation, and coefficient of variation (Miranda et al., 2017). The average NDVI indicates overall vegetation health and density, helping identify areas of high versus low productivity. The standard deviation measures the variability of NDVI values, reflecting landscape heterogeneity; a high standard deviation suggests diverse habitats, while a low one indicates uniformity. The coefficient of variation (CV), which compares the standard deviation to the mean, standardizes this variability, with a higher CV indicating greater relative diversity (Riera et al., 1998). Moreover, Following Maldonado-Enríquez et al. (2020), the coefficient of variation (CV) was categorized into five distinct categories defined as follows: lower variation (≤ 0.14), low variation (between 0.14 and 0.20, inclusive), moderate variation (between 0.20 and 0.25, inclusive), high variation (between 0.25 and 0.32, inclusive), and higher variation (greater than 0.32). In addition, a supervised classification was performed through the Google Earth Engine (GEE) platform, using the Sentinel-2A satellite imagery with a cloud cover threshold of 20%. Training data for land cover classification were prepared based on four classes, namely (barsoil, built-up, *Quercus suber*, *Quercus canariensis*, and mixed *Quercus* formation). Subsequently, a supervised classification model was developed using the Classification and Regression Trees (CART) algorithm, where the training dataset was randomly split into two subsets: 80% for training the model and 20% for testing its performance. Finally, the classifier was applied to the full Sentinel-2A image to produce a classified land cover map.

Invertebrate sampling. We applied the sampling technique described by Leather (2005) and Seidling et al. (2014). For each habitat station, a 3-hectare area was delineated. Within each station, four subplots measuring 50×50 m were systematically selected and spaced at least 10 meters apart to minimize microclimatic variation. Sampling was conducted monthly over one year, thus covering all four seasons and allowing for temporal replication. To characterize the vegetation structure within each station, we also established one vegetation transect measuring 10 m × 50 m. Five study stations were chosen: station 1 (Cork oak forest), station 2 (Zeen Oak Forest), station 3 (Mixed formation of Cork and Zeen Oaks), station 4 (Afares Oak forest), and station 5 (Low scrubland). For collecting arthropods in forests, fields, and ponds, we used minimal and standard entomological equipment, including Barber pots, butterfly nets, sweep nets, and Japanese umbrellas.

The adopted sampling techniques considered the physiognomy of the environment, including the number of strata and vegetation density (Lamotte & Bourlière, 1969). Ground-level sampling involved searching through humus and turning over stones and pieces of wood to detect insects. The Barber pot serves as a tool for studying medium to large arthropods, effectively capturing various walking arthropods and a large number of flying insects that land on the trap's surface (Benkhelil, 1992). Sampling at herbaceous, tree, and shrub strata involved using beating as one of the best methods for collecting living arthropods from the foliage of trees and shrubs. Japanese umbrellas served as beating trays, consisting of a light-colored 120 × 120 cm canvas on a folding wooden frame, held beneath tree branches and shrubs while the vegetation was shaken to dislodge insects (Aissat, 2023). This method required holding a square white umbrella (40 cm per side) at head height under the branches while shaking (10 shakes) the branches with a stick. The sweep net was used to capture beetles, dragonflies, grasshoppers, and insects exposed on vegetation, with quick and forceful movements to startle insects into the net (Benkhelil, 1992).

For capturing insects in flight or resting on the ground, such as Lepidoptera, Odonata, and Diptera, a butterfly net was employed, effective only in flat or slightly sloped open areas, typically not in dense forests (Barbault, 1981). Collected insect specimens were preserved in a 9% formaldehyde solution and stored in glass vials. Morphological examinations were carried out using a Leica® DM750 stereo microscope, and identification was performed using order-specific taxonomic keys: Hymenoptera (Bernard, 1968), Orthoptera (Chopard, 1943; Louveaux & Ben Halima, 1987; Sardet et al., 2015), Coleoptera (Perrier & Delphy, 1932), Odonata (D'Aguilar et al., 1986), Lepidoptera (Tolman & Lewington, 2014), and (Leraut, 2022). Identifications were cross-checked against specimens in established entomological collections deposited in the National Higher School of Agronomy, Algiers. The frequency of occurrence (FO%) was calculated using the formula: FO(%) = (Pi / N) × 100, where Pi is the number of samples in which a given taxon was recorded, and N is the total number of samples. Based on their constancy values, taxa were then classified into four categories: "Very accidental" (0–10%), "Accidental" (11–25%), "Common" (26–50%), and "Constant" (above 50%), reflecting their relative frequency of occurrence across habitat (Chenchouni et al., 2015).

Statistical analysis. In order to explore common and exclusive taxa among habitats, a Venn diagram was created using the R package 'ggvenn' (Yan, 2023). Two non-metric multidimensional scaling (NMDS) based on a Jaccard dissimilarity index were performed on a presence-absence dataset using the R package 'vegan' (Oksanen et al., 2007), to investigate entomofauna assemblages according to forest habitat and strata. Subsequently, the Jaccard distance matrix was calculated using the vegdist function from the vegan package (Oksanen et al., 2007), and plotted as a heatmap using the R package 'pheatmap'. All statistical analyses were performed using R 4.2.2 software (R Development Core Team, 2023).

RESULTS

Land cover and Habitat heterogeneity. Classification results showed that the Boumezrane landscape was primarily composed of bare soil, covering 51.11% of the area (11.61 km²), followed by *Quercus suber* forests, which occupy 30.10% (6.84 km²). *Quercus canariensis* covers 10.23% of the area (2.32 km²), while mixed *Quercus* species account for 6.74% (1.53 km²), thus including *Quercus suber* and *Quercus canariensis*. However, *Quercus afares* was excluded from the classification due to its close association with *Quercus suber* and *Quercus canariensis*, which have similar spectral signatures and overlapping habitat preferences, complicating its differentiation in mixed forest environments. Built-up areas represent only 1.82% (0.41 km²). Overall, the Boumezrane landscape is dominated by open land and cork oak forests, with a sparse presence of other oak species and minimal urbanization (Fig. 2).

The NDVI values ranged from -0.0965 to 0.7050, indicating a diverse spectrum of vegetation health and cover across the landscape. Most values were concentrated between 0.4056 and 0.5577, with a median of 0.49, reflecting moderate to healthy vegetation density (Fig. 3A). Lower NDVI values nearing zero may signify sparse vegetation or bare soil, whereas higher values indicate denser, more vigorous vegetation. Standard Deviation shows variability in vegetation vigor, where higher values suggest greater spatial heterogeneity in plant health/distribution. The standard deviation of NDVI values ranges from 0.0163 to 0.2777, with most values falling between 0.1018 and 0.1397 (Fig. 3B). The classification of the NDVI's coefficient of variation reveals a spectrum of variability across the studied areas (Fig. 3C). The area of 27.30 km² represents the greatest level of variability, followed by 24.76 km², which indicates high variation. An area of 29.22 km² displays moderate variability, while 23.34 km² suggests consistent conditions. Finally, the area showing lower variation was about 1.94 km² (Fig. 3D).

