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Winter insect diversity across regressive stages of evergreen cork oak forests in El Kala national park, Northeastern Algeria

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Abstract

This study examined insect community diversity and structure in five regressive cork oak formations during winter. A total of 1,597 individuals from 36 families and seven orders were collected, with Coleoptera dominating (15 families, 55% of individuals). Forests with undergrowth and shrubland showed higher diversity (34–35 families) and abundance (424– 456 individuals) than open habitats like grasslands (18 families, 114 individuals) and cork oak woodlands without undergrowth (14 families, 83 individuals). Insect abundance and diversity (Shannon_H) increased over winter, while dominance (Dominance_D) declined, indicating better family distribution. Spatial analysis revealed low diversity and high dominance in cork oak forests without undergrowth (Shannon_H: 1.40, Dominance_D: 0.39), contrasting with higher diversity and lower dominance in forests with undergrowth and shrublands (Shannon_H: ~3.15, Dominance_D: 0.05). The Whittaker index highlighted strong dissimilarity between cork oak forests without undergrowth and other habitats (0.617–0.682). These results highlight the critical role of structurally complex forests in supporting insect diversity, while open habitats, such as grasslands and cork oak forests without undergrowth, host less diverse communities dominated by few families. This study emphasises the importance of maintaining forest habitats with a developed shrub layer for biodiversity conservation.

Keywords: El Kala National Park; Cork oak forest; Regressive stages; Entomological diversity.

Introduction

Mediterranean forests have played a fundamental role in maintaining ecosystems for millennia and have been a valuable source of ecosystem services for human populations (Blondel &Bonin, 2018). These forests provide vital resources such as wood, cork, medicinal plants, and fruit, as well as economic and recreational activities (Oliveira & Costa, 2012). Their rich biodiversity makes them one of the world's major ecological hotspots, despite being among the most vulnerable (Myers et al., 2000).

Despite their ecological and economic importance, Mediterranean woodlands are facing multiple human and environmental threats. Overgrazing, extensive pastoralism, recurrent wildfires, and the expansion of urban and agricultural areas all contribute to their degradation (Peñuelas & Sardans, 2021). These disturbances, aggravated by global warming, are causing a reduction in forest area, materialization of the original forests and a reduction in their regeneration capacity (San-Miguel-Ayanz et al., 2022).

In North Africa, these transformations have given rise to mosaics of vegetation representing different regressive stages of the original forests. These formations include cork oak forests with or without undergrowth, wooded scrubland, scrubland and grassland, each offering distinct ecological conditions and resources (Quezel, 1956; Tassin, 2012). These structural changes have significant consequences on biodiversity, particularly affecting insect populations.

Insects play a pivotal role in forest ecosystems, as pollinators, predators, decomposers and prey for other organisms (Hilty & Merenlender, 2000). Their susceptibility to environmental disturbance and short life cycle makes them excellent indicators of ecological change (Price et al., 2011). However, changes in habitat structure can disrupt the diversity and abundance of insects, compromising the essential ecological functions they provide (Fonseca & Diehl, 2004).

This study investigates the impact of different regressive stages of cork oak forests on insect diversity and abundance during winter, by targeting five types of forest formations in El Kala National Park. It aims to elucidate how habitat transformation influences entomological communities. The results will enhance our understanding of the links between habitat structure and entomological biodiversity in this vulnerable region.

Materials and methods

Study area

The study was carried out in the El Kala National Park, created in 1983, located in the extreme north-east of Algeria between 36°55’and 36°90’ N and 08°16’and 08°43’ E, covering an area of 78438 ha. The park is bounded to the north by the Mediterranean Sea, to the east by the Algerian-Tunisian border, to the west by the Annaba plain and to the south by the Medjerda Mountains. This protected area was classified as a Biosphere Reserve in 1990 and is part of one of the hotspots of the western Mediterranean, known for its great landscape diversity and highly diversified biological heritage, as well as its great vulnerability (Médail & Quézel 1997; Stevenson & Moore, 1988; Benyacoub et al.; 1998). The region is located on the southern shore of the Mediterranean, and is hence subject to a subhumid climate with mild winters, where snow rarely covers the ground.

Study sites

Cork oak forest with undergrowth (ST1), covering an area of around 1400 m² at 36° 39' 2.25 N and 8°21'45.18 'E. at an altitude of 277 m. This formation corresponds to the notion of forest in the strict sense of the term and is characterised by the presence of the tree layer, the bush layer and the herb layer. The tree layer is made up of Quercus suber trees, which can reach 18 m in height, with an average crown cover of around 75%. The undergrowth is high and thick, with several plants that flower and bear fruit in winter. *Phillyrea angustifolia, Arbutus unedo, Myrtus communis, Crataegus monogyna, Erica arborea, Rosa canina, Lonicera implexa, Cistus salvifolius, Cistus monspeliensis, Lavandula stoechas* (Figure 2).

A cork oak forest without undergrowth (ST2), located at 36° 37' 3.14 N and 8° 21' 43.47 E, at an altitude of 600 m, covering an area of around 18,200 m². This structure is characterised by a fairly regular canopy with a maximum height of 20 m. The average tree cover is 80%, and the shrub layer is very sparse, consisting of a few *Daphne gnidium, Crataegus monogyna* and mosses, as well as stunted and scattered epiphytic (Figure 2).

