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VEGETATION AND SPECIES ALTITUDINAL DISTRIBUTION IN *AL-JABAL AL-AKHDAR* LANDSCAPE, LIBYA

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Abstract

Cyrenaica is the largest phytogeographical region in Libya. The region holds Al-Jabal Al-Akhdar (the Green Mountain) landscape with the richest vegetation and highest species diversity in the country. Field study of the vegetation was carried out in the different habitat types representing the mountainous landscape. Data were analyzed by Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) against the environmental variables. Vegetation and species richness varied with altitude from the sea level, through mid elevation slope vegetation in wadis, to herbaceous and low-shrub-vegetation towards the mountain top. Vegetation is classified into three major groups: (1) coastal and low altitude vegetation dominated by shrubs and trees which constitute about 60% of the plant life forms; (2) mid altitude and wadi vegetation with the highest species richness and dominated by shrubs and trees which constitute over 60% of the plant life forms; and (3) mountain top vegetation dominated by herbs and few low shrubs constituting up to 90% of the plant life forms. The altitude, aspect and soil parameters do not explain the majority of variance in the obtained data which reveal that other diverse local conditions and habitat types seem to be the main determinant of vegetation variation in Al-Jabal Al-Akhdar landscape.

Introduction

Libya comprises three main provinces: Tripolitania, Cyrenaica and Fezzan. Tripolitania extends over the north western corner of the country and Fezzan south of Tripolitania (Fig. 1). Cyrenaica, the largest geographic region, covers the entire eastern half of the country. Tripolitania holds the Nafusah plateau and Cyrenaica houses Al-Jabal Al-Akhdar (The Green Mountain), hereafter abbreviated (GM), which is, true to its name, green and also the most vegetated part of the country. Fezzan is home to desert lands, including the Sahara (Johnson 1973).

The geographical affinity of the flora is mainly East Mediterranean rather than neighboring regions of North Africa (Gimingham & Walton 1954; Scholz 1974; Boulos 1977; Schishov 1980; Le Houérou 1997; El-Kady 2000; Brullo & Furnari 1994; Huerta-Martínez *et al.*, 2004). Much of the indigenous vegetation of Libya consists of surviving remnants of a more favourable climatic age (Keith 1965). The flora of Libya is not rich in the number of species; however, the GM landscape comprises the richest vegetation and the highest number of species known from Libya (Boulos 1972, 1997). This mountainous landscape confines about 50% of the endemic species in Libya (Qaiser & El- Gadi 1984). Southwards, arid climate prevails and xerophytic vegetation is dominant. The total area of the natural forests in the GM was about 500,000 ha of which more than 35% is converted to cropping areas. About 85% of the country's mean production of wood is used in charcoal production (Al-Idrissi *et al.*, 1996), where the mountainous landscape is intercepted by heavily forested wadis.

The GM landscape runs along the north eastern Mediterranean coast and the climate is generated by the northern winds across the Mediterranean Sea and loaded with humidity. Once these humid winds pass over the GM landscape, they are forced upwards on the northern side (Mediterranean facing side) by the sudden rise in topography. As they rise and continue to cool, the air releases its humidity, falling as rain and the air becomes dry, continuing southwards on the southern side into the Saharan desert. This mountainous landscape is of outstanding botanical interest, due to its altitude, to 878 m above sea level, and the geographical "insular" isolation, resulting from the extension of the Libyan Desert to the coast at Agedabia to the west and Tobruk to the East. The geographical affinities of vegetation and flora of the GM area, belongs to the eastern Mediterranean rather than to the neighbouring parts of North Africa and is considered an important center of plant diversity (Davis *et al*., 1994).

Yet, previous studies and reports on the ecology of the GM are fragmented, very limited and rely on qualitative description of vegetation and flora. The rugged topography of the mountainous escarpment of this region have resulted in a paucity of studies on plant ecology (Gimingham & Walton 1954; Drar 1963; Bartolo *et al*., 1977; Boulos 1997, 1972; Le Houérou 1997, 1986).

The present study focuses on the altitudinal distribution of vegetation and species richness in relation to habitat types covering the coastal habitats and mountainous landscape. The northern and southern slopes of the highlands are considered.

