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Altitudinal patterns of woody vegetation diversity in Al-Jabal Al-Akhdar, a Mediterranean mountain

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Abstract: This study examines the floristic composition, structural attributes, diversity patterns, and distribution of endemic woody species along an altitudinal gradient in the Al-Jabal Al-Akhdar mountain of northeastern Libya. Stratified sampling was conducted across four elevation zones on the northern and southern slopes. Phytosociological parameters – including density, basal area, importance value index, and diversity indices – were assessed, and Pearson correlations were used to evaluate relationships with altitude and aspect. A total of 61 woody species from 43 genera and 26 families were recorded, highlighting the region's biodiversity. Tree and shrub density and basal area increased with elevation, particularly on northern slopes. *Juniperus phoenicea* L. emerged as the most dominant tree, while *Phlomis floccosa* D. Don and *Pistacia lentiscus* L. dominated the shrub layer. Diversity indices showed negative correlations with altitude, indicating declining species richness and evenness at higher elevations under cooler temperatures and greater environmental stress. Ten endemic woody species were documented, with endemic richness positively associated with altitude, reflecting the role of habitat isolation and environmental filtering. These findings provide essential insights for biodiversity conservation, climate adaptation, and ecosystem management in Al-Jabal Al-Akhdar and comparable mountainous ecosystems.

Keywords: elevation; forest ecology; phytosociology; species richness

Mountain ecosystems are globally recognised as biodiversity hotspots and as key contributors to ecological resilience, biogeochemical cycling, and ecosystem service provision (Masoud et al. 2025). Al-Jabal Al-Akhdar, located in northeastern Libya, represents one of the most significant mountain systems in the eastern Mediterranean region. The flora is exceptionally diverse within this unique mountainous terrain, with approximately 1 100 species documented (Al-Jabal Al-Akhdar South Project 2005). Of particular interest is the presence of endemic species, which constitute approximately 4% of the total plant species in the Libyan flora, with more than half of these endemics concentrated in Al-Jabal Al-Akhdar (Al-Jabal Al-Akhdar South Project 2005; Masoud 2016).

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This study conducted a comprehensive field assessment of woody vegetation (trees and shrubs) along altitudinal gradients and across contrasting slope aspects in Al-Jabal Al-Akhdar. The study hypothesises that (*i*) vegetation structure and diversity vary significantly with increasing altitude; and (*ii*) slope aspect further modifies these patterns, producing distinct ecological responses on northern and southern slopes. Pearson's correlation analyses are employed to explore relationships among vegetation metrics and altitudinal zones. By integrating vegetation parameters across environmental gradients, this research contributes to a more comprehensive understanding of the ecological processes governing Mediterranean mountain forests.

MATERIAL AND METHODS

Study area. Al-Jabal Al-Akhdar extends approximately 300 km along a latitude range of 32°00'N to 32°56'N and a longitude range of 20°19'E to 23°08'E (Figure 1). The Al-Jabal Al-Akhdar uplands are characterised by a plateau formation resulting from tectonic uplifts of a primary marine accumulation plain. Its highest point reaches an elevation of 882 m a.s.l. This region assumes paramount significance due to its unique environmental characteristics, notably hosting the only evergreen forest in the Mediterranean, stretching from the Atlas Mountains to the Levant. Its environmental conditions resemble southern European regions such as Italy, the Greek islands, and Turkey (Al-Jabal Al-Akhdar South Project 2005; Masoud 2016).

Data collection. The study area was partitioned into four different study sites for a complete vegetation investigation based on the altitudinal gradient. These sites are designated as Zone I (0–200 m a.s.l.), Zone II (200–400 m a.s.l.), Zone III (400–600 m a.s.l.), and Zone IV (600–800 m a.s.l.). Vegetation examination was performed using the stratified random sample technique, in which random quadrats were placed.

Fourteen quadrants, each measuring 20 by 20 m, were placed at each altitude (7 in the north, 7 in the south). All woody species in each quadrat were counted.

Taxonomists, existing literature, and area flora were used to identify the gathered plants (Boulos 1972, 1997; Jafri, El-Gadi 1993).

