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Altitudinal Zonation of Perennial Vegetation in Al-Jabal Al-Akhdar Forest Ecosystem, Libya

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ABSTRACT

This study aimed to investigate the impact of altitudinal gradients on diversity, species composition, and dominance structures of perennial plant cover in Al-Jabal Al-Akhdar (the Green Mountain) forest in northeastern Libya. The research was conducted along a 5 km wide elevational transect, extending from sea level near Ras Al-Helal village to 650 m near Lamlouda village, the transect was stratified into three elevation levels: Level A (High: 434–650 m), Level B (Mid: 217–434 m), and Level C (Coastal: 0–217 m). At each level, perennial plant species were systematically recorded and quantitatively assessed for species frequency, abundance, and relative cover. The study recorded a total of 12 perennial species at the high level, and 15 species each at the mid and coastal levels. Species richness was higher at the mid and coastal elevations than at the high elevation. The dominance structure shifted markedly across the gradient: Level A was strongly co-dominated by *Ononis mitissima* (30.2% cover) and *Pistacia lentiscus* (24.5% cover). Level B exhibited a more balanced co-dominance of four species, including *Rhamnus alaternus* (18.8% cover) and *Juniperus phoenicea* (15.6% cover). Level C was overwhelmingly dominated by *Juniperus phoenicea* (33.3% cover). Key species showed significant shifts in cover with elevation; *Juniperus phoenicea* decreased with altitude, while *Pistacia lentiscus* increased. The vegetation structure in Al-Jabal Al-Akhdar follows a distinct elevational gradient driven by a combination of abiotic filtering (climate, soil factors) and biotic interactions. this study not only provide up-to-date field documentation of the vegetation status in Ras El Hilal forests, but also contribute to regional research trends on patterns of richness and diversity in Mediterranean environments, highlighting the need to intensify protection and rehabilitation efforts for key species.

التدرج الارتفاعي للغطاء النباتي المعمر في النظام البيئي لغابات الجبل الأخضر، ليبيا

عادل محمود، مسعد الميهوب، عبدالباسط مبارك

هدفت هذه الدراسة إلى تقييم تأثير التدرج الارتفاعي في التنوع النباتي، وتركيب الأنواع، وأنماط السيادة في الغطاء النباتي للأنواع المعمرة بغابات الجبل الأخضر في شمال شرق ليبيا. أُجريت الدراسة على امتداد مقطع ارتفاعي بعرض 5 كم، يبدأ من مستوى سطح البحر بالقرب من قرية رأس الهلال ويمتد حتى ارتفاع 650 م بالقرب من قرية لملودة، وقُسّم المقطع إلى ثلاثة مستويات ارتفاعية، هي: المستوى (A) المرتفع (434–650 م)، والمستوى (B) المتوسط (217–434 م)، والمستوى (C) الساحلي (0–217 م). وفي كل مستوى، جرى حصر الأنواع النباتية المعمرة وتقييمها كمياً من خلال تكرار ظهور الأنواع، ووفرتها، ونسبة تغطيتها النسبية. أظهرت النتائج تسجيل 12 نوعاً نباتياً معمراً في المستوى المرتفع، مقابل 15 نوعاً في كل من المستويين المتوسط والساحلي، مما يشير إلى ارتفاع غنى الأنواع في الارتفاعات المتوسطة والساحلية مقارنة بالارتفاعات العالية. كما أظهرت بنية السيادة النباتية تغيراً واضحاً على طول التدرج الارتفاعي؛ إذ اتسم المستوى (A) بسيادة مشتركة واضحة لنوعي *Ononis mitissima* بنسبة تغطية بلغت 30.2% و *Pistacia lentiscus* بنسبة 24.5%. أما المستوى(B) ، فقد اتسم بتوزيع أكثر توازناً للسيادة بين أربعة أنواع، كان من أبرزها *Rhamnus alaternus* بنسبة تغطية 18.8% و *Juniperus phoenicea* بنسبة 15.6%. في حين أظهر المستوى (C)سيادة واضحة لنوع *Juniperus phoenicea* بنسبة تغطية بلغت 33.3%. كما سجلت الأنواع الرئيسة تغيرات ملحوظة في نسبة تغطيتها تبعاً للارتفاع؛ حيث انخفضت تغطية *Juniperus phoenicea* مع زيادة الارتفاع، في حين ازدادت تغطية *Pistacia lentiscus.* وتشير هذه النتائج إلى أن تركيب الغطاء النباتي وبنيته في الجبل الأخضر يتبعان تدرجاً ارتفاعياً واضحاً، تحكمه مجموعة متداخلة من العوامل غير الحيوية، ولا سيما الظروف المناخية وخصائص التربة، إلى جانب التفاعلات الحيوية بين الأنواع. وتوفر الدراسة توثيقاً ميدانياً حديثاً لحالة الغطاء النباتي في غابات رأس الهلال، كما تسهم في تعزيز المعرفة الإقليمية بأنماط غنى الأنواع وتنوعها في البيئات المتوسطية، وتؤكد أهمية تكثيف جهود حماية الأنواع النباتية الرئيسة وإعادة تأهيل الموائل المتدهورة في المنطقة.