Materials and Methods

Study area: The Green Mountain, a low to medium mountainous landscape, is located in the northeast of Libya, reaching 878 m above sea level (Fig. 2 and Table 1), was created as a result of a tectonic elevation of a primary plain of marine accumulation. It is characterized by a Mediterranean climate, with cool rainy winter and hot dry summer (El-Tantawi, 2005).

Table 1. Study sites in *Al-Jabal Al-Akhdar* landscape. Shahat was known as "Cyrene", Susah known as "Appollonia" and Al-Dercya known as "Tolmeita". Altitude = meter above sea level

	Site	Altitude	Longitude	Latitude	Habitat
1.	Deryanah	6.7	32°24'15.16"N	20°25'2.46"E	Coastal plain
2.	Birccess	0.3	32°27'42.72"N	20°27'1.77"E	Coastal sand dune
3.	Birccess	0.3	32°27'40.14"N	20°27'6.54"E	Coastal salt marsh
4.	Al-Dercya 1	81.3	32°40'38.06"N	20°55'20.13"E	Northern slope
5.	Wadi El-Akar	316.6	32°29'58.80"N	20°43'42.04"E	Wadi
6.	Al-Dercya 2	341.6	32°39'43.08"N	20°55'45.65"E	Northern slope
7.	Shahat	351.4	32°50'43.60"N	21°35'14.50"E	Northern slope
8.	Susah	11.2	32°53'45.31"N	21°35'50.17"E	Coastal plain
9.	El Fadil Abou Omar	349.9	32°51'53.90"N	22°17'24.05"E	Northern slope
10.	Wadi Algharega	643.7	32°43'47.30"N	21°46'47.25"E	Wadi
11.	Sidi Ahmad Al-Hemery	855.5	32°37'55.10"N	21°47'22.70"E	Mountain top
12.	Slanta	734.8	32°34'52.20"N	21°41'19.10"E	Mountain top
13.	Qandulah	744.6	32°34'12.60"N	21°39'6.00"E	Southern slope
14.	Al-Marj-Al-Baida motorway 1	425.5	32°29'1.00"N	20°57'10.60"E	Southern dry slope
15.	Wadi El-Kouf	369.7	32°40'57.00"N	21°33'55.00"E	Wadi
16.	Al-Baida-Al-Marj motorway	425.1	32°33'44.50"N	21°11'50.50"E	Southern slope
17.	Al-Marj-Al-Baida motorway 2	533.7	32°28'12.70"N	21° 3'36.70"E	Southern slope