The calculation of the importance value index (*IVI*) (Phillips 1959), Shannon–Wiener (*H*) diversity index (Shannon, Wiener 1963), the Simpson concentration of dominance (*Cd*) (Simpson 1949), Pielou evenness (*Jsw*) (Pielou 1975), and Margalef indices (*Dmg*) of species richness (Margalef 1958) were calculated. Together, these indices provide a comprehensive assessment of woody vegetation diversity and distribution across different altitudinal zones and slope aspects.

Statistical analysis. Altitude and slope aspect correlations with key phytosociological indices, density, and basal area were analysed using Pearson correlation in R (R Core Team 2024).

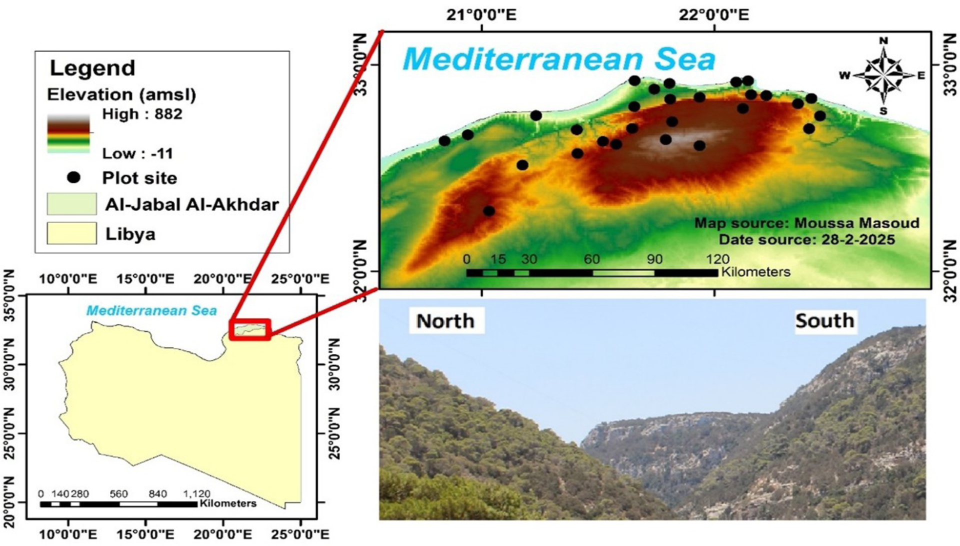

Figure 1. Location of Al-Jabal Al-Akhdar and study area

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RESULTS

The research documented 9 tree species, classified into eight genera and seven families, and 52 shrub species, classified into 35 genera and 21 families, across the altitudinal gradient. The structural features of the forest showed variation in the altitudinal gradient and slopes, as indicated in Table 1.

Altitudinal zone I (0–200 m a.s.l.). A total of 40 woody species were recorded in this altitudinal zone, consisting of 7 tree species (classified into 6 genera and 6 families) and 33 shrub species (classified into 26 genera and 18 families). Their phytosociological attributes and diversity indices are outlined in Table 1. Table 2 presents the values for individual woody species in this zone.

Table 1. Woody species phytosociological attributes and diversity indices at different altitudes on the northern slope and the southern slope