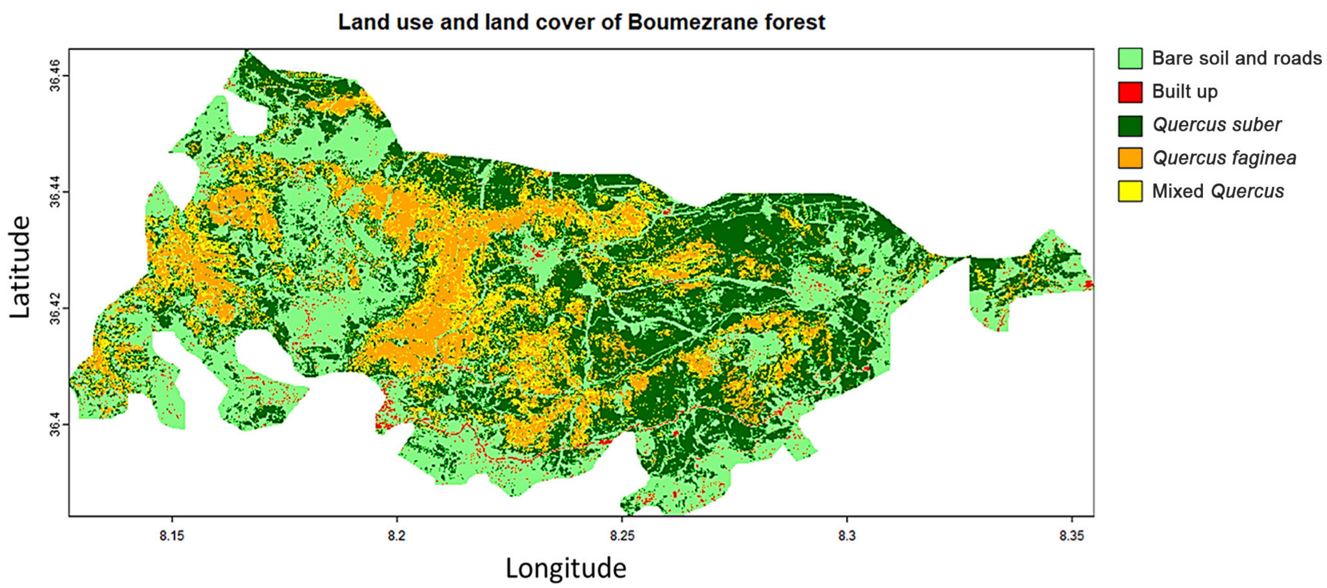

Figure 2. Land use and land cover map of Boumezrane forest.

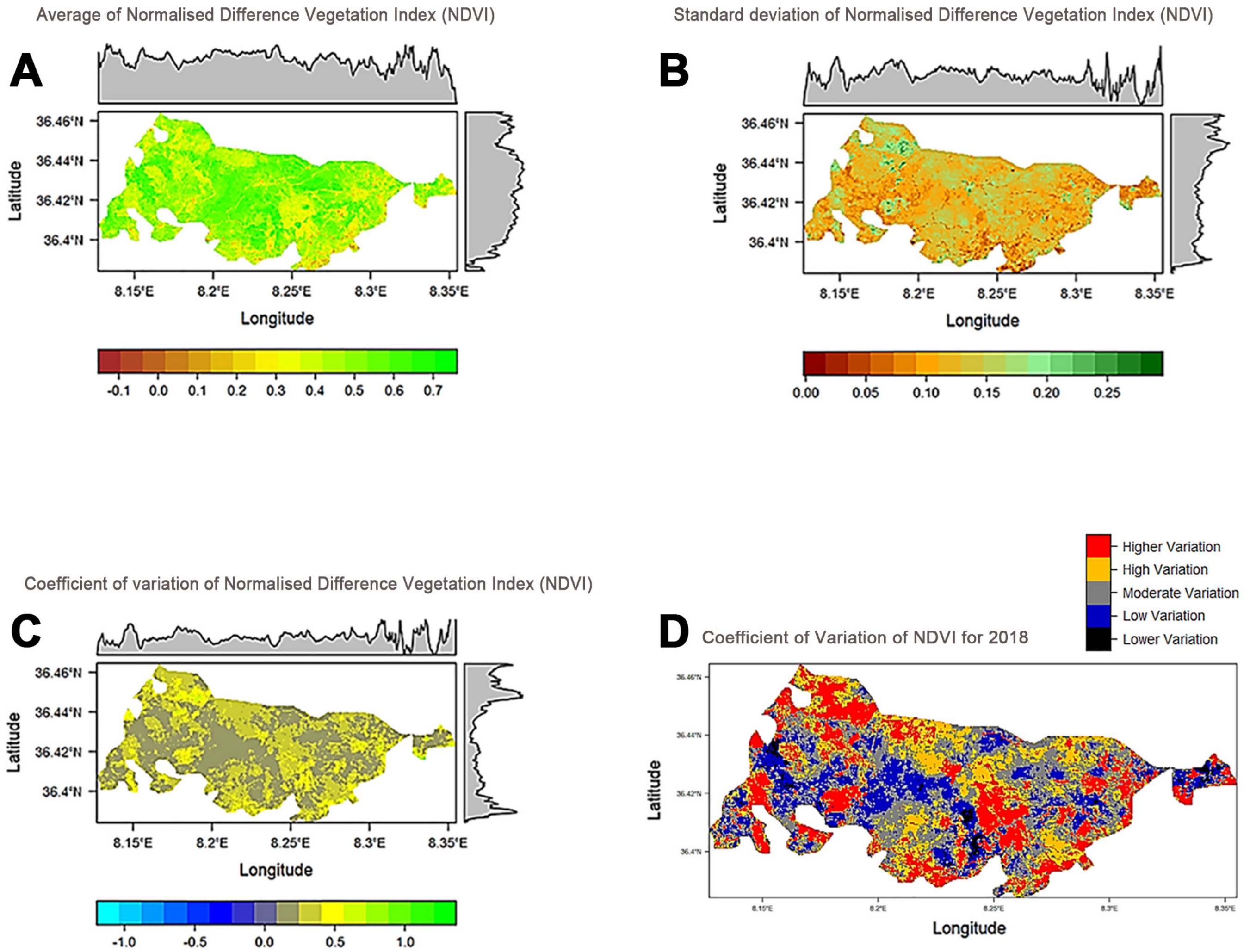

Figure 3. Habitat heterogeneity and complexity in Boumezrane Forest, Algeria. **A.** Mean NDVI; **B.** NDVI standard deviation; **C.** NDVI coefficient of variation; **D.** NDVI coefficient of variation categories.

Arthropoda diversity and assemblages. A total of 116 arthropod taxa associated to different oak formations in the Boumezrane forest were identified. These taxa are categorized into 44 families across 9 orders, with beetles being the most represented, accounting for 36 species (31% of the total insect diversity), followed by Orthoptera with 23 species. Most Coleoptera species belonged to the family Scarabaeidae (8 species), followed by Chrysomelidae and Tenebrionidae (4 species each), while in Orthoptera, the Acrididae family was the most represented, with 15 species (Table 1).

In terms of frequency of occurrence, 80 taxa (approximately 68.97%) were classified as accidental, 21 taxa (18.10%) were classified as common, and 15 taxa (approximately 12.93%) were classified as constant. The most predominant orders in terms of taxon number were Coleoptera (31%) with 36 species, Orthoptera (19.8%) with 23 species, and Odonata (14.7%) with 17 species. In contrast, Blattodea, Dermaptera, and Hemiptera were represented by 4 species and 2 species, respectively (Fig. 4). The low scrubland station exhibited the highest species count at 41, followed closely by the mixed forest (cork and zean oak formation) with 40 species. The Afares oak forest also demonstrated significant diversity, hosting 33 species. In comparison, the cork oak forest had 32 species, while the zean oak forest recorded the lowest diversity with 30 species. In terms of strata, the herbaceous layer accumulated the highest number of species, totaling 67 taxa (36.02%), followed by the soil layer with 63 species (33.87%). The tree layer supported 35 species (18.82%), while the aquatic habitat had the fewest richness, with 21 species (11.29%).

Table 1. Arthropods collected in the study area with the number of individuals (Nb Indi.) and frequency of occurrence (FO%) by species, classified by family and order. CO – Cork oak, ZO – Zean oak, MOF – Mixed Oak Forest, AO – Afares oak, and LS – Low scrubland. FO% levels: (VA) Very accidental, (Acc) Accidental, (C) Common, (CN) Constant.