Wooded scrubland (ST3), located at 36° 44' 0.99''N and 8° 22 4' 41'' E, at an altitude of 220 m, covers an area of more than 30,500 m², the *Quercus suber* tree stratum is very patchy, with a cover not exceeding 10%, and the trees are of moderate size, averaging 7 m in heigh. The shrub layer consists of typical scrub vegetation, including *Pistacia lentiscus, Arbutus unedo, Myrtus communis, Phillyrea angustifolia, Erica arborea, and Calycotome villosa*, among others (Figure 2).

Medium scrubland (ST4), located at 36° 43' 53.94" N and 8° 22' 43.67" E, at an altitude of 196 m, covers an area of more than 24,400 m². It has dense vegetation with an average cover of 80%, primarily composed of *Pistacia lentiscus, Myrtus communis, Cistus monspelliensis, Erica arborea, Lavandula stoechas, and Arbutus unedo*. The average plant height does not exceed 2 m (Figure 2).

Grassland (ST5), located at 36° 36' 54.98'' N and 8°21' 58.15'' E, at an altitude of 659 m, covers a surface area of approximately 33,600 m the final stage of cork oak forest degradation. This habitat often forms clearings where woody plants have completely disappeared, giving way to annual species (Figure 2).

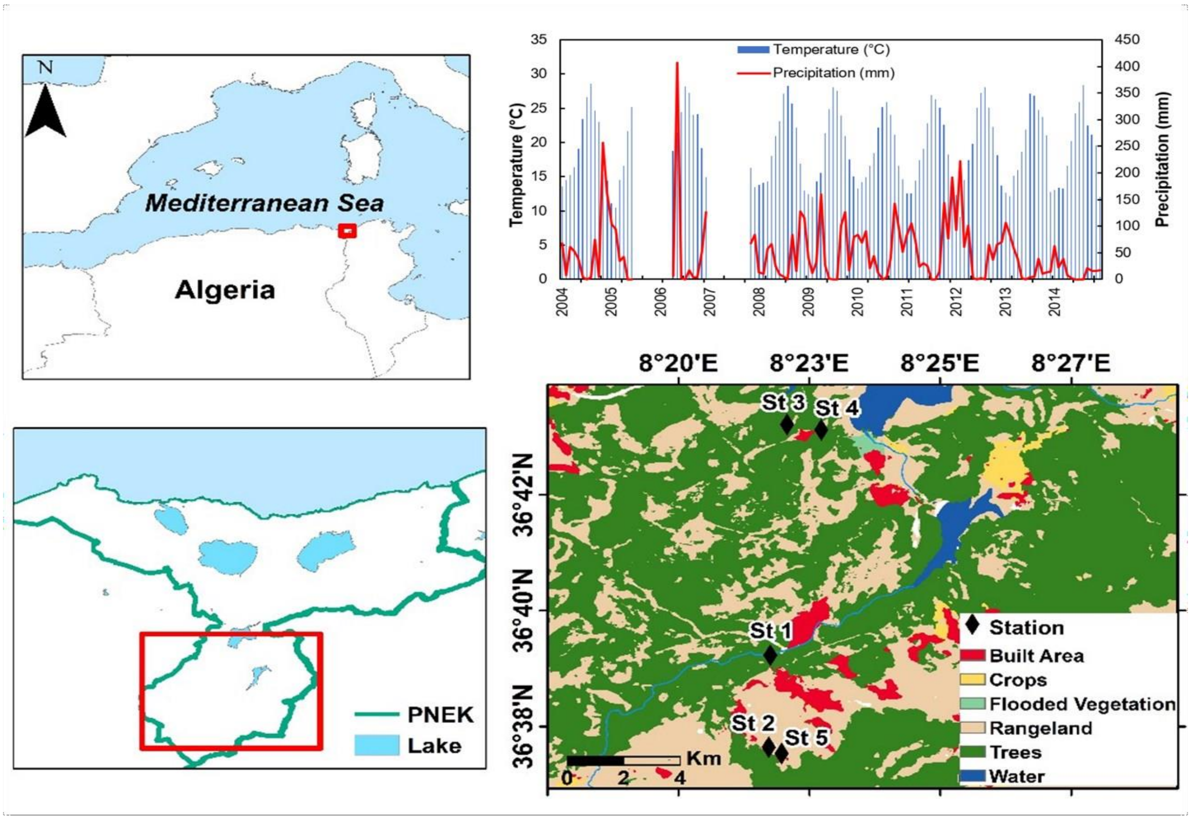


Figure 1. Study area and location of the sampled stations. Land cover information was derived from ESA's Sentinel-2 imagery at 10 m resolution (2024), while meteorological data were provided by the ONM (2021).

Figure 2. Study sites: ST1 (Cork oak forest with undergrowth, ST2 (Cork oak forest without undergrowth), ST3 (Wooded scubland), ST4 (Medium scrubland), ST5 (Grassland)

Methodology

During winter 2021–2022, two sampling methods were used: the active search method (collecting insects from leaves, trunks, under stones, and plant debris) and Barber traps, suited for ground-active species (Barber, 1931). Each of the five forest formations had 30 Barber traps per month, arranged in rows of 10, spaced 10 meters apart, ensuring reliable diversity estimates in homogeneous habitats (Ward et al., 2001; Császár et al., 2018).