Altitude	Zone I (0–200 m a.s.l.)		Zone II (200–400 m a.s.l.)	
Slope aspect	north	south	north	south
Trees				
Density (individuals·ha^{-1})	396 ± 93	328 ± 87	621 ± 128	646 ± 199
Basal area (m^2·ha^{-1})	16.0 ± 4.3	5.7 ± 1.9	25.9 ± 5.3	12.7 ± 4.0
Number of species/genera/families	7/6/6		8/8/7	
Shannon–Wiener index (*H*)	1.19	1.02	1.30	0.81
Simpson index (*Cd*)	0.47	0.52	0.40	0.64
Pielou evenness index (*Jsw*)	0.61	0.57	0.63	0.45
Margalef index (*Dmg*)	1.27	1.10	1.36	0.96
Shrubs				
Density (individuals·20 m^{-2})	79.7 ± 4.3	60.9 ± 3	121 ± 4.5	88.3 ± 3.2
Number of species/genera/families	33/26/18		44/29/20	
Shannon–Wiener index (*H*)	2.68	2.70	3.00	2.94
Simpson index (*Cd*)	0.13	0.10	0.08	0.07
Pielou evenness index (*Jsw*)	0.78	0.82	0.80	0.81
Margalef index (*Dmg*)	5.05	4.46	6.23	5.60
Altitude	Zone III (400–600 m a.s.l.)		Zone IV (600–800 m a.s.l.)	
Slope aspect	north	south	north	south
Trees				
Density (individuals·ha^{-1})	917 ± 179	342 ± 91	1 192 ± 395	653 ± 169
Basal area (m^2·ha^{-1})	55.9 ± 8.2	12.2 ± 2.5	56.8 ± 11.0	16.46 ± 2.5
Number of species/genera/families	8/8/7		6/6/5	
Shannon–Wiener index (*H*)	1.29	1.05	0.59	0.91
Simpson index (*Cd*)	0.37	0.49	0.72	0.45
Pielou evenness index (*Jsw*)	0.67	0.66	0.33	0.65
Margalef index (*Dmg*)	1.08	0.88	0.86	0.58
Shrubs				
Density (individuals·20 m^{-2})	148.3 ± 6.7	110.3 ± 6	243 ± 17.5	109.57 ± 11
Number of species/genera/families	36/27/18		19/17/11	
Shannon–Wiener index (*H*)	2.71	2.50	2.20	1.87
Simpson index (*Cd*)	0.09	0.12	0.15	0.19
Pielou evenness index (*Jsw*)	0.77	0.75	0.75	0.78
Margalef index (*Dmg*)	4.75	4.21	2.41	1.51

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Table 2. Woody species phytosociological attributes at lower altitudes (Zone I, 0–200 m a.s.l.)

Shrub species	*F*	*D*	*IVI*
Anagyris foetida L.	28.57	0.50	1.42
Calicotome villosa (Poir.) Link	71.43	5.86	16.67
Cichorium spinosum L.	35.71	0.50	1.42
Cistus × incanus L.	42.86	1.71	4.88
Cistus salviifolius L.	42.86	1.43	4.07
Ephedra alata Decne.	14.29	0.21	0.61
Erica multiflora L.	28.57	0.79	2.24
Erica sicula Guss.	28.57	0.43	1.22
Euphorbia dendroides L.	71.43	2.57	7.32
Genista acanthoclada DC.	42.86	0.93	2.64
Globularia alypum L.	21.43	0.64	1.83
Lycium europaeum L.	50.00	1.00	2.85
Lycium shawii Roem. & Schult.	42.86	1.00	2.85
Myrtus communis L.	21.43	0.50	1.42
Periploca angustifolia Labill.	78.57	2.21	6.30
Phillyrea angustifolia L.	64.29	1.36	3.86
Phillyrea latifolia L.	78.57	2.43	6.91
Phlomis floccosa D. Don	100.00	17.93	51.02
Pistacia lentiscus L.	100.00	11.71	33.33
Prasium majus L.	14.29	0.29	0.81
Retama raetam (Forssk) Webb & Berthel.	35.71	0.71	2.03
Rhamnus alaternus subsp. *pendula* (Pamp.) Jafri*	57.14	1.14	3.25
Rhamnus lycioides L.	50.00	1.36	3.86
Rhamnus oleoides L.	78.57	2.29	6.50
Rhus tripartita (Ucria) Grande	42.86	1.00	2.85
Rosmarinus officinalis L.	35.71	1.64	4.67
Salvia fruticosa Mill.	7.14	0.50	1.42
Sarcopoterium spinosum (L.) Spach	42.86	4.57	13.01
Smilax aspera L.	21.43	0.36	1.02
Suaeda pruinosa Lange	42.86	0.79	2.24
Suaeda vera Forssk. ex J.F. Gmel.	21.43	0.64	1.83
Teucrium apollinis Maire & Weiller*	35.71	1.00	2.85
Viburnum tinus L.	14.29	0.29	0.81

Tree species	*F*	*D*	*BA*	*IVI*
Arbutus pavarii Pamp.*	14.29	17.86	0.44	13.77
Ceratonia siliqua L.	57.14	26.79	0.62	20.31
Juniperus oxycedrus L.	14.29	10.71	1.23	16.96
Juniperus phoenicea L.	92.86	250.00	8.13	210.80
Olea europaea L.	42.86	30.36	0.24	18.92
Pinus halepensis Mill.	14.29	12.50	0.27	9.30
Quercus coccifera L.	14.29	14.29	0.23	9.93

*endemic; *F* – frequency (%); *D* – density (tree individuals·ha^{-1} and shrub individuals·20 m^{-2}); *IVI* – importance value index; *BA* – basal area

Table 3. Woody species phytosociological attributes in Zone II (200–400 m a.s.l.)