INTRODUCTION

Mountain ecosystems are unique and dynamic environments that play a crucial role in supporting biodiversity and maintaining balance, with one-third of terrestrial biodiversity and half of the world's 34 hotspots found in mountainous regions (Grytnes, 2002; Körner, 2004). These high-altitude landscapes, characterized by rugged terrain, steep slopes, and high elevations, provide habitats for a diverse range of plants and animals. Mountain landscapes are renowned for their rich biodiversity, hosting a wide range of plant and animal species. The diverse range of elevations within mountains creates distinct ecological zones, each supporting specialized flora and fauna adapted to specific environmental conditions. Mountain ecosystems, such as the Mediterranean basin, are among the world's most important biodiversity hotspots. The Mediterranean basin alone contains approximately 10% of the world's plant species in just 1.6% of the Earth's land area (Médail & Quézel, 1999). Perennial plants, which live for many years, are a crucial component of this ecosystem, providing stability and supporting animal diversity.

Environmental gradients represent a fundamental framework for understanding the spatial organization of ecosystems. These gradients, whether climatic, topographic, or edaphic, significantly influence the geographical distribution of vegetation and soil properties, determining species abundance patterns and distribution (Gaston, 2000). Altitude gradients strongly influence plant distribution due to variations in temperature, precipitation, solar radiation, and soil composition (Körner, 2007). The altitude gradient is one of the most prominent and comprehensive environmental gradients for studying biodiversity patterns and ecosystem functions (Lomolino, 2001).

Although several previous studies have described the floristic composition and vegetation patterns of Al-Jabal Al-Akhdar (e.g., Al-Sodany et al., 2003; Hegazy et al., 2011; Abd El-Ghani and Al Borki, 2024), limited information is available on the altitudinal variation in the structure and dominance of perennial vegetation using a standardized field survey across a continuous elevational gradient extending from the Mediterranean coast to the inland uplands. Most previous studies focused primarily on floristic inventories or the relationships between vegetation and environmental variables, while quantitative comparisons of perennial species composition, frequency, and relative abundance among distinct elevational zones remain scarce. Therefore, the present study addresses this gap by providing a field-based assessment of perennial vegetation along an altitudinal gradient in Al-Jabal Al-Akhdar. Accordingly, the objectives of this study were to: (1) evaluate changes in perennial species richness along the elevational gradient; (2) compare species composition and dominance among the three elevational zones; and (3) describe patterns of perennial vegetation distribution in relation to altitude within the Al-Jabal Al-Akhdar forest ecosystem.

The significance of this study lies in its unique geographical and ecological location. Despite covering only about 1% of Libya's total land area, Al-Jabal al-Akhdar (the Green Mountain) region serves as a biodiversity reservoir and a hotspot for plant diversity at the Mediterranean level. Al-Jabal al- Akhdar represents one of the most biologically diverse regions in North Africa, lying at the intersection of Mediterranean and Sahara desert bioclimatic zones. This mountain range is part of the Mediterranean Basin biodiversity hotspot, an area of exceptional endemism under increasing threat from climate change and human disturbance (Myers et al., 2000).