Order	Family	Taxa	CO		ZO		MOF		AO		LS		Code
			Nb Ind.	FO %	Nb Ind.	FO%	Nb Ind.	FO%	Nb Ind.	FO%	Nb Ind.	FO%	
Blattodea	Blattellidae	*Ectobius kervillei* (Bolivar, 1907)	5	10 VA	14	12	17	15 Acc	-	-	-	-	Ec ke
		Ectobius sp.	3	3.7 VA	8	5.8 VA	4	6.5 VA	-	-	-	-	Ec sp
		Loboptera angulata (Chopard, 1943)	-	-	47	40.70 C	48	40.74 C	-	-	-	-	Lo an
		Loboptera decipiens (Germar, 1817)	6	3.7 VA	8	5.8 VA	5	7.41 VA	2	3.7 VA	3	6.5 VA	Lo de
Coleoptera	Aphodiidae	*Aphodius* sp. 1	-	-	-	-	-	-	38	42.11 C	63	51.85 CN	Ap sp1
		Aphodius sp. 2	-	-	-	-	-	-	36	31.58 C	42	37.04 C	Ap sp2
	Buprestidae	*Chalcophora mariana* (Linnaeus, 1758)	-	-	6	11.11Acc	-	-	-	-	-	-	Ch ma
		Capnodis tenebrionis (Linnaeus, 1761)	43	59.26 CN	-	-	-	-	9	15.79 Acc	-	-	Ca te
	Carabidae	*Cicindela campestris* (Linnaeus, 1758)	-	-	-	-	-	-	-	-	7	7.41 VA	Ci ca
		Licinus silphoides (P. Rossi, 1790)	-	-	-	-	46	55.55 CN	-	-	-	-	Li si
	Cerambycidae	*Cerambyx cerdo* (Linnaeus, 1758)	-	-	9	29.63 C	-	-	-	-	-	-	Ce ce
		Phoracantha semipunctata (Fabricius, 1775)	-	-	3	3.7 VA	-	-	-	-	-	-	Ph se
		Stenopterus ater (Linnaeus, 1767)	-	-	-	-	4	3.7 VA	-	-	-	-	St at
	Chrysomelidae	*Galeruca* sp.	-	-	-	-	-	-	-	-	26	29.63 C	Ga sp
		Hispa sp.	-	-	-	-	3	3.7 VA	-	-	-	-	Hi sp
		Labidostomis hybrida (Lucas, 1845)	-	-	-	-	-	-	-	-	14	11.11 Acc	La hy
		Labidostomis taxicornis (Fabricius, 1792)	-	-	-	-	-	-	-	-	23	18.52 Acc	La ta
	Coccinellidae	*Coccinella septempunctata* (Linnaeus, 1758)	-	-	-	-	-	-		10.53 VA	-	-	Co se
	Curculionidae	*Brachycerus* sp.	-	-	-	-	-	-		-	16	11.11 Acc	Br sp
		Sitona sp.	3	3.7 VA	-	-	-	-		-	-	-	Si sp
	Dytiscidae	*Cybister* sp.	-	-	7	3.7 VA	-	-		-	-	-	Cy sp
	Elateridae	*Adelocera punctata* (Herbst, 1779)	-	-	-	-	7	3.7 VA		-	-	-	Ad pu
	Geotrupidae	*Geotrupes* sp.	26	37.03 C	-	-	-	-		-	43	29.63 C	Ge sp
	Hydrophilidae	*Hydrophilus piceus* (Linnaeus, 1758)	-	-	4	3.7 VA	-	-		-	-	-	Hy pi
	Lucanidae	*Dorcus* sp.	-	-	-	-	8	7.41 VA		-	-	-	Do sp
	Meloidae	*Meloe cavensis* (Petagna, 1819)	-	-	-	-	-	-	-	-	8	11.11 Acc	Me ca
	Scarabaeidae	*Aethiessa floralis* (Fabricius, 1787)	-	-	-	-	-	-	-	-	43	40.74 C	Ae fl
		Bubas bison (Linnaeus, 1767)	-	-	-	-	-	-	54	57.89 CN	-	-	Bu bi
		Copris hispanus (Linnaeus, 1764)	-	-	-	-	15	18.52 Acc	-	-	-	-	Co hi
		Onthophagus andalusicus (Waltl, 1835)	-	-	210	74.04 CN	-	-		-	123	62.96	On an
		Onthophagus sp.	-	-	320	74.07 CN	-	-	-	-	-	-	On sp
		Sisyphus schaefferi (Linnaeus, 1758)	67	25.93Acc	125	48.15 C	56	48.15 C	-	-	-	-	Si sc
		Trichius fasciatus (Linnaeus, 1758)	-	-	-	-	-	-	-	-	3	3.7 VA	Ti fa
		Tropinota squalida (Scopoli, 1763)	-	-	-	-	-	-	-	-	17	18.52 Acc	Tr sq
	Silphidae	*Silpha* sp.	-	-	-	-	-	-	-	-	24	18.52 Acc	Si sp
	Staphylinidae	*Ocypus olens* (O.F. Müller, 1764)	-	-	-	-	-	-	-	-	6	7.41VA	Oc ol
		Scaurus striatus (Fabricius, 1792)	-	-	-	-	-	-	-	-	16	33.33 C	Sc st
	Tenebrionidae	*Omophlus* sp.	-	-	-	-	-	-	-	-	8	11.11 Acc	Om sp
		Pachychila sp.	-	-	-	-	-	-	-	-	36	25.93 Acc	Pa sp
		Stenosis sp.	-	-	-	-	-	-	-	-	41	25.93 Acc	St sp
Dermaptera	Labiduridae	*Anisolabis mauritanica* (Lucas, 1849)	4	11.11Acc	11	7.41 VA	11	7.41 VA	16	7.41 VA		-	An ma
	Forficulidae	*Forficula auricularia* (Linnaeus, 1758)	14	29.63 C	25	18.52 Acc	32	22.22 Acc	28	15.79 Acc		-	Fo au
Diptera	Asilidae	*Asilus* sp. 1	5	7.41 VA	-	-	-	-	-	-		-	As sp1
		Asilus sp. 2	-	-	-	-	-	-	-	-	32	22.22 Acc	As sp2
	Bombyliidae	*Bombylius* sp.	-	-	-	-	12	14.81 Acc	-	-		-	Bo sp
	Calliphoridae	*Lucilia* sp.	-	-	-	-	-	-	-	-	38	22.22 Acc	Lu sp
	Syrphidae	*Eristalis tenax* (Linnaeus, 1758)	-	-	-	-	-	-	-	-	41	29.63 C	Er te
		Syrphus sp.	12	14.81 Acc	-	-	-	-	-	-	-	-	Sy sp
Hemiptera	Lygaeidae	*Lygaeus equestris* (Linnaeus, 1758)	-	-	-	-	13	44.44 C	-	-	-	-	Ly eq
		Lygaeus militaris (Fabricius, 1775)	-	-	-	-	26	48.15 C	-	-	-	-	Ly mi
		Lygaeus punctatoguttatus (Fabricius, 1781)	-	-	-	-	-	-	16	21.05 Acc	-	-	Ly pu
	Pyrrhocoridae	*Pyrrhocoris apterus* (Linnaeus, 1758)	-	-	-	-	-	-	36	31.58 C	-	-	Py ap
Hymenoptera	Apidae	*Apis mellifera* (Linnaeus, 1758)	-	-	-	-	-	-	-	-	15	22.22 Acc	Ap me
		Bombus terrestris (Linnaeus, 1758)	-	-	-	-	-	-	-	-	78	37.04 C	Bo te
	Formicidae	*Aphaenogaster testaceopilosa* (Lucas, 1849)	123	62.93 CN	88	51.85 CN	-	-	52	26.32 C	-	-	Ap te
		Camponotus sp.	-	-	34	29.63 C	-	-	46	42.11 C	-	-	Cam sp
		Cataglyphis bicolor (Fabricius, 1793)	-	-	620	51.85 CN	-	-	540	47.37 C	-	-	Ca bi
		Cataglyphis sp.	-	-	420	48.15 C	-	-	635	63.16 CN	-	-	Cat sp
		Crematogaster scutellaris (Olivier, 1792)	152	51.85 CN	-	-	-	-	-	-	-	-	Cr sc
		Messor barbarus (Linnaeus, 1767)	-	-	-	-	-	-	-	-	410	44.44 C	Me ba
		Messor sp.	-	-	-	-	-	-	-	-	265	37.04 C	Me sp
		Pheidole pallidula (Nylander, 1849)	-	-	-	-	-	-	-	31.58 C	-	-	Ph pa
		Tetramorium sp.	-	-	110	25.93 Acc		-	-	-	-	-	Te sp
	Scoliidae	*Scolia* sp.	-	-	-	-		-	-	-	78	37.03 C	Sc sp
	Vespidae	*Vespula germanica* (Fabricius, 1793)	-	-	-	-		-	-	-	98	48.15 C	Ve ge