Due to identification challenges in diverse forest insect communities, supra-specific identification (genera or families) was preferred (Bouget, 2009), with taxonomic classification limited to the family level, a practical and reliable approach (Beattie & Oliver, 1996). Specimens were identified using keys at the laboratories of Badji Mokhtar University (Algeria) and the University of Bari Aldo Moro (Italy).

Data Analysis

A comparative analysis of ecological indices was conducted, including taxonomic and specific diversity, abundance, equitability, and dominance. Beta diversity was assessed using Whittaker's similarity index to compare unique taxa across ecosystems. To evaluate hypotheses related to temporal and spatial variables, a two-criteria analysis of variance with a fixed-model classification was applied. The analysis was performed using R software and the Rcmdr package (R Core Team, 2024). A methodology integrating component factor analysis with hierarchical classification based on Ward's criterion was implemented to study the typology of the examined factors, using the FactoMineR package (Pagès, 2020). In summary, the combination of CFA and Ward's classification facilitates the structuring of the data, thereby improving understanding of the differences between sites and months in terms of taxonomic composition. This analysis provides valuable information on beta diversity and serves as a tool for identifying distinct ecological patterns within insect communities.

Results

A total of 1597 insect individuals were collected in five regressive evergreen cork oak formations during the winter. These specimens belonged to 36 families and seven orders. Coleoptera was the most diverse order, comprising 15 families, followed by Hemiptera (7), Diptera (5), Hymenoptera (4), Blattoptera (2), Dermaptera (2), and Archaeognatha, which included at least one family (Table 1).

The most abundant order is also Coleoptera 55% (883), representing slightly more than half the population, followed by Hymenoptera 13% (212), Diptera 12% (194), Hemiptera 10% (163), Blattodea 6% (93), the least abundant are Dermaptera 2% (28) and Archaeognathes 2% (24). The most abundant families were Formicidae (158) (Hymenoptera); Dasytidae (109), Scarabaeidae (107), Tenebrionidae (100), Carabidae (97), Chrysomelidae (84), Curculionidae (75), Geotrupidae (54) Brentidae (53) belonging to the order (Coleoptera) ; Culicidae (56) (Diptera) ; Ectobiidae (53) (Blattodea).

Table 1. Distribution of Insect Families Across Sampled Habitats

Order	Family	ST1	ST2	ST3	ST4	ST5
Coleoptera	Dasytidae	29	4	25	29	22
	Scarabaeidae	23	2	23	31	28
	Carabidae	28	4	26	24	15
	Geotrupidae	19	2	14	12	7
	Curculionidae	24	0	25	26	0
	Chrysomelidae	21	1	25	23	14
	Tenebrionidae	24	3	25	26	22
	Trogidae	16	1	14	11	3
	Staphilinidae	14	0	12	9	2
	Brentidae	20	0	17	16	0
	Leiodidae	15	0	13	17	3
	Silphidae	2	0	5	0	0
	Elateridae	9	0	8	9	0
	Endomychidae	11	0	10	8	0
	Histeridae	6	0	1	1	4
Diptera	Syrphidae	7	0	3	6	0
	Culicidae	20	0	13	12	11
	Tabanidae	13	0	16	11	0
	Calliphoridae	11	0	11	12	0
	Tipulidae	10	0	13	14	11
Hemiptera	Cicadelidae	7	4	0	0	0
	Reduviidae	12	2	10	10	7
	Pentatomidae	0	0	4	3	0
	Pyrrhocoridae	7	0	6	6	3
	Ceratocombidae	11	5	13	8	0
	Corimelaenidae	12	0	7	10	0
	Cydnidae	5	0	6	5	0
Hymenopetra	Apidae	3	5	2	5	0
	Formicidae	37	40	24	28	29
	Argidae	3	0	6	15	0
	Andrenidae	0	0	9	6	0

Blattodea	Ectobiidae	15	6	15	15	2
	Blattellidae	12	4	10	14	0
Dermaptera	Anisolabididae	0	0	2	5	7
	Forficulidae	0	0	3	7	4
Archaeognatha	Archaeognathasp	10	0	8	6	0

Monthly variation in ecological parameters of local diversity

Insect abundance increased over the season; from December to March 2022, rising from 211 individuals in December 2021 to 635 individuals in March 2022.This noticeable increase probably corresponds to the spring season, which offers optimal conditions for insect proliferation (higher temperatures, food availability, etc.) (Figure 3).