MATERIALS AND METHODS

Study area location and morphology:

Al-Jabal al- Akhdar is located in northeastern Libya and forms an elevated, curved plateau approximately 250 km in length and 100 km in width, with its highest elevation (882 meters above sea level) found in the Sidi Al-Hamri area near the village of Al-Faidiya, at about 21.50°E longitude and 32.40°N latitude, south of the city of Al-Bayda (Figure 1). The terrain is rugged, as the plateau rises from a narrow coastal plain forming a series of deeply dissected escarpments, followed by intersecting valleys, and finally transitions into flat sedimentary plains that channel seasonal floodwaters into several large flat depressions situated at around 150 meters above sea level (Mahmoud et al., 2022).

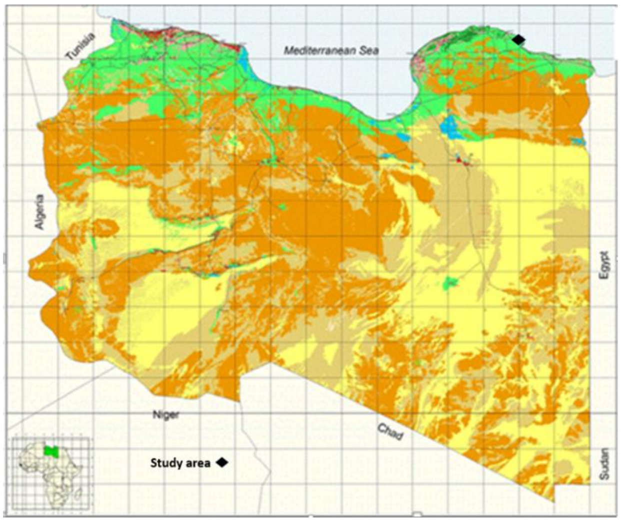

Figure (1): Vegetation cover classification map of Libya showing the location of the study area.

Al-Jabal al- Akhdar experiences a Mediterranean climate with cool, wet winters (November–March) influenced by European cold fronts and long, hot, dry summers (May–

October) accompanied by "Ghibli" winds from the Sahara. Annual rainfall ranges from less than 200 mm on the southern slopes to over 600 mm in the northern highlands due to the orographic effect, with occasional snowfall on the upper plateau (SWECO, 1986). Temperatures vary sharply, dropping below 0 °C in winter and reaching about 35 °C in summer. The mountain's geology consists mainly of Cretaceous and Tertiary carbonate and marl sediments overlying older Palaeozoic formations, forming a long-standing sedimentary basin. Vegetation reflects both climatic and topographic gradients: the northern slopes host typical Mediterranean flora such as *Arbutus pavarii*, *Pistacia lentiscus*, *Juniperus phoenicea*, *Quercus coccifera*, and *Rosmarinus officinalis*, while the southern arid transition zone supports drought-adapted species including *Artemisia herba-alba, Hamada scoparium, Anabasis articulata,* and *Atriplex halimus* (El-Darier & El-Mogaspi, 2009).

Methodology and Research Design:
A field survey was conducted during the summer of 2023 along a 5-km-wide transect extending from Ras Al-Helal village at sea level to Lamlouda village (650 m a.s.l.), the transect was stratified into three elevational levels: Level A (434–650 m), Level B (217–434 m), and Level C (0–217 m) (Table 2, Figure 2). Within each elevational level, three sampling sites were established using a systematic sampling design, with approximately 1.5 km between adjacent sites. At each site, five linear transects, each 100 m in length, and 10 meters between the lines, were positioned using simple random sampling. Consequently, a total of nine sampling sites (three sites per elevational level) and 45 linear transects (15 transects per elevational level) were surveyed across the study area. The same sampling procedure was applied at all elevational levels to ensure consistency and allow reliable comparisons among vegetation communities.

Table (1): Climatic data for the three elevational levels.