Order	Family	Taxa	CO Nb Ind.	CO FO %	ZO Nb Ind.	ZO FO%	MOF Nb Ind.	MOF FO%	AO Nb Ind.	AO FO%	LS Nb Ind.	LS FO%	Code
Lepidoptera	Erebidae	*Lymantria dispar* (Linnaeus, 1758)		10.15 VA		5.8 VA		8.6 VA	-	-	-	-	Ly di
	Noctuidae	*Autographa gamma* (Linnaeus, 1758)	-	-	-	-		-	-	-	75	33.33 C	Au ga
	Nymphalidae	*Coenonympha arcania* (Linnaeus, 1761)	-	-	-	-	14	18.51 Acc	-	-	-	-	Co ar
		Lasiommata megera (Linnaeus, 1767)	-	-	-	-	23	33.33 C	-	-	-	-	La me
		Maniola jurtina (Linnaeus, 1758)	-	-	-	-	15	33.33 C	-	-	-	-	Ma ju
		Vanessa cardui (Linnaeus, 1758)		26.32 C		11.11 Acc		15.1 Acc	-	-	-	-	Va ca
	Pieridae	*Aporia crataegi* (Linnaeus, 1758)	-	-	-	-	-	-	-	-	156	44.44 C	Ap cr
		Colias croceus (Geoffroy, 1785)	11	18.52 Acc	-	-	-	-	-	-	-	-	Co cr
		Gonepteryx cleopatra (Linnaeus, 1767)	14	18.52 Acc	-	-	-	-	-	-	54	22.22 Acc	Ge cl
		Pieris brassicae (Linnaeus, 1758)	-	-	-	-	-	-	15	26.32 C	-	-	Pi br
		Pieris rapae (Linnaeus, 1758)	-	-	-	-	-	-	57	42.11 C	-	-	Pi ra
Odonata	Aeshnidae	*Anax imperator* (Leach, 1815)	-	-	4	11.11 Acc	-	-	-	-	-	-	An im
		Anax parthenope (Selys, 1839)	6	10.15 VA	12	15.1 Acc	-	-	-	-	-	-	An pa
		Aeshna mixta (Latreille, 1805)	16	25.93	-	-	-	-	-	-	-	-	Ae mi
	Calopterygidae	*Calopteryx haemorrhoidalis* (Vander Linden, 1825)	12	10.53 VA	16	14.81 Acc	6	5.8 VA	-	-	-	-	Ca ha
	Coenagrionidae	*Ceriagrion tenellum* (de Villers, 1789)	13	14.81Acc	13	12 Acc	8	11.11 Acc	-	-	-	-	Ce te
		Ischnura graellsii (Rambur, 1842)	8	11.11Acc	10	8.6 VA	-	-	-	-	8	13.1 Acc	Is gr
	Libellulidae	*Crocothemis erythraea* (Brullé, 1832)		-		-	4	8.6 VA	-	-		-	Cr er
		Diplacodes lefebvrii (Rambur, 1842)		-		-	19	25.12 Acc	-	-		-	Di le
		Orthetrum cancellatum (Linnaeus, 1758)		-		-	22	25.93 Acc	-	-		-	Or ca
		Orthetrum chrysostigma (Burmeister, 1839)		-		-	28	29.63 C	-	-		-	Or ch
		Orthetrum coerulescens (Fabricius, 1798)		-		-	12	15.14 Acc	-	-		-	Or co
		Sympetrum fonscolombii (Selys, 1840)	-	-	7	6.5 VA	-	-	-	-	-	-	Sy fo
		Sympetrum sanguineum (Müller, 1764)	-	-	-	-	6	11.11 Acc	-	-	-	-	Sy sa
		Sympetrum striolatum (Charpentier, 1840)	-	-	-	-	4	5.8 VA	-	-	-	-	Sy st
		Trithemis annulata (Palisot de Beauvois, 1807)	-	-	-	-	18	14.1 Acc	-	-	-	-	Tr an
	Lestidae	*Lestes virens* (Charpentier, 1825)	-	-	-	-	9	12.2 Acc	-	-	-	-	Le vi
		Sympecma fusca (Vander Linden, 1820)	-	-	-	-	21	14.81 Acc	-	-	-	-	Sy fu
Orthoptera	Acrididae	*Acrotylus insubricus* (Scopoli, 1786)	-	-	-	-	45	14.81 Acc	-	-	-	-	Ac in
		Acrotylus patruelis (Herrich-Schäffer, 1838)		-	-	-	78	29.63 C	36	15.79 Acc	-	-	Ac pa
		Calliptamus barbarus (Costa, 1836)	88	48.15 C	-	-	-	-	42	26.32 C	-	-	Ca ba
		Calliptamus wattenwylianus (Pantel, 1896)		-	-	-	-	-	26	15.79 Acc	-	-	Ca wa
		Dociostaurus jagoi occidentalis (Soltani, 1978)	123	55.56 CN	-	40.74 C	136	44.44C	210	52.63 CN	15	18.52 Acc	Do ja
		Dociostaurus maroccanus (Thunberg, 1815)	-	-	-	-	-	-	122	63.16 CN	-	-	Do ma
		Locusta migratoria cinerascens (Fabricius, 1781)	3	3.7 VA	-	-	-	-	-	-	4	3.7 VA	Lo mi
		Ochrilidia tibialis (Fieber, 1853)	-	-	-	33.33 C	-	-	-	-	-	-	Oc ti
		Oedipoda caerulescens (Linnaeus, 1758)	152	51.85 CN	-	33.33 C	46	37.04 C	231	36.84 C	165	48.15 C	Oe ca
		Oedipoda fuscocincta (Lucas, 1847)	-	-	-	-	-	-	17	5.7 VA	36	25.93 Acc	Oe fu
		Oedipoda miniata (Pallas, 1771)	-	-	-	-	-	-	27	15.79 Acc	7	3.7 VA	Oe mi
		Omocestus raymondi (Yersin, 1863)	-	-	-	-	-	-	3	5.26VA	-	-	Om ra
		Omocestus rufipes (Zetterstedt, 1821)	158	59.26 CN	-	-	-	-	23	15.79 Acc	14	14.81 Acc	Om ru
		Pezotettix giornae (Rossi, 1794)	-	-	-	-	41	33.33 C	51	42.11 C	-	-	Pe gi
		Thalpomena algeriana (Lucas, 1847)	63	37.03 C	-	-	-	-		-	34	22.22 Acc	Th al
	Baissogryllidae	*Aiolopus strepens* (Latreille, 1804)	-	-	-	-	-	-	42	26.32 C	124	40.74 C	Ai st
	Gryllidae	*Gryllus bimaculatus* (De Geer, 1773)	-	-	-	-	18	25.93 Acc		-	-	-	Gr bi
		Gryllus sp.	14	18.52 Acc	-	-	-	-	14	26.32 C	-	-	Gr sp
		Modicogryllus algirius (Saussure, 1877)	11	18.52 Acc	-	-	-	-	41	42.11 C	-	-	Mo al
	Tettigoniidae	*Odontura algerica* (Brunner von Wattenwyl, 1878)	6	3.7 VA	-	-	-	-	-	-	-	-	Od al
		Odontura microptera (Chopard, 1943)	-	-	-	-	-	-	19	10.53 VA	-	-	Od mi
		Phaneroptera nana (Fieber, 1853)	16	14.81 Acc	-	-	-	-	-	-	-	-	Ph na
	Pamphaginae	*Pamphagus elephas* (Linnaeus, 1758)	-	-	-	-	14	7.41 VA	21	10.53 VA	-	-	Pa el
Total			**1177**		**2131**		**894**		**1830**		**2309**		

Arthropoda assemblages across habitat. The Venn diagram (Fig. 5) shows the distribution of arthropod taxa across the five sampled habitats: Cork oak forest, Zean oak, Mixed oak, Afares oak, and Low scrub. Unique taxa are most prominent in Low scrub, which harbors 26 species (23%), followed closely by Mixed CO.ZO with 24 species (22%). Cork oak forest and Afares oak forest show fewer unique species, with eight (7.2%) and nine (8.1 %), respectively. While Loboptera decipiens (0.9%) was the sole taxon found in all habitats, pairwise comparisons revealed limited overlap: Afares oak and low scrub shared five taxa (4.5%), and Cork oak and Afares oak shared four taxa (3.6%).