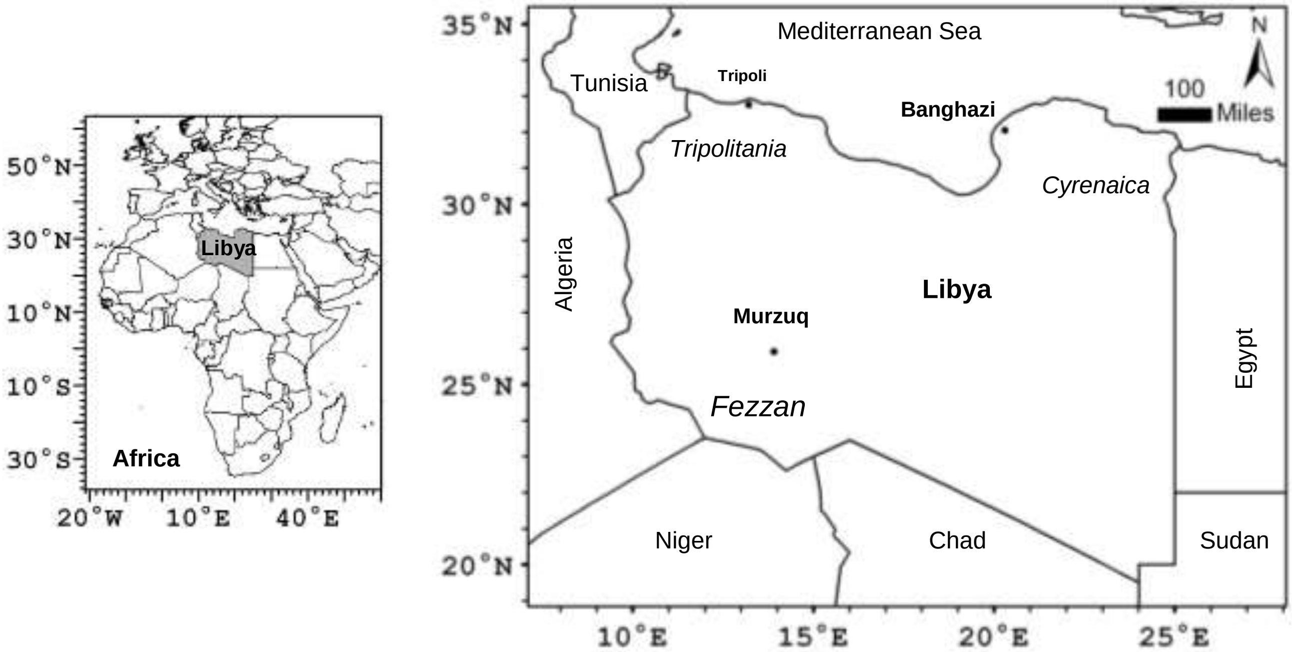

Fig. 1. The location of Libya and the major phytogeographical regions (provinces) of the country: Tripolitania, Cyrenaica, Fezzan.

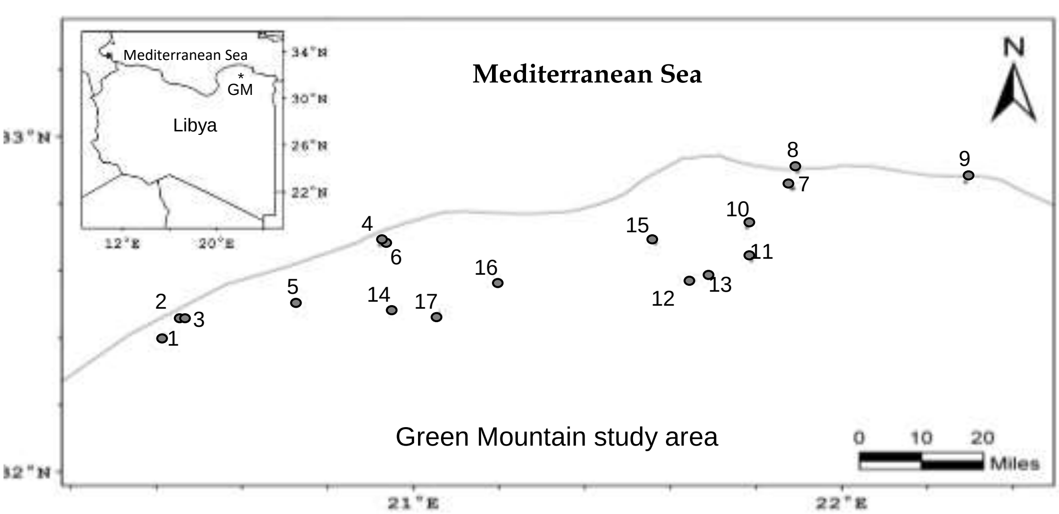

Fig. 2. The study area and site location in *Al-Jabal Al-Akhdar* (The Green Mountain) region. The site numbers are indicated on the map; see Table 1 for detailed information. GM = the Green Mountain.

The average annual rainfall for the country is 26 mm, whereas it reaches 250-600 mm in the GM (Anon., 2000; Al-Idrissi *et al*., 1996). Most precipitation is in the form of rain; snow is rare and the soils are mainly terra-rossa or heavy clay (El-Tantawi, 2005). The temperature decreases with altitude but the rainfall increases. Data from two weather stations: Derna and Shahat, on the northern slope are shown in Fig. 3. Derna has comparatively higher temperature (mean annual temperature 20.10°C) and mean annual rainfall averaged 261.60 mm, and has lower rainfall compared with Shahat in which the mean annual temperature 16.62°C and the mean annual rainfall 542.7 mm (Anon., 2000).