Level	Code	Average Annual Rainfall (mm)	Average Annual Temperature (°C)
Top	A	356.0	15.79
Mid.	B	378.8	16.88
Coastal	C	362.9	20.38

Climatic data were compiled from published climatic records and recent regional studies representing the study area. Mean annual temperature for each elevational level was estimated using the standard environmental lapse rate (0.64°C per 100 m elevation difference) with Derna meteorological station as the reference station, whereas rainfall values were obtained from published regional climatic studies(Hunt et al., 2024). These climatic values are presented only to characterize the general environmental conditions of the study area and were not included as measured variables in the statistical analysis.

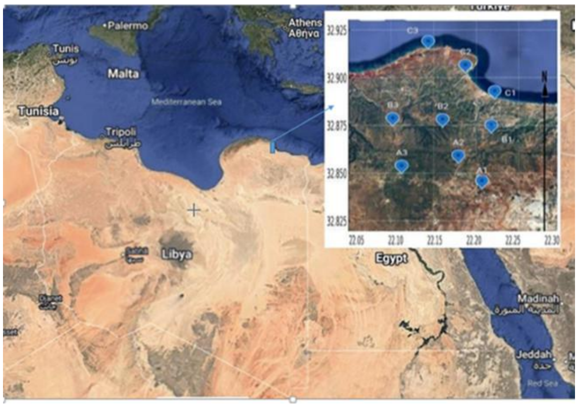

Figure (2): Satellite image of Libya showing the location of the study area and the selected sampling sites.

Table (2): Geographic coordinates and elevation of the selected sampling sites within each elevational level.

Elevation level	Sites	coordinates Latitude	Longitude	Elevation (m)
A	A1	32.778803	22.187785	590
	A2	32.796945	22.149393	636
	A3	32.794678	22.098080	650
B	B1	32.831671	22.174242	237
	B2	32.827908	22.140328	250
	B3	32.857775	22.087446	408
C	C1	32.877901	22.196195	53
	C2	32.905871	22.165858	50
	C3	32.918667	22.147116	45

Measurement of Perennial Plant Species Richness:
All perennial plant species were systematically recorded along each transect within a 10 m belt width. Each species was documented. For each transect, a comprehensive checklist was compiled, detailing the total number of recorded species, their scientific and local names, as well as their corresponding botanical families. Perennial plant species were identified in the field using the available floristic keys and taxonomic references for Libyan and Mediterranean flora. Scientific nomenclature was verified according to currently accepted botanical databases. Species identification was further checked by specialists from the Department of Ecology, Faculty of Natural Resources and Environmental Sciences, Omar Al-Mukhtar University.

Quantitative Assessment of Perennial Vegetation:
The quantitative evaluation of perennial vegetation included the collection of both descriptive and quantitative data for the main species present. The parameters were measured for each perennial species are:
Species abundance: Species abundance expresses the number of individuals of each plant species within the different transects of the study, regardless of their spatial distribution among the fifteen transects. This provided a

percentage contribution of each species to the total vegetation cover, an indicator of species dominance.

Frequency (%): Frequency indicates the extent of distribution of various plant species within the plant community. Communities are often named after the dominant species. The frequency percentage for each species was calculated using the formula:

$$\boldsymbol{F}\,(\%) = \frac{\boldsymbol{n}}{\boldsymbol{N}} * \mathbf{100} \text{........ Equation1}$$

Where F (%) = Frequency (%), n = Number of sampling units in which the species occurred, N = Total number of sampling units. Frequency (%) was calculated separately for each elevational level based on the occurrence of each species across the three sampling sites within that level. Thus, the denominator in the frequency calculation was the total number of line transects (n = 15) within each elevational level. This approach was adopted to identify the dominant perennial species at each elevational level.

Relative Cover (%): Relative cover is a measure that expresses the proportion of individuals of a particular plant species relative to the total number of individuals of all plant species within the studied plant community in a defined sampling area. In this study, the relative cover of each perennial plant species was calculated by dividing the total number of individuals of that species by the total number of individuals of all perennial species recorded across all surveyed transects. The resulting value, expressed as a percentage, represents the contribution of each species to the overall vegetation cover and serves as a reliable indicator of its dominance within the plant community.

$$\boldsymbol{RC}\,(\%) = \frac{\boldsymbol{n}}{\boldsymbol{N}} * \mathbf{100} \text{........ Equation2}$$

Where RC (%) = Relative Cover (%), n = number of individuals of each plant species, N = Total number of individuals plant species

Statistical Analysis

The Least Significant Difference (LSD) test was applied, where number of plant species are dependent variable, and Elevation above sea level Independent variable. Significance level: α = 0.05.