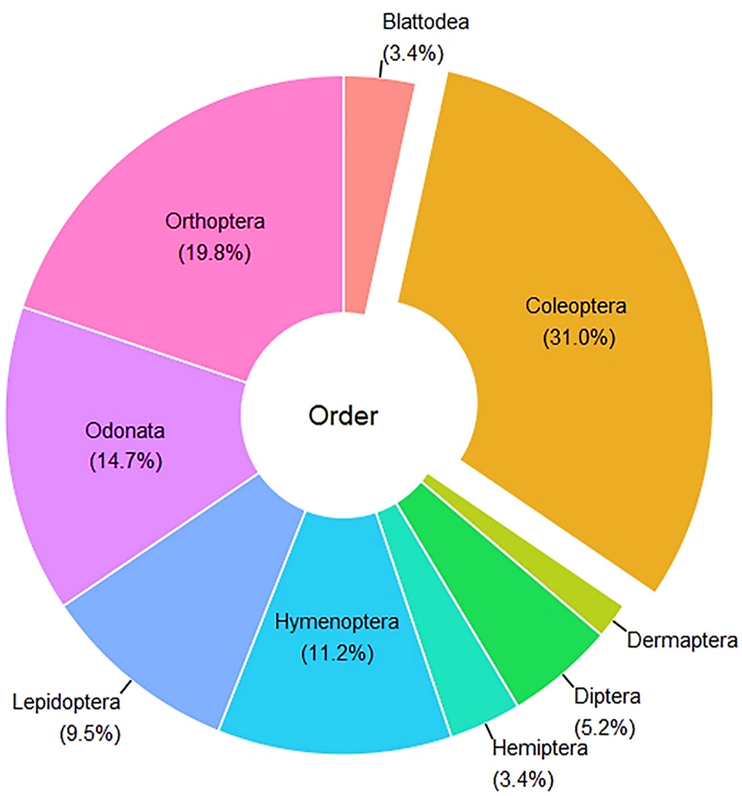

Figure 4. Pie chart showing the systematic distribution of arthropods inventoried in the Boumezrane forest massif, classified by Order.

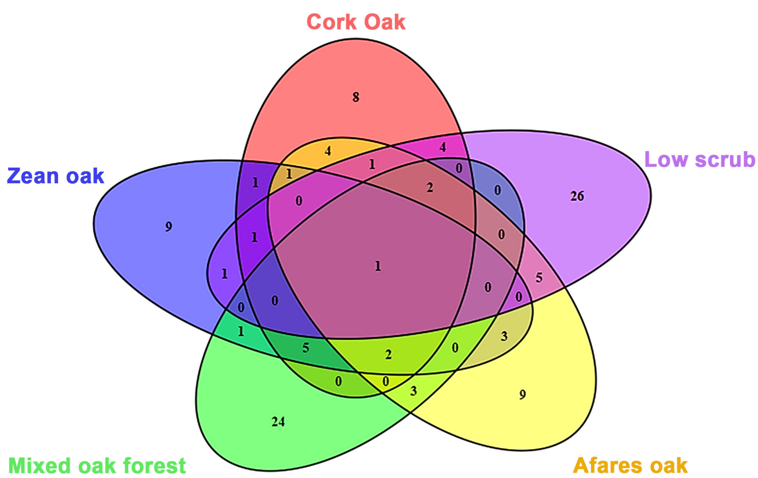

Figure 5. Venn diagram showing unique and shared taxa across the five habitat types.

Ecological metrics (Fig. 6) indicate varying biodiversity levels across the stations, with the total data showing significant overall diversity (Shannon index = 3.67), high species richness (111), and a balanced species distribution (Pielou's evenness = 0.54; Simpson index = 0.89). Among the individual stations, Low scrubland habitat exhibits the highest diversity (Shannon index = 2.59) and species richness (41), coupled with high evenness (0.48) and Simpson index (0.80), highlighting it as a biodiversity hotspot. In contrast, Cork oak habitat shows the lowest diversity (Shannon index = 1.41) and evenness (0.29), despite a moderate richness (30). Zean Oak and Mixed Oak forests also demonstrate notable diversity, with the Mixed Oak forest having the highest richness (38).

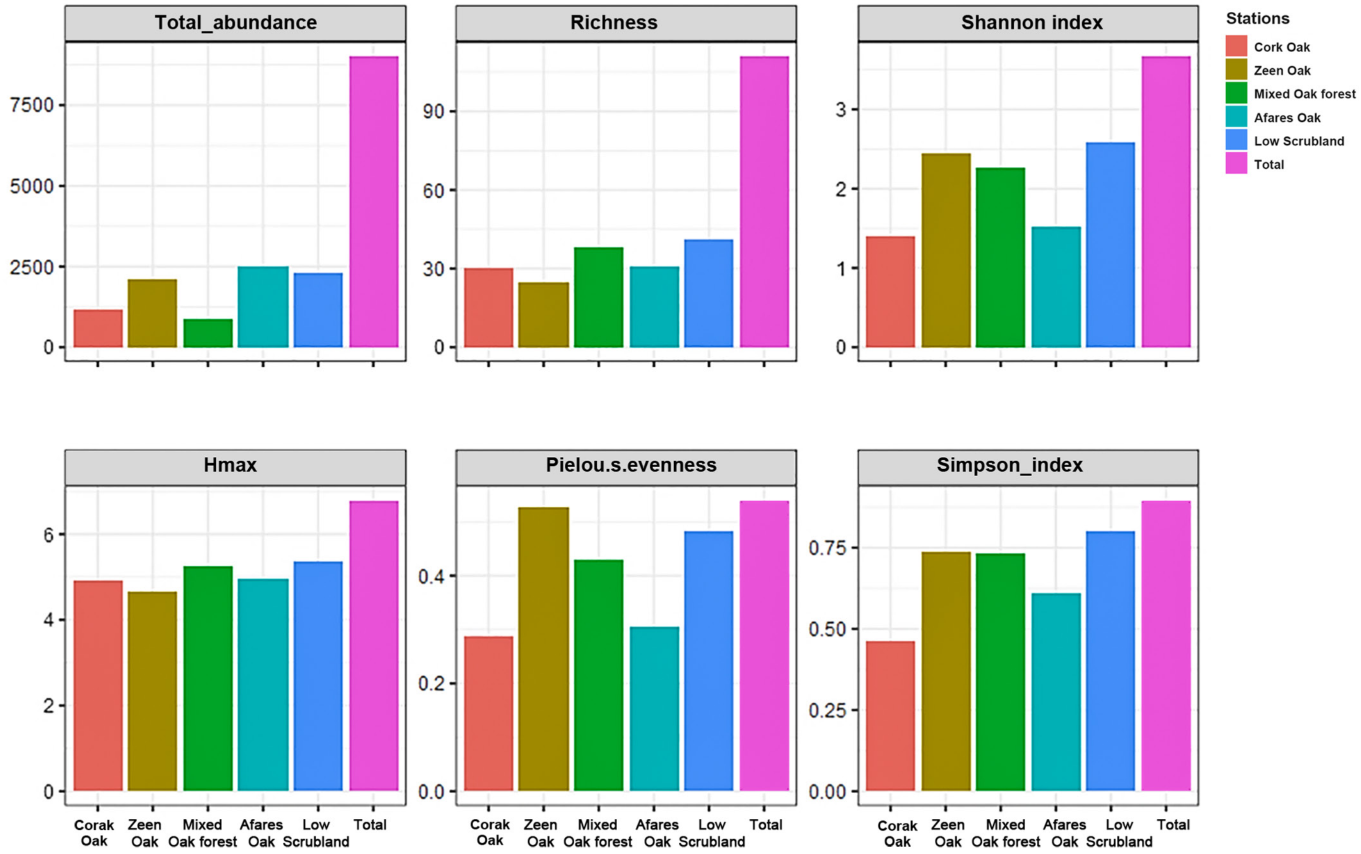

Figure 6. Ecological diversity patterns across habitats, showing variation in total abundance, species richness, and diversity indices (*Shannon, Simpson, Hmax, and Pielou's evenness*) across different habitat types (Cork Oak, Zeen Oak, Mixed Oak forest, Afares Oak, Low scrubland, and overall total).