Shrub species	*F*	*D*	*IVI*
Anagyris foetida L.	21.43	0.5	0.95
Ballota andreuzziana Pamp.*	42.86	0.93	1.77
Ballota pseudodictamnus (L.) Benth.	57.14	1.79	3.40
Calicotome spinosa (L.) Link.	71.43	3.14	5.99
Calicotome villosa (Poir.) Link.	71.43	7.00	13.34
Capparis spinosa L.*	14.29	0.21	0.41
Cichorium spinosum L.	14.29	0.29	0.54
Cistus × incanus L.	85.71	9.43	17.97
Cistus parviflorus Lam.	71.43	6.79	12.93
Cistus salviifolius L.	71.43	7.43	14.16
Ephedra alata Decne.	14.29	0.14	0.27
Erica multiflora L.	35.71	0.86	1.63
Erica sicula Guss.	28.57	0.57	1.09
Euphorbia characias L.	28.57	0.50	0.95
Euphorbia dendroides L.	28.57	0.50	0.95
Genista acanthoclada DC.	7.14	0.29	0.54
Globularia alypum L.	42.86	7.00	13.34
Lonicera etrusca Santi.	21.43	0.36	0.68
Lonicera nummulariifolia Jaub. & Spach.	14.29	0.14	0.27
Lycium europaeum L.	42.86	0.79	1.50
Lycium shawii Roem. & Schult.	35.71	0.43	0.82
Marrubium vulgare L.	50.00	1.14	2.18
Myrtus communis L.	14.29	0.21	0.41
Periploca angustifolia Labill.	35.71	0.86	1.63
Phillyrea angustifolia L.	35.71	1.57	3.00
Phillyrea latifolia L.	71.43	2.57	4.90
Phlomis floccosa D. Don	100.00	12.86	24.51
Pistacia lentiscus L.	100.00	16.21	30.91
Pistacia terebinthus L.	57.14	1.43	2.72
Prasium majus L.	14.29	0.14	0.27
Rhamnus alaternus subsp. *pendula* (Pamp.) Jafri*	57.14	1.79	3.40
Rhamnus lycioides L.	57.14	1.64	3.13
Rhamnus oleoides L.	100.00	4.43	8.44
Rosmarinus officinalis L.	50.00	2.57	4.90
Salvia fruticosa Mill.	14.29	0.36	0.68
Sarcopoterium spinosum (L.) Spach.	57.14	1.64	3.13
Satureja thymbra L.	21.43	1.93	3.68
Smilax aspera L.	7.14	0.14	0.27
Suaeda pruinosa Lange.	28.57	0.64	1.23
Teucrium barbeyanum Asch. & Taub. ex E.A. Durand & Barratte*	50.00	1.07	2.04
Teucrium brevifolium Schreb.	28.57	0.43	0.82
Teucrium davaeanum Coss.*	50.00	0.79	1.50
Teucrium polium L.	50.00	0.93	1.77
Viburnum tinus L.	14.29	0.50	0.95

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Table 3. To be continued

Tree species	F	D	BA	IVI
Arbutus pavarii Pamp.*	57.14	66.07	0.89	25.13
Ceratonia siliqua L.	42.86	14.29	0.27	5.81
Cupressus sempervirens L.*	7.14	8.93	3.05	17.50
Juniperus phoenicea L.	100.00	451.79	13.23	206.28
Laurus nobilis L.	14.29	7.14	0.41	4.22
Olea europaea L.	78.57	42.86	0.75	17.11
Pinus halepensis Mill.	21.43	17.86	1.57	13.21
Quercus coccifera L.	42.86	25.00	0.59	10.75

*endemic; *F* – frequency (%); *D* – density (tree individuals·ha^{-1} and shrub individuals·20 m^{-2}); *IVI* – importance value index; *BA* – basal area

Altitudinal zone II (200–400 m a.s.l.). The altitudinal zone provided 52 woody species, comprising 8 tree species (classified into 8 genera and 7 families) and 44 shrub species (classified into 29 genera and 20 families) (Table 1). Table 3 presents the values of each species' fundamental characteristics.