RESULTS AND DISCUSSION

Level A:

The plant community at this elevation includes 12 perennial plant species, belonging to 9 different plant families (Table 3). These numbers indicate a moderate level of biodiversity. The only family represented by more than one species is Fabaceae (Leguminosae), which includes *Ononis mitissima* and Ceratonia siliqua. The most striking feature of this elevation is the strong dominance of two particular species, resulting in reduced competition and a distinct community structure. *Ononis mitissima* is the dominant and most important species, ranking first in importance with the highest relative cover (30.2%) and complete frequency (100%). This absolute dominance suggests that the environmental conditions (e.g., soil type, sunlight exposure, or moisture) are exceptionally favorable for this species, allowing it to outcompete all others. *Pistacia lentiscus* ranks second in importance with a high relative cover (24.5%) and complete frequency (100%).

Although it is a major co-dominant species, it remains slightly overshadowed by *Ononis mitissima.* Its strong presence indicates excellent adaptation to the site's environmental conditions. *Phlomis floccosa* ranks third, with a relative cover of 13.2% and complete frequency (100%). It is a common and widespread species, though not as dominant as the first two. *Juniperus phoenicea* shows a high frequency (77.8%) but a lower relative cover (7.5%), suggesting it occurs widely but in scattered, small individuals unable to compete effectively for space with the dominant dense shrubs (*Ononis mitissima* and *Pistacia lentiscus).* The remaining species play secondary or marginal roles within the community.

Low-cover, low-frequency species (e.g., *Quercus coccifera*, *Ononis mitissima*, *Ceratonia siliqua*, *Stachys aegyptiaca*) are rare, appearing as isolated individuals. Moderate-frequency but low-cover species (e.g., *Olea europaea*, with 55.6% occurrence but only 1.9% cover) suggest a broad but sparse distribution, likely due to competitive exclusion by dominant species.

Table (3): Inventory of perennial plant species at Level A.

Species	Family	F%	RC%	OA
Pistacia lentiscus L.	Anacardiaceae	100	24.5	2
Ononis mitissima L.	Fabaceae	100	30.2	1
Juniperus phoenicea L.	Cupressaceae	77.8	24.5	5
Phlomis floccosa D.	Lamiaceae	100	30.2	3
Rhamnus alaternus L.	Rhamnaceae	44.4	7.5	7
Cistus parviflorus L.	Cistaceae	33.4	13.2	4
Arbutus pavarii Pump.	Ericaceae	44.4	3.8	6
Phillyrea latifolia L.	Oleaceae	33.4	7.5	8
Olea europaea L.	Oleaceae	55.6	6.6	9
Quercus coccifera L.	Fagaceae	33.4	1.9	12

Helichrysum stoechas L.	Asteraceae	66.7	1.9	10
Ceratonia siliqua L.	Fabaceae	44.4	1	11

F% = Frequency%, RC% = Relative Cover %, OA=Order of Abundance

In summary, the results for Level A reveal a perennial plant community strongly dominated by two key species, *Ononis mitissima* and *Pistacia lentiscus*, which together account for approximately 54.7% of the total vegetation cover. This dual dominance indicates selective environmental conditions favoring drought-tolerant and competitive species, limiting the establishment and spread of others. Although 12 species are present, the community structure is unbalanced, with few dominant species and several subordinate or scattered species, resulting in low evenness within the ecosystem.

Level B:

The perennial plant community at this level includes 15 species, representing 11 families, this number indicates good biodiversity. The only two families represented by more than one species are the Oleaceae family, which includes two species: *Phillyrea latifolia* and *Olea europaea*, and the Lamiaceae family, which also includes two species: *Phlomis floccosa* and *Saliva officinalis*, which may indicate the family's longevity. The most notable feature at this level is that no single species competes alone, but rather a group of species participates in monitoring the environment. The forerunner, *Rhamnus alaternus*, is the most important (relative distance 18.8%). This indicates that the pioneer species is well adapted to the requirements of this level and may have a high capacity for resources (water, light, materials).