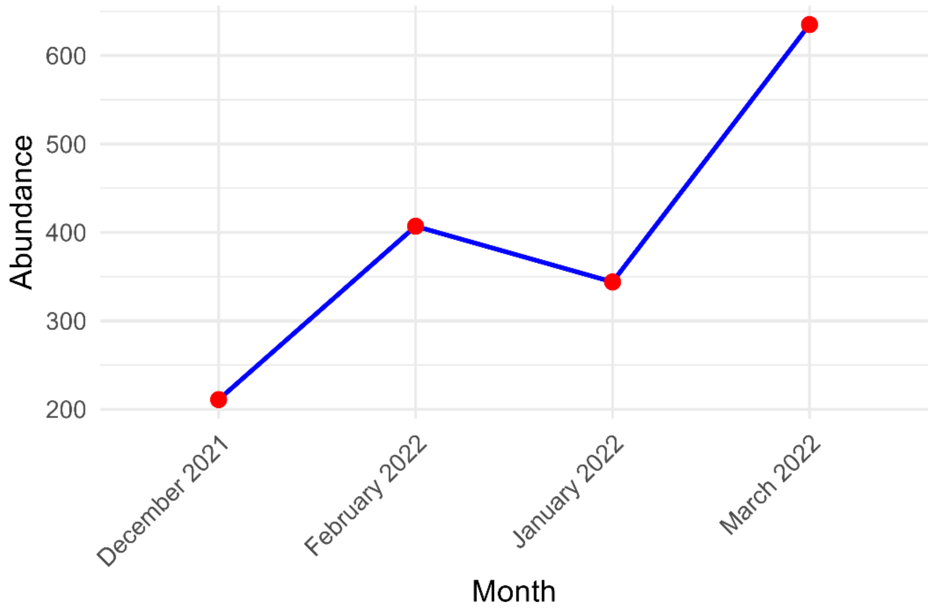


Figure 3: Monthly trends in insect abundance

Monthly abundance of insects by order

The Coleoptera order significantly increased, from around 120 insects in December to over 300 in March. The orders Diptera, Hemiptera and Hymenoptera show moderate but steady progression, reaching an abundance of between 50 and 80 insects in March. Dermaptera, Blattoptera and Archaeognatha show only slight variation (Figure 4).

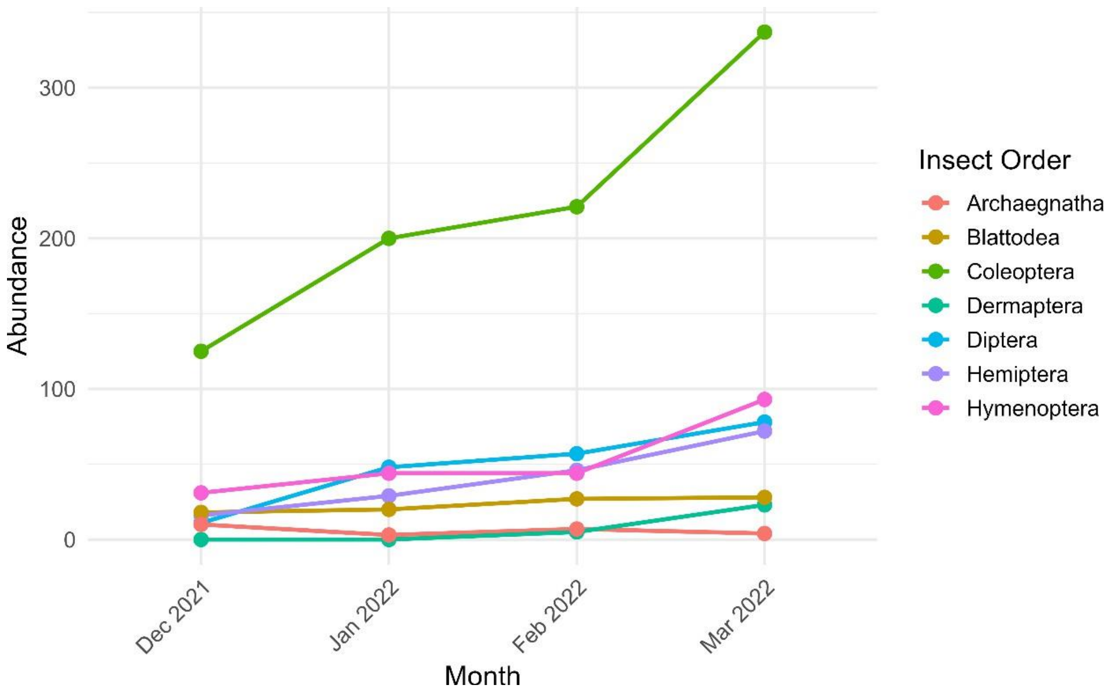


Figure 4: Monthly trends in abundance by insect order

Spatial diversity of insect abundance

The cork oak forest with undergrowth (ST1), the wooded scrubland (ST3) and the medium scrubland (ST4) show the highest insect abundance (456, 424, and 440 individuals, respectively) and high family diversity (32–35 families). The grassland (ST5) has moderate abundance (194 individuals) and lower diversity (18 families), while ST2 records the lowest values (83 individuals, 14 families). The trend suggests that structurally complex habitats support richer insect communities, whereas less complex environments (ST2, ST5) host fewer species and individuals (Figure 4).