The NMDS ordination (Fig. 7A) reveals clear distinctions in taxa associations among habitats. The Afares oak forest was strongly associated with species such as *Pieris rapae*, *Omocestus raymondi*, *Calliptamus wattenwylianus*, *Bubas bison*, *Lygaeus punctatoguttatus*, and *Pheidole pallidula*. The Zean oak habitat exhibited a species assemblage similar to that of Afares oak but included distinctive taxa such as *Phoracantha semipunctata*, *Anax imperator*, *Cerambyx cerdo*, *Hydrophilus piceus*, and Tetramorium sp. Cork Oak forests were characterized by species like *Odontura algerica*, *Colias croceus*, *Phaneroptera nana*, and Sitona sp., reflecting their intermediate ecological conditions. In contrast, low scrub habitats were distinguished by unique taxa such as *Labidostomis hybrida*, *Apis mellifera*, *Labidostomis taxicornis*, *Meloe cavensis*, *Aporia crataegi*, and Brachycerus sp., thus forming a well-separated cluster in the ordination. Similarly, mixed Cork Oak/Zean Oak forests hosted characteristic species including *Sympetrum sanguineum*, *Lestes virens*, *Licinus silphoides*, *Maniola jurtina*, and Hispa sp., further emphasizing habitat-specific community composition.

The Jaccard index heatmap (Fig. 7B) revealed that forest types (Mixed Oak, Cork oak, Zeen Oak, Afares Oak) are relatively similar to each other with moderate Jaccard distances (0.6–0.77), while Low scrubland was distinctly different from all forest types with high dissimilarity values (0.75-0.92). Notably, the Mixed Oak and Afares Oak forest pair showed the highest dissimilarity (Jaccard = 0.77) among forested habitats, indicating pronounced ecological divergence despite their structural similarities. The NMDS plot (Fig. 8A) illustrates distinct groupings of taxa based on habitat types. The herbaceous strata were characterized by taxa such as *Vespula germanica*, *Scolia* sp., *Vanessa cardui*, *Omophlus* sp., *Eristalis tenax*, *Lasiommata megera*, and *Labidostomis hybrida*, while the soil strata were represented by taxa such as *Galeruca* sp., *Bombylius* sp., *Aphodius* sp., *Ectobius kervillei*, *Phaneroptera nana*, and *Cicindela campestris*.

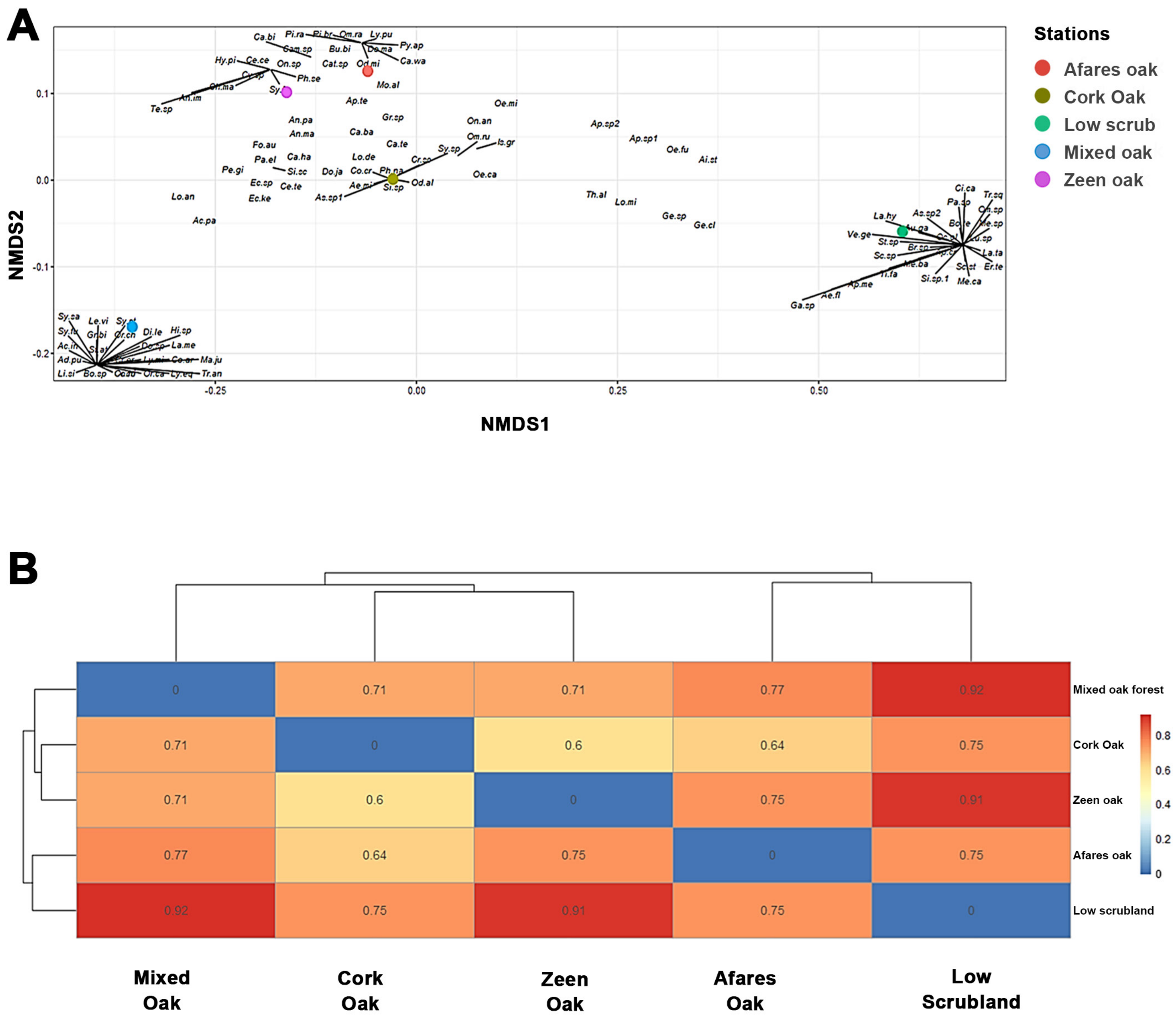

Figure 7. Dissimilarity of oak habitat structure based on the Jaccard index. **A.** Non-metric multi-dimensional scaling (NMDS) illustrating Entomofauna assemblages according to forest habitat; **B.** Clustered heatmap based on the Jaccard index displaying similarity values between forest types.

Despite these habitat-specific taxa, there was an overlap between the herbaceous and soil strata, with shared taxa like *Omophlus* sp., *Modicogryllus algirius*, *Omocestus raymondi*, *Dociostaurus jagoi occidentalis*, *Coccinella septempunctata*, and *Pamphagus elephas*, indicating some degree of ecological similarity and shared assemblages between these two habitats. The arboreal strata were dominated by taxa such as *Dorcus* sp., *Lymantria dispar*, *Adelocera punctata*, *Hydrophilus piceus*, and *Phoracantha semipunctata*, and shared some taxa with the herbaceous strata, including *Aporia crataegi*, *Bombus terrestris*, *Stenopterus ater*, *Apis mellifera*, *Messor* sp., *Camponotus* sp., *Messor barbarus*, and *Colias croceus*, while the aquatic strata were characterized by odonate species. In terms of dissimilarity (Fig. 8B), soil and aquatic strata exhibit the highest dissimilarity (0.95), followed by arboreal and aquatic strata (0.94), suggesting minimal overlap in arthropod communities between these habitats. Conversely, soil and herbaceous strata were most similar (0.76), with arboreal and herbaceous strata showing moderate dissimilarity (0.88). The clustering highlights distinct habitat-specific arthropod assemblages across different ecological strata.