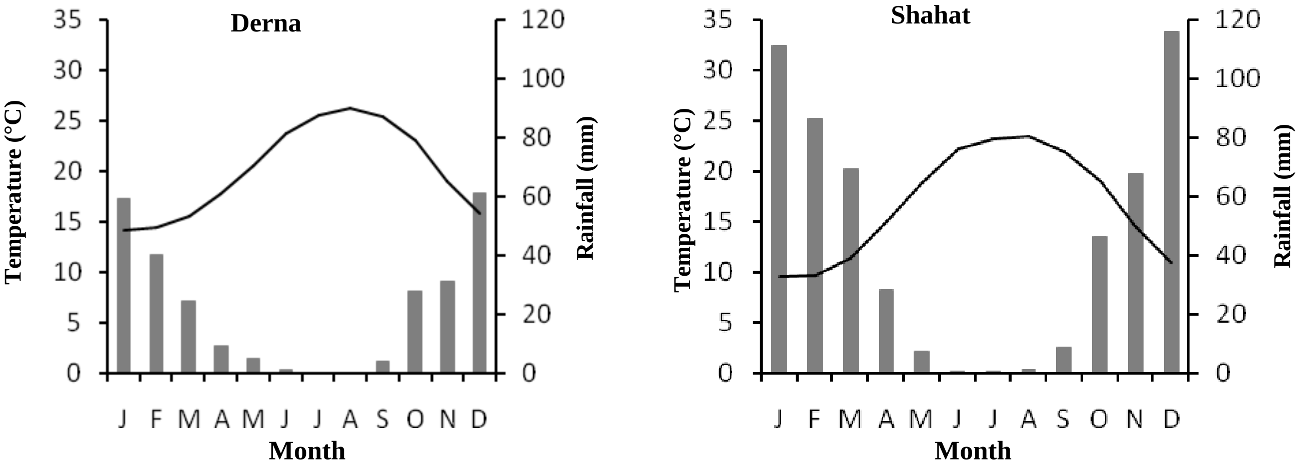

Fig. 3. Mean monthly temperature for Derna and Shahat in *Al-Jabal Al-Akhdar* (Anon., 2000).

Soil analysis: Physical and chemical characteristics of the soil were analyzed following (Allen *et al*., 1974; Isaac & Johnson 1983; Ohno *et al*., 2007). Soil samples were taken at a depth of 20-30 cm. Five replicate samples were taken from each study site, air dried, and sieved through 2mm sieve before analysis. Mechanical analysis was carried out by sieve method. Total organic matter was determined by loss-on-ignition at 450ºC. Calcium carbonate was estimated by titration against 1N HCl. Electric conductivity and soil reaction were determined in soil water extracts 1:5 by using conductivity and pH meter (model Jenway 4330). Mineral ions were measured by atomic absorption (Varian, spectra AA220).

Vegetation: The field study of vegetation was carried out during late April and early May 2008. The landscape in the GM region was subdivided into three major units: (1) the coastal belt with a width varying between a few to several kilometers along the sea; (2) the northern side comprises the sea facing northern and northwestern slopes; and (3) the southern side with the north facing slopes.

A total of 17 stands were investigated along the altitudinal gradient in the GM landscape and were distributed in the different landscape units. The GPS location and altitude was recorded in each study stand (Table 1). Study sites were selected to represent the variation of vegetational, climatic and edaphic characteristics prevalent in the region, taking into consideration a reasonable degree of physiographic and physiognomic homogeneity of both habitat and vegetation. For every stand, a floristic list was recorded from 10 quadrates (10x10 m). Five soil samples, each about 500 g, were pooled together in one composite sample per stand. These samples were dried, sieved through 2mm sieve and stored under lab conditions in paper bags till analysis.

Floristic identification was carried out mainly according to Boulos (1999-2005 and 2009) and Jafri & El-Gadi (1977-1993). Voucher specimens of all recorded plant species were collected, identified and deposited in Cairo University Herbarium (CAI), and Sabha University. A third set is deposited in L. Boulos Herbarium, Giza.

Classification and ordination methods were used to characterize vegetation groups and to reveal possible relationships with environmental variables. Cluster analysis in a matrix of 17 sites x 111 perennial species was performed using Czekanowski coefficient (Ludwig & Reynolds 1988). The Bray-Curtis variance regression ordination was used for the overlay diagrams showing the distribution of some characteristic species in the study sites (McCune & Grace, 2002). These analyses were performed using the software: PC-ORD 4.10 (McCune & Mefford, 1999).