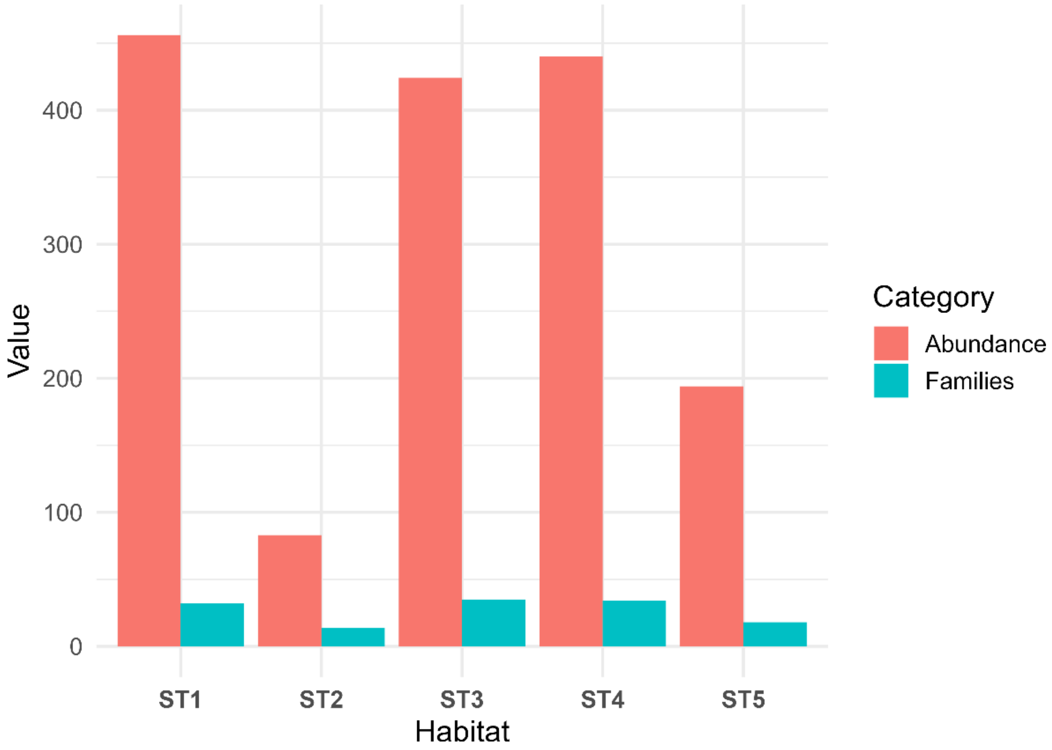


Figure 5. Insect diversity and abundance in the five habitats

Monthly Variations in Alpha Diversity and Taxonomic Distribution During Winter

The analysis of temporal variations in alpha diversity, using Fisher’s F-test (ANOVA I) and Tukey’s multiple comparison tests, reveals significant differences in ecological parameters across the study months. The number of individuals rose sharply from 20 in December to 126 in March, suggesting seasonal influences or environmental changes that favor higher abundance (F = 22.8, p = 0.000). Similarly, taxonomic richness (Taxa_S) increased from 13 families in December to 26 in March, indicating a notable rise in species diversity (F = 49.48, p = 0.000).

This trend is further supported by the Shannon diversity index, which grew from 2.10 in December to 2.97 in March, reflecting an increasing diversity of insect families (F = 12.04, p = 0.001). Equitability also showed a slight but significant improvement from 0.8661 in December to 0.9326 in March, demonstrating a more balanced distribution of individuals among families (F = 1.07, p = 0.0398). Meanwhile, the dominance index (Dominance_D) declined from 0.223 in December to 0.075 in March, indicating a reduced prevalence of specific insect families and a shift towards a more even taxonomic distribution (F = 2.24, p = 0.012).

December exhibited the least balanced community structure, with dominance by a few Coleoptera families (Dasytidae, Chrysomelidae, Curculionidae) and the Formicidae family (Hymenoptera). Overall, the results indicate an upward trend in biodiversity, characterised by an increase in individuals and taxa, reduced dominance of certain families, and a more equitable distribution. These findings highlight seasonal changes that enhance ecological diversity. The statistical significance of these variations, confirmed by Fisher’s tests, reinforces the robustness of the results (**Table 2**).

Table 2: Monthlyvariations in insect structure parameters

Months	**Taxa_S**		**Individuals**		**Dominance-D**		**Shannon_H**		**Equitability_J**	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
Dec	13	8,7635	20	26,0518	0,22385	0,26612	2,1046	0,9944	0,8661	0,1798
Jan	20	11,5195	68	38,1077	0,15494	0,20274	2,5448	0,96170	0,889	0,1195
Feb	23	9,5760	80	43,6921	0,08688	0,07249	2,8354	0,60905	0,92696	0,0545
Mar	26	10,4976	126	60,6523	0,07509	0,05708	2,9706	0,57457	0,93264	0,0438

Spatial Variations in Ecological Parameters

The analysis of spatial variations in ecological parameters reveals significant differences between stations. The cork oak forest with undergrowth (ST1), wooded scrubland (ST3), and medium scrubland (ST4) support the highest number of individuals (104 to 111), whereas the cork oak forest without undergrowth (ST2) has the lowest count (21), and the grassland (ST5) holds an intermediate position (49). The Fisher test (F = 24.42, p = 0.000) confirms these significant variations.

A similar pattern is observed in taxonomic richness, with ST1, ST3, and ST4 showing high values (26 to 28 families), while ST2 and ST5 exhibit much lower richness (7 and 12 families, respectively), as confirmed by the highly significant Fisher test (F = 142.63, p = 0.000). Shannon's diversity index (Shannon_H) is also higher in ST1, ST3, and ST4 (around 3.12 to 3.15), but considerably lower in ST2 (1.40) and intermediate in ST5 (2.24), indicating notable differences in diversity distribution across stations (F = 39.9, p = 0.000).