There is a group of species with a medium to good frequency (66.7%) and moderate relative cover (between 3.1% and 7.3%), which gives them a vital role in increasing the cover and richness of the general vegetation cover. These species are: *Ephedra sinica* and *Saliva officinalis* (7.3% cover each), *Cistus parviflorus* (6.3% cover), *Ceratonia siliqua* (3.1%), and *Helichrysum stoechas* (1% cover, but its frequency of 66.7% indicates its good geographical distribution). There are species with a low frequency (33.4%) and very weak cover (1% - 2.1%), such as *Phillyrea latifolia*, *Olea europaea*, *Quercus coccifera*, *Arbutus pavarii*, and *Ononis mitissima*. These values indicate that these species are rare or specialized in small sub-habitats (such as rocky areas or specific slopes). They have a limited ecological impact on shaping the general vegetation cover, as they appear as scattered individuals.

The results of the second-level vegetation inventory reveal a rich and diverse plant community characterized by the co-dominance of four major species (*Rhamnus alaternus*, *Juniperus phoenicea*, *Phlomis floccosa*, and *Pistacia lentiscus*) rather than the dominance of a single species (Table 4). This indicates an ecological balance where these strong species coexist and share resources, resulting in a dense and complex vegetation cover. The presence of other common species supporting this cover is also evident, along with scattered secondary species occupying specialized niches. Overall, the results demonstrate that the environmental conditions at this level are favorable and stable, allowing for the existence of such a balanced and rich plant community.

Table (4): Inventory of perennial plant species at Level B.

Species	Family	F%	RC%	OA
Pistacia lentiscus L.	Anacardiaceae	100	14.6	4
Sarcopoterium spinosum L	Rosaceae	33.4	3.1	8
Juniperus phoenicea L	Cupressaceae	100	15.6	2
Phlomis floccosa D.	Lamiaceae	100	15.6	3
Rhamnus alaternus L.	Rhamnaceae	100	18.8	1
Cistus parviflorus L.	Cistaceae	66.7	6.3	7
Arbutus pavarii Pump.	Ericaceae	77.8	2.1	10
Phillyrea latifolia L.	Oleaceae	33.4	1	12
Olea europaea L.	Oleaceae	55.6	1	13
Quercus coccifera L.	Fagaceae	33.4	2.1	11
Helichrysum stoechas L.	Asteraceae	66.7	1	14
Rubus fruticosus	Rosaceae	33.4	1	15
Ephedra sinica	Ephedraceae	66.7	7.3	6
Ceratonia siliqua L.	Caesalpiniaceae	66.7	3.1	9
Saliva officinalis	Lamiaceae	66.7	7.3	5

F% = Frequency%, RC% = Relative Cover %, OA=Order of Abundance

Level C:

Based on the data in Table 5, plant diversity is medium to good. The plant community at this elevation level includes 15 perennial plant species belonging to 11 different plant families. These figures indicate moderate biodiversity, as only two families, each containing two species, are represented by more than one species. These include the Oleaceae family, which includes two species: *Phillyrea latifolia* and *Olea europaea*; the Lamiaceae family, which also includes two perennial species: *Rosmarinus officinalis* and *Thymus capitatus*. The data also shows a clear ecological dominance of *Juniperus phoenicea*, with a 100% presence rate. This means that this species was found in all the surveyed areas, demonstrating its widespread distribution and complete suitability for the conditions at this elevation (soil and climate). Very high relative cover (33.3%): *Juniperus phoenicea* alone occupies approximately one-third of the area, making it the dominant species and the main component of the plant community at this elevation level. This indicates that it is a climax species at this level. There is a group of species with good distribution (medium to high prevalence) but with weaker cover, meaning that they are present in many places but as shrubs or small plants that do not occupy large areas. The most prominent of these species are *Pistacia lentiscus*, *Rosmarinus officinalis*, and *Pinus halepensis*, all of which have high prevalence (between 77.8% and 88.9%), indicating their good adaptation to the environment and their wide geographical distribution in the study area. Their relative cover (between 6.4% and 12.8%) is good compared to other species (except *Juniperus phoenicea*), giving them moderate ecological importance. Most of the remaining species (e.g., *Quercus coccifera*, *Cistus parviflorus*, *Ceratonia siliqua*, etc.) show identical and low occurrences (33.4%). This suggests that their distribution is similar and restricted, as they are found in only about one-third of the sampled sites. Their relative cover is very poor (1.3% for most), meaning that they are rare or grow as scattered individuals and do not form a significant vegetation mass. These species may be specialized in specific sub-habitats within this level (e.g., rocky areas, calcareous soils, etc.).