Detrended Correspondence Analysis (DCA) was used to separate vegetation groups and Canonical Correspondence Analysis (CCA) was used to reveal the influence of the study environmental variables (17 sites x 12 variable matrix) on vegetation distribution (CANOCO version 4.5 software; ter Braak, 2008). Regression between the altitude and the number of species was analyzed using the best fit curve. Polynomial equation was used for north facing and south facing slopes (SPSS software version 12).

Results

Soil characteristics: The results in Table 2 demonstrate the differences in soil characteristics supporting the vegetation groups in the study area. The soil texture is generally coarse sand with values ranged from 9% to 84% in sites 13 and 4, respectively. The silt and clay content ranged from 0.4% in the coastal salt marshes (site 3) to 21.5% in the coastal plain (site 1). The mineral ion content is variable among sites, and the pH value slightly alkaline to slightly acidic. The soil organic matter content was variable and ranged from 0.16% to 6.51% in coastal sand dunes (site 2) and the northern slope (site 6), respectively.

Table 2. Soil characteristics of the study sites. See Table 1 for explanation of the site numbers.

Site	CS	FS	SC	Fe	Mg	Ca	K	Na	Cl	PH	EC	OM
1	55.50	22.90	21.50	68.27	22.19	9.36	98.03	154.70	70.86	6.20	81.80	1.07
2	82.00	16.70	1.30	14.92	93.83	963.30	69.92	153.30	5.00	8.17	91.20	0.16
3	48.40	1.20	0.40	9.50	109.50	155.50	30.28	179.20	57.97	5.00	67.60	0.24
4	84.30	7.00	4.10	75.14	22.59	6.33	197.10	169.40	5.00	7.60	166.30	6.63
5	74.00	14.80	9.70	39.97	13.09	461.80	100.10	79.99	143.86	5.00	172.90	3.65
6	83.50	15.40	3.40	71.98	9.93	11.08	99.15	176.30	111.65	7.10	135.50	6.51
7	77.90	13.50	8.20	95.08	9.93	15.71	87.17	40.19	4.00	7.54	142.60	4.32
8	66.20	16.60	11.50	126.40	36.94	14.69	171.10	173.50	100.00	7.72	754.00	2.68
9	57.20	19.80	6.60	86.67	30.95	402.30	91.21	106.70	5.00	7.82	150.20	3.48
10	84.80	7.20	5.30	104.90	32.29	250.60	82.98	192.40	4.00	7.69	130.60	6.47
11	55.50	9.40	3.90	93.09	56.70	536.70	45.42	99.34	4.00	7.61	139.80	3.61
12	48.80	20.10	15.60	124.20	29.22	376.10	116.40	57.40	4.00	7.59	132.90	4.35
13	9.00	73.20	17.80	6.95	114.50	167.20	86.68	20.45	94.48	6.80	94.80	1.40
14	72.40	16.30	10.80	107.30	159.20	78.88	102.30	85.24	4.00	7.41	121.00	4.91
15	74.00	15.60	9.70	112.70	6.14	30.50	86.02	45.14	4.00	7.54	118.30	4.30
16	65.60	18.80	8.20	111.60	56.62	275.00	92.75	72.69	126.68	7.12	206.00	5.65
17	78.30	13.40	8.10	109.50	20.37	233.75	98.42	171.10	88.04	6.90	105.90	5.72

CS = Coarse sand (%), FS = Fine sand (%), SC = Silt and Clay (%), Fe^{+++} = iron concentration in ppm, Mg^{++} = magnesium concentration in ppm, Ca^{++} = calcium concentration in ppm, K^{+} = potassium concentration in ppm, Na^{+} = sodium concentration in ppm, EC = electrical conductivity in µs /cm, and OM = percent organic matter.