Equitability follows a similar trend, with ST1, ST3, and ST4 displaying high values (0.94 to 0.96), suggesting a balanced distribution of individuals among families. In contrast, ST2 exhibits the lowest equitability (0.73), indicating the dominance of certain families (F = 8, p = 0.002). The dominance index further supports these findings, revealing weak dominance in ST1, ST3, and ST4 (around 0.05), in contrast to strong dominance in ST2 (0.39) and moderate dominance in ST5 (0.13). These disparities are statistically significant, as confirmed by the Fisher test (F = 8.39, p = 0.002) (Table 3).

Overall, these results highlight distinct ecological structures among the different habitats. The cork oak forest with undergrowth, wooded scrubland, and medium scrubland harbor more balanced and diverse insect communities, whereas the cork oak forest without undergrowth is characterized by lower diversity and a higher dominance of specific families.

Table 3: Spatial variations in insect structure parameters

Station	**Taxa_S**		**Individuals**		**Dominance-D**		**Shannon_H**		**Equitability_J**	
	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev	Mean	StDev
ST1	28	5	111	44	0,05	0,01	3,15	0,22	0,95	0,01
ST2	7	4	21	11	0,39	0,25	1,4	0,75	0,73	0,15
ST3	26	7	104	47	0,05	0,02	3,12	0,3	0,96	0,01
ST4	28	6	108	46	0,05	0,01	3,15	0,25	0,94	0,02
ST5	12	5	49	34	0,13	0,06	2,24	0,46	0,94	0,03

Analysis of Beta Diversity Variation Using Whittaker's Index"

The cork oak forest without undergrowth (ST2) shows a notable dissimilarity compared to the other sites, with Whittaker's index ranging between 0.617 and 0.682. In contrast, the wooded scrubland and medium scrubland (ST3 and ST4) display substantial similarity, both with each other and with the cork oak forest with undergrowth (ST1), as indicated by their relatively low indices (ranging from 0.080 to 0.132). This suggests a high number of shared species among these sites, likely reflecting similar environmental conditions or strong ecological connectivity. Finally, the intermediate position of the grassland (ST5) may indicate the presence of an ecological gradient within the study area.

Ecological Patterns and Habitat Differentiation: A Correspondence Analysis of Insect Community

The chi-square test is significant (p-value = 4.376e-38), indicating a significant dependence between the sites and family composition. The first two axes explain 84.3% of the total variance: Axis 1 accounts for 52.1% of the inertia, and Axis 2 accounts for 32.2%. This high proportion indicates that these two axes effectively represent the data structure (**Figures 6 and 7**).

Axis 1 (52.1% of total inertia): Contrasting Pre-Forest and Open Habitats

Axis 1 contrasts the Formicidae, Apidae, and Cicadellidae families, which dominate the cork oak forest without undergrowth (ST2), with the Curculionidae, Brentidae, Tabanidae, Calliphoridae, Corimelaenidae, Endomychidae, Elateridae, Archaeognatha sp., Argidae, and Leionidae families, which characterize the wooded scrubland (ST3), the medium scrubland (ST4), and the cork oak forest with undergrowth (ST1).

This axis distinguishes omnivorous and thermophilic families thriving in resource-poor environments (cork oak forest without undergrowth) from those preferring habitats with high plant diversity. These families belong to various trophic guilds, including phytophages (Curculionidae, Chrysomelidae), pollinators (Argidae, Calliphoridae, Elateridae, Syrphidae), hematophagous species (Tabanidae), decomposers (Brentidae, Endomychidae, Leionidae, Archaeognatha), and predators (Corimelaenidae).

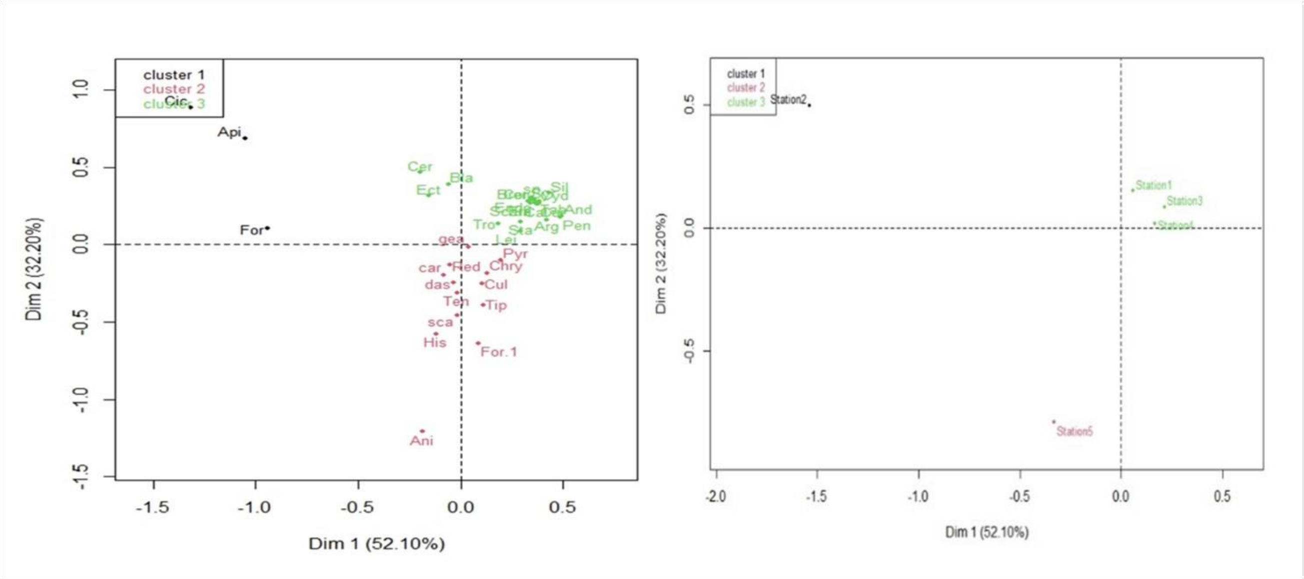
These results highlight the role of vegetation complexity, density, and diversity in structuring insect communities.