Altitudinal zone III (400–600 m a.s.l.). A total of 44 woody species were found in the altitudinal zone, consisting of 8 tree species (classified into 8 genera and 7 families) and 36 shrub species (classified into 27 genera and 18 families) (Table 1). Table 4 displays the frequency, density, and *IVI*

Table 4. Woody species phytosociological attributes in Zone III (400–600 m a.s.l.)

Shrub species	F	D	IVI
Anagyris foetida L.	7.14	0.21	0.33
Ballota andreuzziana Pamp.*	35.71	1.07	1.66
Ballota pseudodictamnus (L.) Benth.	64.29	3.64	5.63
Calicotome spinosa (L.) Link.	21.43	1.36	2.10
Calicotome villosa (Poir.) Link	57.14	9.93	15.35
Capparis spinosa L.*	14.29	0.21	0.33
Cistus parviflorus Lam.	50.00	9.29	14.36
Cistus salviifolius L.	50.00	19.07	29.49
Convolvulus maireanus Pamp.*	21.43	0.29	0.44
Ephedra alata Decne.	14.29	0.43	0.66
Erica multiflora L.	42.86	1.21	1.88
Euphorbia characias L.	14.29	0.36	0.55
Euphorbia dendroides L.	14.29	0.29	0.44
Genista acanthoclada DC.	14.29	0.50	0.77
Globularia alypum L.	28.57	14.07	21.76
Lonicera etrusca Santi.	14.29	0.29	0.44
Lycium europaeum L.	35.71	1.71	2.65
Marrubium vulgare L.	57.14	3.00	4.64
Origanum cyrenaicum Bég. & Vacc.*	21.43	0.29	0.44
Phillyrea angustifolia L.	21.43	0.36	0.55
Phillyrea latifolia L.	50.00	2.79	4.31
Phlomis floccosa D. Don	71.43	14.71	22.75
Pistacia lentiscus L.	85.71	18.64	28.82
Pistacia terebinthus L.	35.71	0.79	1.21
Rhamnus oleoides L.	85.71	4.71	7.29
Rubus sanctus Schreber.	14.29	0.14	0.22
Salvia fruticosa Mill.	14.29	0.57	0.88
Sarcopoterium spinosum (L.) Spach.	35.71	10.14	15.68
Satureja thymbra L.	7.14	1.93	2.98
Smilax aspera L.	7.14	0.07	0.11
Suaeda pruinosa Lange.	50.00	2.29	3.53
Teucrium barbeyanum Asch. & Taub. ex E.A. Durand & Barratte*	50.00	1.21	1.88
Teucrium brevifolium Schreb.	50.00	0.93	1.44
Teucrium davaeanum Coss.	50.00	1.14	1.77
Teucrium polium L.	42.86	0.86	1.33
Viburnum tinus L.	14.29	0.86	1.33

Tree species	F	D	BA	IVI
Arbutus pavarii Pamp.*	28.57	123.21	7.01	56.23
Ceratonia siliqua L.	21.43	23.21	2.69	13.95
Cupressus sempervirens L.*	14.29	19.64	7.35	24.20
Juniperus phoenicea L.	100.00	369.64	15.78	155.87
Laurus nobilis L.	7.14	3.57	0.48	2.30
Olea europaea L.	50.00	41.07	1.76	17.34
Pinus halepensis Mill.	14.29	7.14	1.05	4.84
Quercus coccifera L.	21.43	42.86	4.78	25.28

*endemic; *F* – frequency (%); *D* – density (tree individuals·ha^{-1} and shrub individuals·20 m^{-2}); *IVI* – importance value index; *BA* – basal area

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Table 5. Woody species phytosociological attributes in Zone IV (600–800 m a.s.l.)