Indirect gradient analysis: The cluster dendrogram and the Detrended Correspondence Analysis (DCA) rank the vegetation into six groups (Figs. 4 and 5). Most of the recorded species belong to Asteraceae, Lamiaceae, Apiaceae, Poaceae and Fabaceae, cited in the order of decreasing numbers. Group A clustered the vegetation in the coastal plain (Site 1), coastal sand dune (Site 2) and low elevation rocky sea facing habitats (Site 4); 25 families and 43 species were recorded in this vegetation group (Fig. 6a). Herbs constitute 39.5% of the species pool, shrubs 53.5% and trees 7% (Fig. 6b). The indicator species in group A are: *Atriplex halimus* (shrub), *Echium angustifolium* (herb), *Sarcopoterium spinosum* (shrub), and *Rhus tripartita* (shrub).

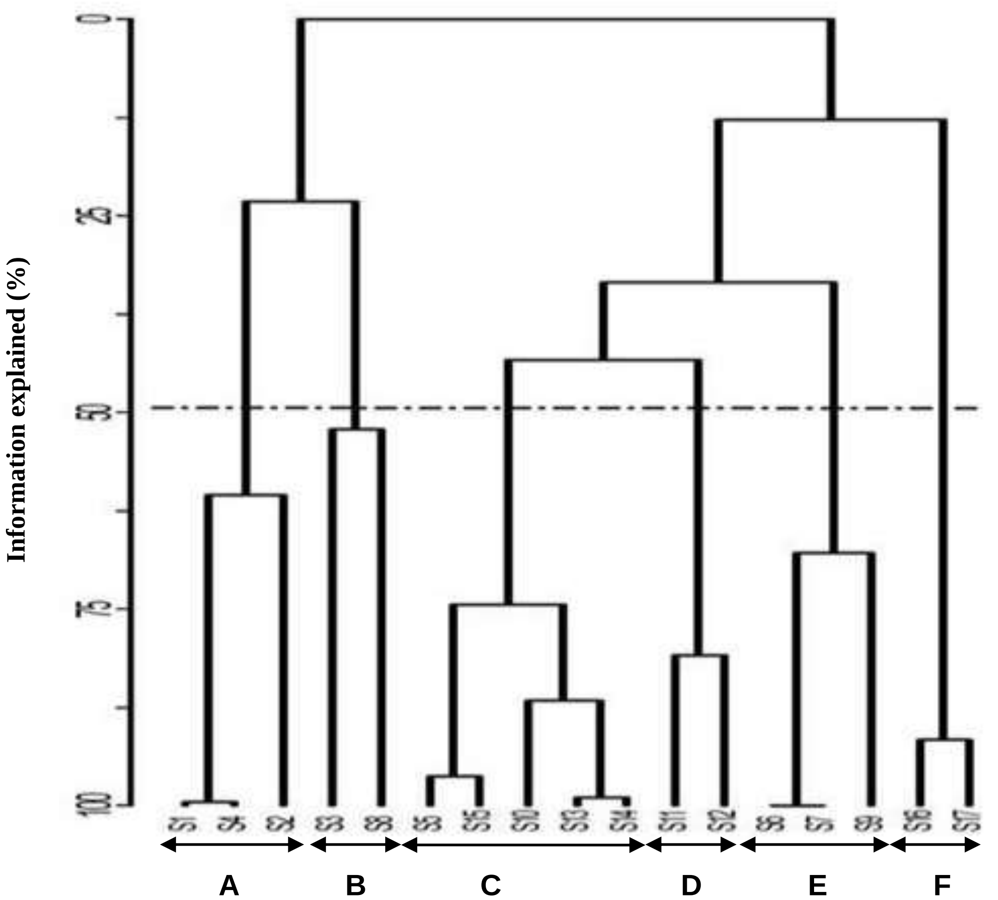

Fig. 4. Cluster dendrogram showing vegetation groups. The principal characteristic species in each group are cited within the text. See Table 1 for explanation of the site numbers.