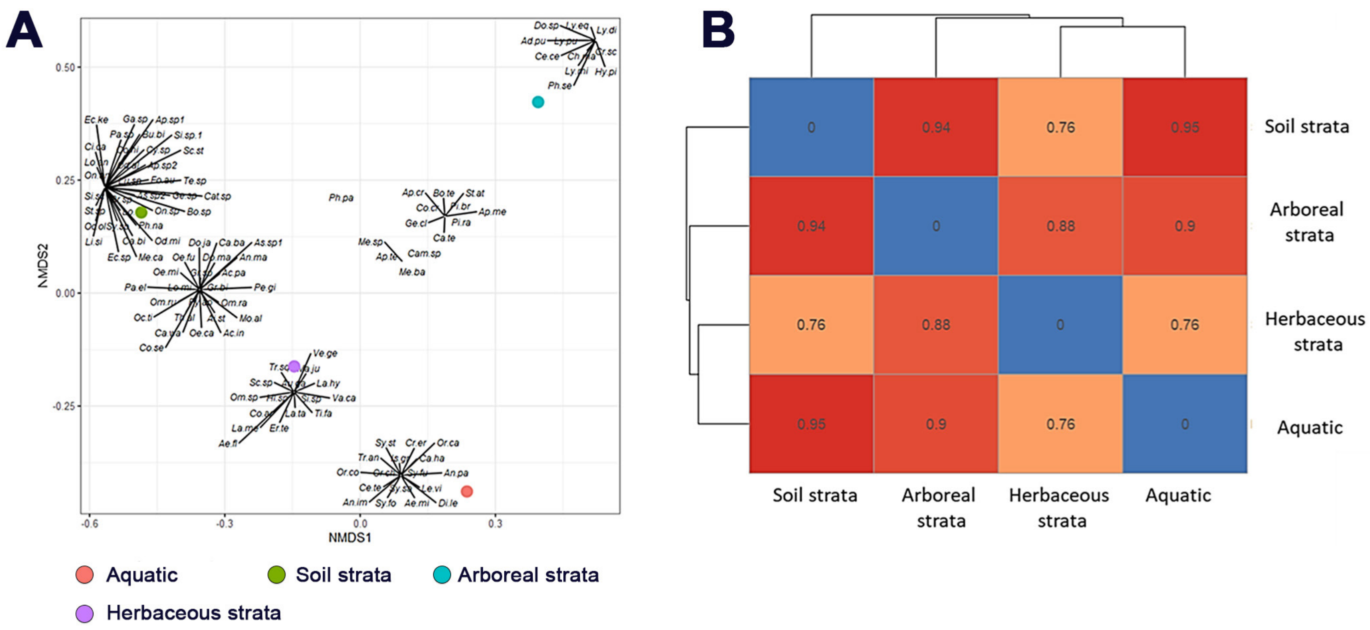

Figure 8. Jaccard dissimilarity of forest habitat structure. **A.** Non-metric multidimensional scaling (NMDS) illustrating Entomofauna assemblages according to vegetation strata; **B.** Clustered heatmap based on Jaccard index showing dissimilarity between vegetation strata.

DISCUSSION

The Boumezrane landscape is characterized by a distinct land cover composition featuring a mosaic of oak species dominated by cork oak (Menaa et al., 2016). These ecosystems are known to support both flora and fauna that thrive in Mediterranean climates, contributing to overall ecological health. *Quercus suber* covers approximately 22,000 km² of its natural area in the western Mediterranean basin, and is known for its unique structure that combines scattered mature trees with dense shrub grasslands and shrub layers (Costa et al., 2014), and its ability for fire resistance, thus promoting a rich habitat for various species (Silva & Catry, 2006; Telailia et al., 2018). Additionally, *Quercus suber* thrives in diverse forest mosaics in the Mediterranean region, often found alongside various other tree species, including different types of oaks and wild olive trees (Menaa et al., 2016). Unfortunately, cork oak forests are increasingly threatened by economic exploitation, dieback, environmental changes (Younsi et al., 2021), as well as the expansion of pine species, particularly Pinus pinaster, causing habitat alteration and heightened competition for resources (Djema & Messaoudene, 2009; Meliani et al., 2021).

In addition, the loss of wild herbivores and traditional livestock farming in Mediterranean drylands has led to more uniform landscapes of *Quercus suber* formation, which can intensify annual wildfire frequency and spread by creating uninterrupted fire fuels (Pausas, 2004). The landscape shows a healthy range of vegetation cover, with most areas exhibiting moderate to dense vegetation. The variation in NDVI values reflects the heterogeneous nature of the landscape, including areas of sparse vegetation and others with more vigorous plant growth. This variation could be influenced by factors such as soil type, water availability, and land use.

The cork oak forest stands out for its high heterogeneity, forming a mosaic of diverse environments that range from areas with dense shrub layers to open maquis, fallows, and grasslands, thereby offering favorable conditions for the establishment of a diverse entomofauna (Ganaoui et al., 2020). Among the taxa collected in the Boumezrane, seven endemics were identified, all of which are integral to the local ecosystems. Notable species include the endemic cockroach, *Ectobius kervillei,* and the grasshopper, *Loboptera angulata*. Additionally, *Aphodius* sp. and *Aethiessa floralis*, both beetles, play important roles in nutrient cycling. The grasshopper, *Dociostaurus maroccanus,* and the cricket, *Thalpomena algeriana,* are adapted to the region's arid conditions, while the bush-cricket, *Odontura algerica* is exclusive to Algeria. Two near-threatened species were also encountered: the Great Capricorn Beetle, *Cerambyx cerdo*, threatened by habitat loss, and the Buff-tailed Bumblebee, *Bombus terrestris*, which faces declines due to pesticide use and habitat destruction. These species highlight both the biodiversity and conservation challenges in Boumezrane, underscoring the need for continued research and protective measures to sustain the region's unique ecological balance.

Comparative analysis of this inventory with prior research by Larid (1989), and Nichane et al. (2013) highlights a recurring trend: species from the Coleoptera order consistently represent a dominant proportion relative to other taxonomic orders. Similar patterns were observed in other regions, where Coleoptera were found to dominate insect communities, suggesting that oak habitats provide a particularly conducive environment for beetle diversity. The structural complexity of oak forests, with their variety of microhabitats (such as leaf litter, bark, and decaying wood), likely supports a wide range of Coleopteran species, contributing to their high diversity. Our survey is consistent with those reported by Ganaoui et al. (2020), which highlighted that Coleopteran assemblages and diversity exhibit significant variability depending on habitat type, especially in oak forests.