Shrub Species	*F*	*D*		*IVI*
Ballota andreuzziana Pamp.*	14.29	0.93		1.05
Calicotome villosa L.	42.86	8.79		9.96
Capparis spinosa L.*	21.43	0.43		0.49
Cistus parviflorus Lam.	50.00	5.64		6.40
Cistus salvifolius L.	71.43	47.50		53.87
Lycium europaeum L.	7.14	0.29		0.32
Origanum cyrenaicum Beg. & Vacc.*	14.29	0.71		0.81
Phillyrea angustifolia L.	57.14	3.50		3.97
Phlomis floccosa D. Don	57.14	28.86		32.73
Pistacia lentiscus L.	78.57	22.50		25.52
Rhamnus oleoides L.	64.29	6.29		7.13
Salvia fruticosa Mill.	7.14	0.43		0.49
Sarcopoterium spinosum (L.) Spach.	78.57	31.00		35.16
Satureja thymbra L.	21.43	0.57		0.65
Smilax aspera L.	14.29	0.64		0.73
Teucrium barbeyanum Asch. & Taub. ex E.A. Durand & Barratte*	21.43	1.07		1.22
Teucrium davaeanum Coss.*	14.29	0.36		0.41
Thymus capitatus (L.) Hoffmanns. & Link.	35.71	11.43		12.96
Viburnum tinus L.	35.71	5.43		6.16
Tree Species	*F*	*D*	*BA*	*IVI*
Arbutus pavarii Pamp.*	64.29	678.57	19.30	197.26
Ceratonia siliqua L.	7.14	1.79	1.04	3.02
Cupressus sempervirens L.*	21.43	26.79	6.28	21.75
Juniperus phoenicea L.	92.86	187.50	10.15	66.69
Olea europaea L.	28.57	8.93	0.48	3.16
Quercus coccifera L.	7.14	10.71	2.28	8.12

*endemic; *F* – frequency (%); *D* – density (tree individuals·ha^{-1} and shrub individuals·20 m^{-2}); *IVI* – importance value index; *BA* – basal area

of individual tree and shrub species and the basal area of trees.

Altitudinal zone IV (600–800 m a.s.l.). A total of 25 woody species were documented in Zone IV, comprising six tree species belonging to six genera and five families, as well as 19 shrub species belonging to 17 genera and 11 families (Table 1). Table 5 presents the values for several essential variables (frequency, density, *IVI*, and basal area) for individual woody species within this zone.

The correlation between altitude and community characteristics. The Karl Pearson correlation test indicated a positive correlation with altitude for tree density (r = 0.85) and shrub density (r = 0.93), indicating that areas of higher altitudes exhibit a higher density of vegetation (Table 6). Furthermore, altitude correlates positively with basal area (r = 0.77) and concentration of dominance. Conversely, altitude demonstrated negative correlations with several tree and shrub diversity indices, such as the tree *Dmg* (r = –0.91) and shrub *Dmg* (r = –0.88).

DISCUSSION

Floristic composition of woody species. The floristic survey revealed 61 woody species belonging to 43 genera and 26 families, reflecting the high biodiversity of the Al-Jabal Al-Akhdar area (Figure 2). This finding agrees with earlier botanical studies that highlighted the region's exceptional species richness and ecological importance within the Mediterranean basin (Boulos 1972; Al-Jabal Al-Akhdar South Project 2005).

The basal area of trees and the density of trees and shrubs increased with altitude, indicating a distinct vertical distribution of vegetation within the Al-Jabal Al-Akhdar region. This trend is consistent with the topographical features of the region, including mountainous terrain characterised by altitudinal gradients (Braun et al. 2020). Altitude and slope aspects exhibited a strong positive correlation with the basal area. The increase in the basal area of trees and the density of trees and shrubs can be elucidated by considering the rainfall patterns within the region where the precipitation rate increases significantly with increasing altitude (Al-Jabal Al-Akhdar South Project 2005; Braun et al. 2020). Water availability, crucial for plant growth and development, would facilitate greater productivity and expansion of woody vegetation, particularly at higher eleva-

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Table 6. Karl Pearson correlation coefficients between altitude, slope aspect, and different phytosociological parameters of trees and shrubs