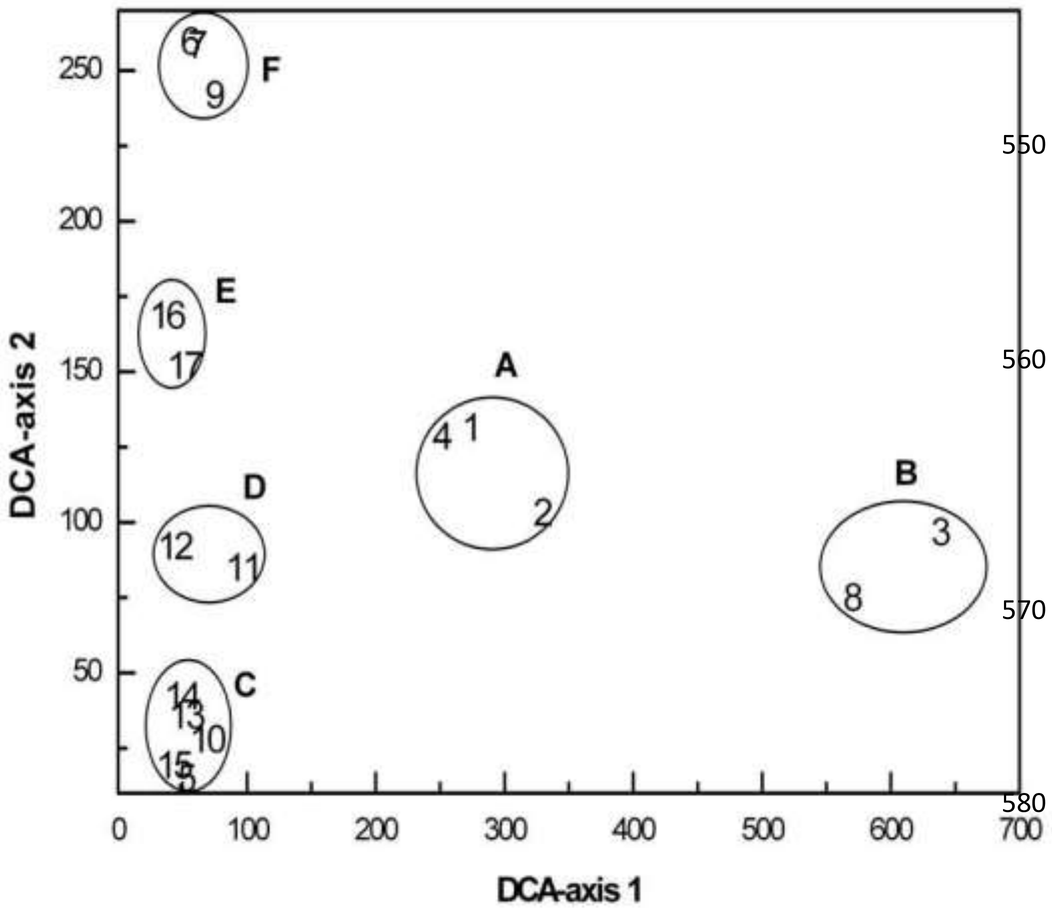

Fig. 5. DCA showing vegetation groups. The principal characteristic species in each group are cited within the text. See Table 1 for explanation of the site numbers.