In contrast to the findings of Habbaz et al. (2025), who reported Tenebrionidae and Carabidae as the most dominant coleopteran families in the Maamora cork oak forest in Morocco, our study identified Scarabaeidae as the dominant family. Such differences may be attributed to variations in local ecological conditions and the sampling methods employed (Zereg et al., 2025), highlighting the context-dependent and dynamic nature of coleopteran community structure across different environments. Each family of Coleoptera within the study has distinct ecological roles, which contribute to their prevalence in the area. For instance, Carabidae, including species like *Cicindela campestris* and *Licinus silphoides*, are known for their predatory habits, typically feeding on other arthropods. This predation plays a critical role in regulating populations of smaller insects (Lövei & Sunderland, 1996). The presence of these species suggests a healthy and balanced ecosystem, with ample prey species available for these beetles. The presence of Scarabaeidae species, such as *Onthophagus* sp., *Trichius fasciatus*, and *Sisyphus schaefferi*, is noteworthy. These beetles are primarily detritivores, playing a key role in the breakdown of organic matter and recycling nutrients back into the soil (Shah & Shah, 2022). The diversity of families such as Buprestidae, Lucanidae, and Meloidae in the list indicates a varied habitat structure. These families encompass a range of feeding habits, from plant feeding to predation and scavenging. The dominance of coprophagous taxa such as *Geotrupes* sp., *Bubas bison*, *Copris hispanus*, *Onthophagus andalusicus*, *Onthophagus* sp., and *Sisyphus schaefferi* indicates significant grazing activity in the ecosystem (Daas et al., 2016). The presence of lepidopteran species such as *Lasiommata megera*, *Maniola jurtina*, *Vanessa cardui*, and *Colias croceus*, which are particularly sensitive to habitat fragmentation and loss, serves as a valuable indicator of the ecological health of the Boumezrane forest. This implies that the forest sustains a variety of plant species crucial for their life cycles, demonstrating a healthy and balanced ecosystem. Their populations reflect the forest's health, as they depend on habitats and food sources that signify environmental richness and stability.

The ecological metrics analyzed across various stations reveal significant biodiversity variations, emphasizing the need for targeted conservation strategies. Overall, the landscape exhibits a robust biodiversity profile, with a Shannon index of 3.67, indicating 111 species and a balanced distribution (Pielou's evenness = 0.54; Simpson index = 0.89). Low Scrubland stands out as a biodiversity hotspot, showing the highest diversity (Shannon index = 2.59) and species richness (41 species), alongside strong evenness (0.48) and a high Simpson index (0.80). This suggests favorable conditions for diverse species. In contrast, Cork Ork has the lowest biodiversity metrics, with a Shannon index of 1.41 and an evenness score of 0.29, despite moderate richness (30 species). This indicates potential ecological stressors affecting species distribution. Both Zean Oak and Mixed Oak Forest contribute significantly to overall biodiversity, with Mixed Oak Forest registering the highest richness among forests at 38 species. These findings underscore the importance of tailored conservation efforts to enhance biodiversity in less diverse areas while maintaining ecological integrity in hotspots.

The structural complexity of each habitat plays a crucial role in shaping arthropod communities. Oak habitats, particularly those with a well-developed canopy, provide diverse microhabitats that support a variety of species. For instance, the presence of multiple layers (canopy, understory, and forest floor) in oak forests allows for different ecological niches that can accommodate various arthropod guilds (Valencia-Cuevas & Tovar-Sánchez, 2015). Therefore, the lack of such complexity in Cork Oak could indeed lead to lower diversity metrics among arthropod populations. Several studies have demonstrated that habitat type significantly mediates elevational patterns of biodiversity, with different groups of arthropods responding variably to changes in elevation based on their specific habitat requirements (Uhey et al., 2022).

Scrub habitats are often found in transitional areas where woodland is either developing or receding, thus arising in various environmental conditions, including abandoned agricultural fields or areas with poor soil quality. This habitat type is characterized by its ability to recover quickly from disturbances due to the resilience of pioneer species that thrive in open spaces. In addition, variations in microclimatic conditions (e.g., humidity, temperature) within the canopy can influence arthropod distribution (Valencia-Cuevas & Tovar-Sánchez, 2015). While cork oak forests are typically rich in biodiversity, specific environmental stressors, management practices, climate change effects, and human activities can contribute to reduced diversity in certain areas. Cork oaks thrive in Mediterranean climates characterized by hot, dry summers and mild, wet winters. However, extreme conditions such as prolonged drought or poor soil quality can limit the variety of species that can survive in these habitats (Rodríguez-Calcerrada et al., 2017). In regions where these conditions are more pronounced, such as drier areas of Algeria, the diversity of both flora and fauna may be reduced due to stress on the ecosystem (Younsi et al., 2021).

The Boumezrane Forest is a critical biodiversity reservoir, hosting a rich assemblage of arthropod taxa shaped by the heterogeneity of its oak-dominated habitats. Our results show that habitat structure, particularly the interplay of canopy layers, understory density, and microhabitats, plays a pivotal role in determining arthropod diversity and distribution. Low scrubland emerged as a biodiversity hotspot, supporting unique taxa under favorable ecological conditions, whereas cork oak forests, despite their ecological value, showed lower diversity, possibly due to environmental stressors and human pressures. The dominance of Coleoptera reflects the ecological complexity of these habitats and their role as indicators of environmental health. The presence of endemic and near-threatened species, with their restricted ranges and vulnerability to disturbance, highlights the forest's importance as a refuge for species of high conservation value. These findings emphasize the need to conserve habitat heterogeneity, mitigate degradation, and promote ecological resilience to ensure the long-term sustainability and ecological integrity of the Boumezrane Forest.

AUTHOR'S CONTRIBUTION

The authors confirm their contribution to the paper as follows: A. Aouadi: data analysis, drafting the manuscript; L. Boutabia: conceptualization and design of the study, field sampling, data analysis, drafting the manuscript; F. Ayaichia: data analysis, drafting the manuscript; D. Zeghouma: revising the manuscript; M. Menaa: Data curation, formal analyses, drafting the manuscript; M.C. Maazi: revising and editing of the manuscript; B. Bouacha: field sampling; S. Doumandji: assisted in the identification of specimens; S. Telailia: conceptualization and design of the study, field sampling, revising the manuscript. All authors read and approved the final version of the manuscript.

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AVAILABILITY OF DATA AND MATERIAL

The specimens listed in this study are deposited in the Laboratory of Agriculture and Ecosystem Functioning, Chadli Bendjedid University El Tarf and are available from the curator, upon request.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study only included plants and arthropod material, and all required ethical guidelines for the treatment and use of animals were strictly adhered to in accordance with international, national, and institutional regulations. No human participants were involved in any studies conducted by the authors for this article.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this paper.

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ناهمگونی زیستگاه بلوط و تأثیر آن بر تنوع بندپایان و پویایی زیست‌بوم در جنگل بومقران (سوک احراس، الجزایر)

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چکیده: جنگل بومقران در شمال‌شرقی الجزایر، یک منطقه با تنوع زیستی فوق‌العاده است که با وجود انواع اکوسیستم بلوط و زیستگاه‌های گوناگون شناخته می‌شود. این مطالعه تأثیر ناهمگونی زیستگاهی را بر تنوع بندپایان در پنج زیست‌بوم جنگلی شامل بلوط چرمی، بلوط زین، جنگل بلوط مختلط، بلوط آفار و رویشگاه درختچه‌ای را مورد بررسی قرار می‌دهد. در مجموع ۱۱۶ گونه از بندپایان متعلق به ۴۴ خانواده و ۹ راسته شناسایی شدند که سوسک‌ها (قاب‌بالان) متنوع‌ترین گروه بودند. نتایج نشان داد که ساختار زیستگاه تأثیر قابل توجهی بر ترکیب بندپایان دارد، به طوری که رویشگاه درختچه‌ای بیشترین تنوع و جنگل‌های بلوط چرم کمترین تنوع را داشتند. گونه‌های منحصربه‌فرد عمدتاً در زیستگاه‌های انتقالی دیده شدند، در حالی که گونه‌های مشترک ارتباط زیست‌محیطی بین زیستگاه‌ها را نشان می‌دادند. تحلیل‌های چندبعدی غیرمتریک (NMDS) و شاخص یاکارد ترکیب‌های گونه‌ای متمایز در زیستگاه‌ها و لایه‌های گیاهی را تأیید کردند. این یافته‌ها نقش حیاتی ناهمگونی زیستگاهی در شکل‌دهی تنوع زیستی را نشان داده و بر ضرورت اقدامات حفاظتی منطبق بر ویژگی‌های بوم‌شناختی منحصر به فرد مناظر جنگلی بلوط تأکید دارند.

واژگان کلیدی: سخت‌بالپوشان، حفاظت، حشرات، جنگل‌ها، چشم‌انداز، شمال‌شرقی الجزایر