	Elevation	Slope	*BA*	*TD*	*TH*	*TCd*	*TJsw*	*TDmg*	*SD*	*SH*	*SCd*	*SJsw*	*SDmg*
Slope	−0.101 (0.743)												
BA	0.773 (0.002)	−0.680 (0.011)											
TD	0.848 (< 0.001)	−0.503 (0.080)	0.962 (< 0.001)										
TH	−0.842 (< 0.001)	−0.367 (0.217)	−0.402 (0.173)	−0.602 (0.029)									
TCd	0.759 (0.003)	0.397 (0.180)	0.348 (0.244)	0.573 (0.041)	−0.981 (< 0.001)								
TJsw	−0.783 (0.002)	−0.244 (0.422)	−0.471 (0.104)	−0.686 (0.010)	0.956 (< 0.001)	−0.984 (< 0.001)							
TDmg	−0.912 (< 0.001)	−0.306 (0.310)	−0.456 (0.117)	−0.596 (0.032)	0.952 (< 0.001)	−0.877 (< 0.001)	0.836 (< 0.001)						
SD	0.930 (< 0.001)	−0.414 (0.160)	0.936 (< 0.001)	0.976 (< 0.001)	−0.685 (0.010)	0.631 (0.021)	−0.717 (0.006)	−0.716 (0.006)					
SH	−0.857 (< 0.001)	−0.065 (0.833)	−0.491 (0.089)	−0.560 (0.047)	0.767 (0.002)	−0.644 (0.017)	0.616 (0.025)	0.878 (< 0.001)	−0.707 (0.007)				
SCd	0.707 (0.007)	0.003 (0.993)	0.384 (0.196)	0.406 (0.168)	−0.577 (0.039)	0.435 (0.137)	−0.400 (0.176)	−0.724 (0.005)	0.567 (0.043)	−0.962 (< 0.001)			
SJsw	−0.658 (0.015)	0.718 (0.006)	−0.846 (< 0.001)	−0.745 (0.003)	0.226 (0.458)	−0.125 (0.684)	0.215 (0.480)	0.360 (0.227)	−0.794 (0.001)	0.612 (0.026)	−0.633 (0.020)		
SDmg	−0.876 (< 0.001)	−0.174 (0.570)	−0.457 (0.117)	−0.560 (0.047)	0.850 (<0.001)	−0.743 (0.004)	0.707 (0.007)	0.934 (< 0.001)	−0.703 (0.007)	0.988 (< 0.001)	−0.917 (< 0.001)	0.518 (0.070)	

BA – basal area; *TD* – tree density; *TH* – tree Shannon–Wiener diversity index; *TCd* – tree Simpson concentration of dominance; *TJsw* – tree Pielou evenness; *TDmg* – tree Margalef indices; *SD* – shrub density; *SH* – shrub Shannon–Wiener diversity index; *SCd* – shrub Simpson concentration of dominance; *SJsw* – shrub Pielou evenness; *SDmg* – shrub Margalef indices; computed correlation used Pearson method with listwise-deletion

tions and north slopes where moisture levels and organic matter are comparatively higher (Masoud et al. 2024). South-facing slopes in the Mediterranean basin region receive more solar radiation than north-facing slopes. This impacts temperature, soil moisture, nutrient availability, and soil aggregation processes, ultimately affecting plant growth (Alsanousi et al. 2025; Masoud et al. 2025).

Further analysis using *IVI* revealed the dominance of specific species within the woody plant community. *Juniperus phoenicea* L., identified as the most dominant tree species, aligns with previous assertions regarding the Al-Jabal Al-Akhdar forest, which contains more than 60% of the *Juniperus phoenicea* L. (Al-Jabal Al-Akhdar South Project 2005). Similarly, *Phlomis floccosa* D. Don and *Pistacia lentiscus* L. emerged as the most dominant shrub species along the altitude gradient. This observation corresponds with earlier reports highlighting the presence of these species within the Al-Jabal Al-Akhdar region and their ecological significance within the Mediterranean ecosystem (Boulos 1972).

Diversity indices. The strong negative correlations of *H*, *Jsw*, and *Dmg* with altitude reflect a decline in species richness and evenness at higher elevations. Similar altitudinal diversity patterns have been reported globally (Sinha et al. 2018),

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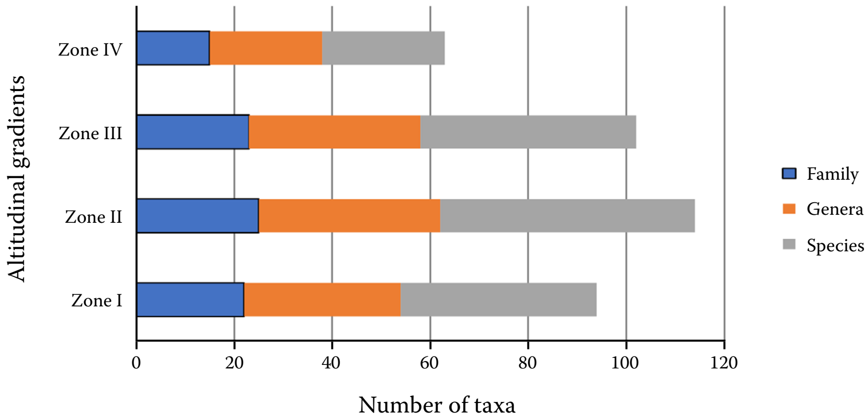