Table (5): Inventory of perennial plant species at Level C.

Species	Family	F%	RC%	OA
Pistacia lentiscus L.	Anacardiaceae	88.9	12.8	3
Sarcopoterium spinosum L	Rosaceae	33.4	1.3	15
Juniperus phoenicea L	Cupressaceae	100	33.3	1
Phlomis floccosa D.	Lamiaceae	66.7	16.7	2
Rhamnus alaternus L.	Rhamnaceae	33.4	1.3	8
Cistus parviflorus L.	Cistaceae	33.4	3.8	7
Arbutus pavarii Pump.	Ericaceae	33.4	1.3	9
Phillyrea latifolia L.	Oleaceae	33.4	1.3	10
Olea europaea L.	Oleaceae	44.4	1.3	11
Quercus coccifera L.	Fagaceae	33.4	1.3	12
Helichrysum stoechas L.	Asteraceae	33.4	1.3	13
Ceratonia siliqua L.	Caesalpiniaceae	33.4	1.3	14
Rosmarinus officinalis	Lamiaceae	77.8	6.4	6
Pinus halepensis	Pinaceae	77.8	9	4
Thymus capitatus	Lamiaceae	66.7	7.7	5

F% = Frequency%, RC% = Relative Cover %, OA=Order of Abundance

Comparison between Elevation levels

A comparative analysis of the three elevational levels reveals a distinct pattern in perennial plant diversity and dominance. Species richness was highest at the coastal and intermediate levels (15 species each), compared to the top (12 species) (Table 6). This aligns with the elevational diversity gradient, where optimal climatic conditions and habitat heterogeneity at mid-elevation often foster peak diversity (Abd El-Ghani & Al Borki, 2024). The decline at the top may be attributed to environmental constraints such as colder temperatures, stronger winds, and shallow soils.

The species composition and dominance structure also varied markedly across the gradient. *Juniperus phoenicea* showed clear ecological dominance at the coastal level (33.3% relative cover), reflecting its adaptation to coastal conditions. In contrast, the intermediate level exhibited a co-dominance of four species (*Rhamnus alaternus*, *Juniperus phoenicea*, *Phlomis floccosa*, and *Pistacia lentiscus*), with similar cover values (14.6% - 18.8%), indicating a balanced community under more favourable environmental conditions (Masoud et al., 2024). At the coastal level, dominance was concentrated in *Ononis mitissima* and *Pistacia lentiscus* (combined cover of 54.7%).

Table (6): Comparison between elevation levels.

Elevation Level	A	B	C	LSD	Significance
Number of Perennial Species	12	15	15	B = C > A	Number of perennial species is significantly higher in the Coastal and Mid-levels compared to the High level.

The shifts in relative cover for key species further underscore this environmental filtering. The cover of *Juniperus phoenicea* decreased consistently with elevation (7.5% → 15.6% → 33.3%), confirming its preference for lower, and more stressful habitats. Conversely, *Pistacia lentiscus* cover increased sharply with elevation (12.8%→14.6%→24.5%), indicating its restriction to milder, higher elevations (Abd El-Ghani & Al Borki, 2024). The relatively low diversity and high dominance by few species at the coastal level may also be influenced by anthropogenic pressures, given the area's tourist activity (Hegazy et al., 2011).

In conclusion, the vegetation structure follows a clear elevational gradient, driven by a combination of abiotic stress, habitat suitability, and likely anthropogenic influence, which collectively modify the classic convex diversity pattern (Di Musciano et al., 2024).