Axis 2 (32.2% of total inertia): Differentiating Grassland and Forest Habitats

Axis 2 contrasts the families Scarabaeidae, Tenebrionidae, Anisolabidae, Forficulidae, and Dasytidae, along with the Tipulidae, which are primarily associated with grassland (ST5), against the families Cicadellidae, Apidae, and Ceratocombidae, which characterize cork oak forests with or without undergrowth (ST1, ST2) (Figures 6).

This axis highlights a contrast between families associated with open, thermophilous environments, characterized by omnivorous or decomposer feeding habits, which benefit from simple resources and structurally less complex habitats, and which often overwinter near the soil surface, versus families linked to humid and wooded forest habitats rich in organic litter and vegetation, and specialized in specific trophic niches: phytophagous species (Cicadellidae), pollinators, and nectar or sap consumers (Apidae, Ceratocombidae).

Furthermore, this axis emphasizes the contrast between the vertical structure of vegetation and a gradient of landscape openness, with the grassland representing the final stage of the regressive succession of the original forest.



Figures 6: Dim1 x Dim2 Correspondence Analysis (CA) Biplot. (a) CA biplot illustrating the projection of taxa (families). (b) CA biplot illustrating the projection of sites. The colors indicate the clusters resulting from the classification.

Hierarchical Classification of Insect Communities

Cluster Characterization

Cluster 1 (ST2): The cork oak forest without undergrowth, strongly characterized by the family Formicidae (48.2% vs. 9.9% globally), the family Apidae (6.0% vs. 0.9%), and the family Cicadellidae (4.8% vs. 0.7% globally).

Cluster 2 (ST5): The grassland, characterized by a strong presence of the family Scarabaeidae (14.4% vs. 6.7%), as well as Anisolabididae, Tenebrionidae, Dasytidae, Forficulidae, and Tipulidae.

Cluster 3 (ST1, ST3, and ST4): The cork oak forest with undergrowth, the wooded Scrubland, and the medium Scrubland, characterized by the family Curculionidae (5.7% vs. 4.7% globally) and an overrepresentation of numerous taxa: Brentidae, Tabanidae, Calliphoridae, Corimelaenidae, Endomychidae, Elateridae, Archaeognatha sp., Argidae, Scaritidae, and Leionidae.

Ecological Complementarity of Sites Based on Taxonomic Composition

The combined approach of Correspondence Analysis (CA) and Ward's hierarchical classification highlights the complementarity between the sites, emphasizing both their specificity and certain ecological overlaps. These results illustrate the richness and complexity of the interactions between habitats and entomological diversity.

Families shared between clusters (1, 2 and 3): Despite distinct ecological differences, some families are present in all three clusters, revealing points of ecological convergence. These include: Dasytidae, Tenebrionidae, Carabidae, Geotropidae, Chrysomelidae, Trogidae, Staphylinidae, Reduviidae and Pyrrochoridae. Their presence in various habitats reflects their considerable adaptability and ecological flexibility. These frequent families contribute to maintaining ecological connectivity between different environments, promoting functional continuity within the ecosystems studied.

Families shared by clusters 1 and 2 (ST2 and ST5): The only shared family between the cork oak forest without undergrowth (ST2) and the grassland (ST5) is Formicidae. This omnivorous family is characteristic of open, thermophilic environments, demonstrating tolerance to contrasting ecological conditions.

Families shared by clusters 1 and 3: (ST2) and (ST1, ST3, ST4): No family is shared between the cork oak forest without undergrowth (ST2) and the wooded or pre-forest formations (ST1: cork oak forest with undergrowth, ST3: wooded scrubland, ST4: medium scrubland). This lack of overlap emphasize the obvious ecological demarcation between these environments.

Families shared by clusters 2 and 3: (ST5) and 3 (ST1, ST3, ST4): Similarly, no families are shared between grassland and woodland or pre-forest formations, pondering a prominent ecological differentiation between these habitat types.

Families Unique to Each Cluster

- **Cluster 1 (ST2) Cork Oak Forest Without Undergrowth:** Two families are specific to this environment—Apidae (nectarivorous pollinators) and Cicadellidae (phytophagous sap feeders). Their presence is linked to habitats with limited undergrowth.