Figure 2. Number of species, genera and families found in Al-Jabal Al-Akhdar mountains in the four altitudinal gradients

but the present findings are also consistent with documented environmental conditions in Al-Jabal Al-Akhdar. Increasing elevation results in cooler temperatures, shallower soils, and reduced habitat diversity, all of which limit the establishment of many woody species (Al-Jabal Al-Akhdar South Project 2005; Masoud 2016).

The present study revealed that Zone IV exhibited the highest recorded *Cd* value, possibly due to the comparatively reduced species richness seen in this particular zone. According to Malik et al. (2015), *Cd*'s value is contingent upon species richness, with lower values indicative of higher species richness. Additionally, the decrease in *Jsw* values suggests a less even distribution of species within these communities, potentially indicating niche specialisation or the dominance of certain species adapted to specific environmental conditions that prevail at higher altitudes. These findings corroborate the theory of altitudinal zonation, which posits that species composition and diversity change with altitude due to changes in environmental factors such as temperature, precipitation, and soil properties (Masoud 2012). The findings emphasise that the upper portions of Al-Jabal Al-Akhdar function as more selective environments, favouring fewer species with greater dominance, while lower elevations maintain richer, more evenly distributed woody communities.

Altitudinal patterns of endemic woody species in Al-Jabal Al-Akhdar. Endemic species play a crucial role in preserving regional biodiversity and are frequently regarded as highly responsive indicators of environmental fluctuations (Theurillat, Guisan 2001).

This study identified 10 species of endemic woody plants in Al-Jabal Al-Akhdar, representing six different families. One of the critical observations of this study was the positive relationship between altitude and the number of endemic woody plant species (Figure 3). As altitude increased, a greater number of endemic species

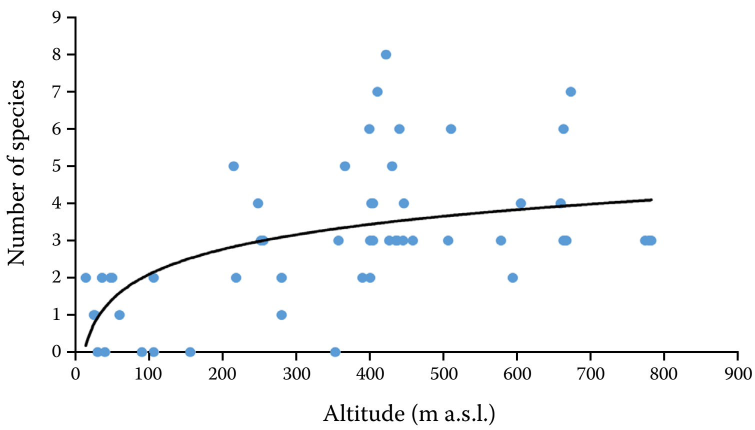

Figure 3. The distribution of endemic species at different altitudes in Al-Jabal Al-Akhdar

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were encountered. This trend aligns with the broader ecological concept that altitude often correlates with increased endemism, as demonstrated in various mountainous regions worldwide (Vetaas, Grytnes 2002; Steinbauer et al. 2016). Altitude can serve as a selective barrier to species distribution in mountain ecosystems, leading to endemic concentration at higher elevations (Steinbauer et al. 2016).

CONCLUSION

This study examines how elevation and slope aspect shape woody vegetation in the Al-Jabal Al-Akhdar forest, Libya. Elevation strongly influences species distribution, with higher altitudes supporting denser canopies and more endemic species, while lower elevations show greater species richness and evenness. Distinct dominance patterns were identified: *Juniperus phoenicea* L. is the leading tree species, and *Phlomis floccosa* D. Don and *Pistacia lentiscus* L. dominate the shrub layer. These findings enhance understanding of ecological patterns in mountainous ecosystems and provide essential guidance for biodiversity conservation and climate-adaptation strategies.

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