General Discussion

When placing the results in the broader Mediterranean context, the pattern observed in Al-Jabal Al-Akhdar is consistent with vegetation changes reported from several Mediterranean mountain ecosystems, including the Apennines in Italy (Di Biase et al., 2021) and the Sierra Nevada in Spain (Molina-Venegas et al., 2016). Although the magnitude of species richness and species composition differs among mountain systems, these variations reflect differences in local climatic conditions, geological characteristics, land-use history, and disturbance regimes. This regional similarity, together with the unique floristic composition of Al-Jabal Al-Akhdar, emphasizes its importance as one of the principal biodiversity hotspots in Libya and the Mediterranean region.

The present study showed that perennial species richness increased from the high-elevation sites to the mid-elevation sites and remained at a similar level in the coastal zone. This indicates that the mid- and low-elevation zones provide favorable environmental conditions for a relatively higher number of perennial species than the high-elevation zone. The observed differences in species richness are likely related to the combined influence of altitude and associated environmental variation. However, because environmental variables such as soil characteristics, moisture availability, salinity, and grazing intensity were not directly measured, their effects cannot be confirmed by the present study and should be investigated in future research.

The recorded vegetation was dominated by characteristic Mediterranean perennial species, including *Olea europaea*, *Pistacia lentiscus*, *Arbutus pavarii*, *Juniperus phoenicea*, and *Quercus coccifera*. These species constitute the main structural components of the natural vegetation of Al-Jabal Al-Akhdar and play an important role in maintaining ecosystem stability. The floristic composition recorded in this study agrees with previous investigations reporting that the vegetation of Al-Jabal Al-Akhdar is characterized by Mediterranean species adapted to semi-arid environmental conditions (Eldoumi et al., 2002). Likewise, El-Darier and El-Mogaspi (2009) emphasized the exceptional floristic richness of the region, which contains more than half of Libya's recorded plant species. The results confirm that elevation influences the distribution and richness of perennial plant species in Al-Jabal Al-Akhdar forests. Species richness was lower at the high-elevation sites than at the mid- and coastal levels, whereas the latter two levels exhibited comparable richness. These findings indicate that vegetation composition varies along the elevational gradient and highlight the ecological importance of conserving plant communities throughout the different elevational zones. The present study focused on perennial vegetation along an elevational gradient and did not directly measure soil properties, salinity, moisture, grazing intensity, or other environmental variables. Therefore, the observed vegetation patterns should be interpreted primarily as descriptive relationships with elevation. Future studies integrating environmental measurements are recommended to better explain the underlying ecological mechanisms.

CONCLUSION

This study investigated the altitudinal variation in perennial vegetation along a coastal-to-upland gradient in Al-Jabal Al-Akhdar Forest, northeastern Libya. The results demonstrated that perennial species richness varied among the three elevational levels, with the mid- and coastal elevations supporting a higher number of species (15 species each) than the high-elevation zone (12 species). In addition to differences in species richness, marked changes were observed in species composition and dominance structure across the elevational gradient. *Ononis mitissima* and Pistacia lentiscus dominated the high-elevation sites, whereas the mid-elevation sites were characterized by the co-dominance of several species, including Rhamnus *alaternus*, Juniperus phoenicea, *Phlomis floccosa*, and Pistacia lentiscus. In contrast, the coastal sites were clearly dominated by Juniperus phoenicea.

These findings demonstrate that elevation is an important factor influencing the distribution and composition of perennial vegetation in Al-Jabal Al-Akhdar. However, the present study focused on floristic patterns and did not directly evaluate the influence of environmental variables such as soil properties, moisture, salinity, or grazing intensity. Consequently, the observed vegetation patterns should be interpreted primarily in relation to elevation, while the underlying ecological drivers require further investigation.

The present study provides updated field-based information on perennial vegetation in Al-Jabal Al-Akhdar and contributes to the ecological knowledge of Mediterranean mountain ecosystems. The results provide a useful baseline for future vegetation monitoring and support the development of conservation and management strategies aimed at protecting the floristic diversity and ecological integrity of this important forest ecosystem.

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