- **Cluster 2 (ST5) Grassland:** Three families are characteristic of grasslands—Scarabaeidae (coprophagous and detritivorous), Anisolabididae (opportunistic omnivores), and Tipulidae (detritivorous larvae). These families thrive in open, thermophilic conditions with essential resources.
- **Cluster 3 (ST1, ST3, ST4) Forest and Pre-Forest Formations):** The following families are typical of these environments: Curculionidae, Brentidae, Tabanidae, Calliphoridae, Corimelaenidae, Endomychidae, Elateridae, Archaeognatha sp., Argidae, and Leionidae. These families exhibit diverse feeding strategies (phytophagous, xylophagous, hematophagous, mycophagous, etc.), highlighting the trophic complexity, ecological richness, and biodiversity of these structured habitats.

This classification underlines the significant ecological distinctions among the study sites while revealing key taxonomic groups that contribute to ecosystem stability and connectivity.

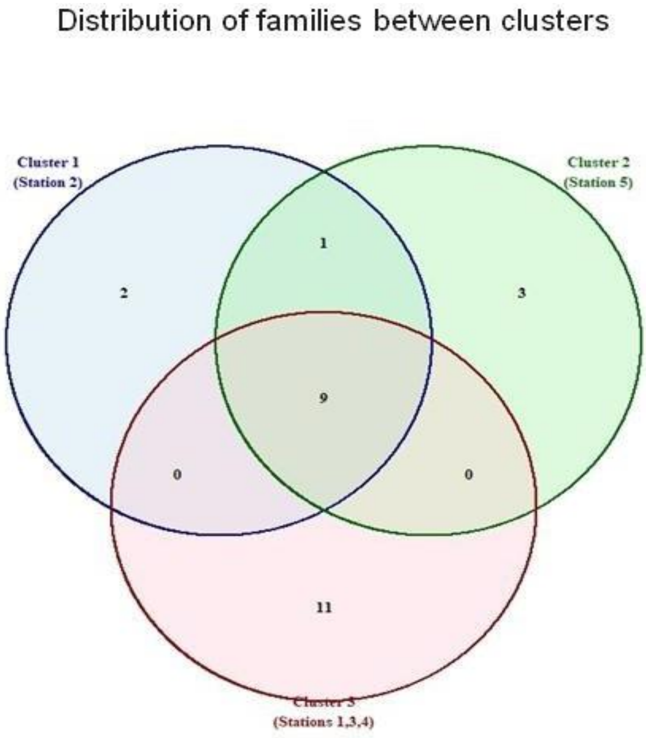


Figure 7: Venn diagram, illustrating the number of families in each section and representing the complementarity of the stations in terms of taxonomic composition.

Discussion

Ecological differentiation between sites

The results of this study show a considerable ecological differentiation between sites in terms of their taxonomic composition and structural characteristics. Forest habitats, such as cork oak forest with undergrowth and scrublands, have much higher insect family's richness than open environments, such as grasslands. This observation is consistent with previous studies showing that the structural complexity of habitats promotes a broader diversity of species by offering a variety of ecological niches (Siemann et al., 1998).

A dense shrub layer is essential for maintaining entomological communities in cork oak forests and scrublands. It supplies a variety of resources such as pollen, nectar, decomposing organic matter and microhabitats ideal for insect reproduction and development (Knuff et al., 2020; Basset et al., 2012; McConnell & Dhiviya, 2024). On the other hand, the grasslands and cork oak without undergrowth, while suited to certain generalist species, offer less diverse resources, which explain their reduced species richness.

Role of environmental conditions on entomological communities

The discrepancies found in the composition of insect families between stations illustrate the impact of environmental conditions on the structuring of communities. For example, the dominance of Formicidae, linked to their colonial nature (Tarihoran et al., 2020) and their omnivorous diet, reflecting their ability to adapt to open, thermophilic environments that are relatively limited in resources, such as Cork oak forest without undergrowth. This ability to colonize restrictive environments (Batra, 1984) is evidence of their ecological plasticity.

Meanwhile, families specific to cork oak forests with undergrowth, such as Curculionidae, Brentidae, and Endomychidae, are associated with habitats rich in vegetation and complex trophic resources. Their presence indicates an ecological dependence on specific microhabitats and a high diversity of plant species, which provides them with varied food resources (leaves, fruit, fungi, dead wood, and flowers) as well as favorable winter conditions for reproduction (Tomàs et al., 2022).

Importance of the shrub layer in forest ecosystems

A dense shrub layer is a key to maintaining entomological biodiversity (Basset et al., 2012; Haddad et al., 2011; Stiegel et al., 2020). As well as offering diverse food resources in winter, it provides shelter and refuge from predators and extreme weather conditions. This structural complexity is particularly vital for trophic guilds such as pollinators (Apidae), predators (Carabidae) and decomposers (Tenebrionidae, Scarabaeidae).

In addition, ecosystems with a high degree of botanical stratification create a continuum of ecological niches that favors the coexistence of species with varied environmental needs. These observations corroborate the work of Moreno-Fernández and al., 2021; Knuff et al., 2020), who emphasizes that botanical stratification, is a key factor in regulating animal communities.

Conclusion

The regression of forests towards less structured forms could result in a significant loss of diversity and essential ecological functions, such as pollination, predation and nutrient recycling. Hence the need to maintain complex forest habitats and ensure the resilience of Mediterranean ecosystems to anthropogenic and climatic disturbances to preserve biodiversity, through further research into the links between vegetation stratification, microhabitats and the insect community dynamic, to acquire knowledge that can enlighten strategies for the sustainable management of forest ecosystems, particularly in Mediterranean regions severely affected by anthropogenic activities and climate change.

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