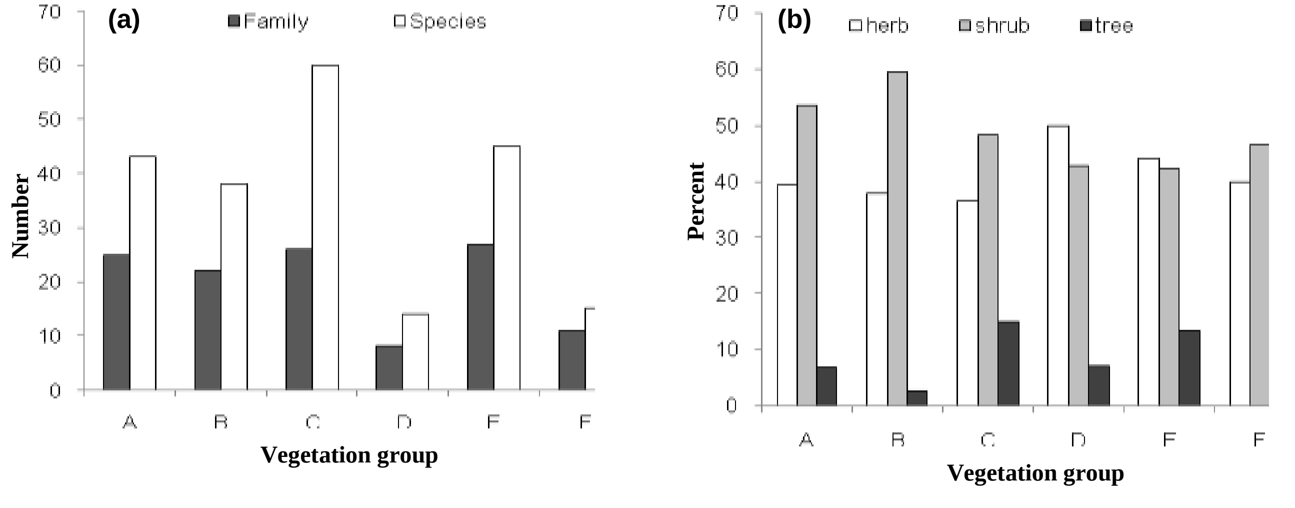

Fig. 6. Total number of families and species (a) and the percentage contribution of herbs, shrubs and trees in the communities of the vegetation groups.

Group B clustered the vegetation in the coastal salt marsh habitats (Site 3) and rocky ridges on the sea coast (Site 8); 22 families and 38 species were recorded in this vegetation group (Fig. 6a). Herbs constitute 38% of the species pool, shrubs 59% and trees 3% (Fig. 6b).The indicator species in group B are: *Cichorium spinosum* (herb), *Echium angustifolium* (herb), and *Phlomis floccosa* (shrub).

Group C clustered the vegetation in the wadi system habitats on the northern side of the mountain landscape (Sites 5, 10, and 15) and on the southern mountain slope (Sites 13 and14); 26 families and 60 species were recorded in this vegetation group (Fig. 6a). Herbs constitute 37% of the species pool, shrubs 48% and trees 15% (Fig. 6b).The indicator species in group C are: *Asphodelus aestivus* (herb), *Arbutus pavarii* (tree), *Juniperus phoenicea* (shrub or tree), *Phlomis floccosa* (shrub), and *Sarcopoterium spinosum* (shrub).

Group D clustered the vegetation in the high elevation (Sites 11 and 12) either north or south facing habitats; 8 families and 14 species were recorded in this vegetation group (Fig. 6a). Herbs constitute 50% of the species pool, shrubs 43% and trees 7% (Fig. 6b). The indicator species in group D are: *Echium angustifolium* (herb), and *Sarcopoterium spinosum* (shrub).

Group E clustered the vegetation around the mid elevation of the southern slopes (Sites 16 and 17); 27 families and 45 species were recorded in this vegetation group (Fig. 6a). Herbs constitute 44% of the species pool, shrubs 42% and trees 14% (Fig. 6b).The indicator species in group E are: *Asphodelus aestivus* (herb), *Cistus parviflorus* (shrub), *Juniperus phoenicea* (shrub or tree), *Calicotome spinosa* (shrub), and *Ephedra alata* (shrub).

Group F clustered the vegetation in the habitats on the northern slope (Sites 9, 6, and 7); 11 families and 15 species were recorded in this vegetation group (Fig. 6a). Herbs constitute 40% of the species pool, shrubs 47% and trees 13% (Fig. 6b). The indicator species in group F are: *Globularia alypum* (shrub), and *Cistus parviflorus* (shrub).

Among the most frequent species recorded in more than 50% of the study sites are: *Sarcopoterium spinosum*, *Phlomis floccosa*, *Echium angustifolium*, *Juniperus phoenicea*, *Cistus parviflorus* and *Globularia alypum*. On the other hand, four endemic species were recorded in our study area: *Arbutus pavarii* Pamp. (tree), *Arum cyrenaicum* Hruby (herb), *Origanum cyrenaicum* Beg. ex Vaccari (shrub), and *Thapsia garganica* Lag. (herb). Among the study species are the trees *Juniperus phoenicea* and *Arbutus pavarii* showing common and restricted distributions, along the mountainous landscape, respectively. *Juniperus phoenicea* attained continuous distribution and was recorded in wadis, northern and southern slopes but lacking in the mountain peak (Fig. 7). However, the endemic *Arbutus pavarii* is restricted to sites belonging to group C; in El-Akar & Algharega wadis (sites 5 and 10) and along the southern side in sites 13 and 14 (Fig. 8).

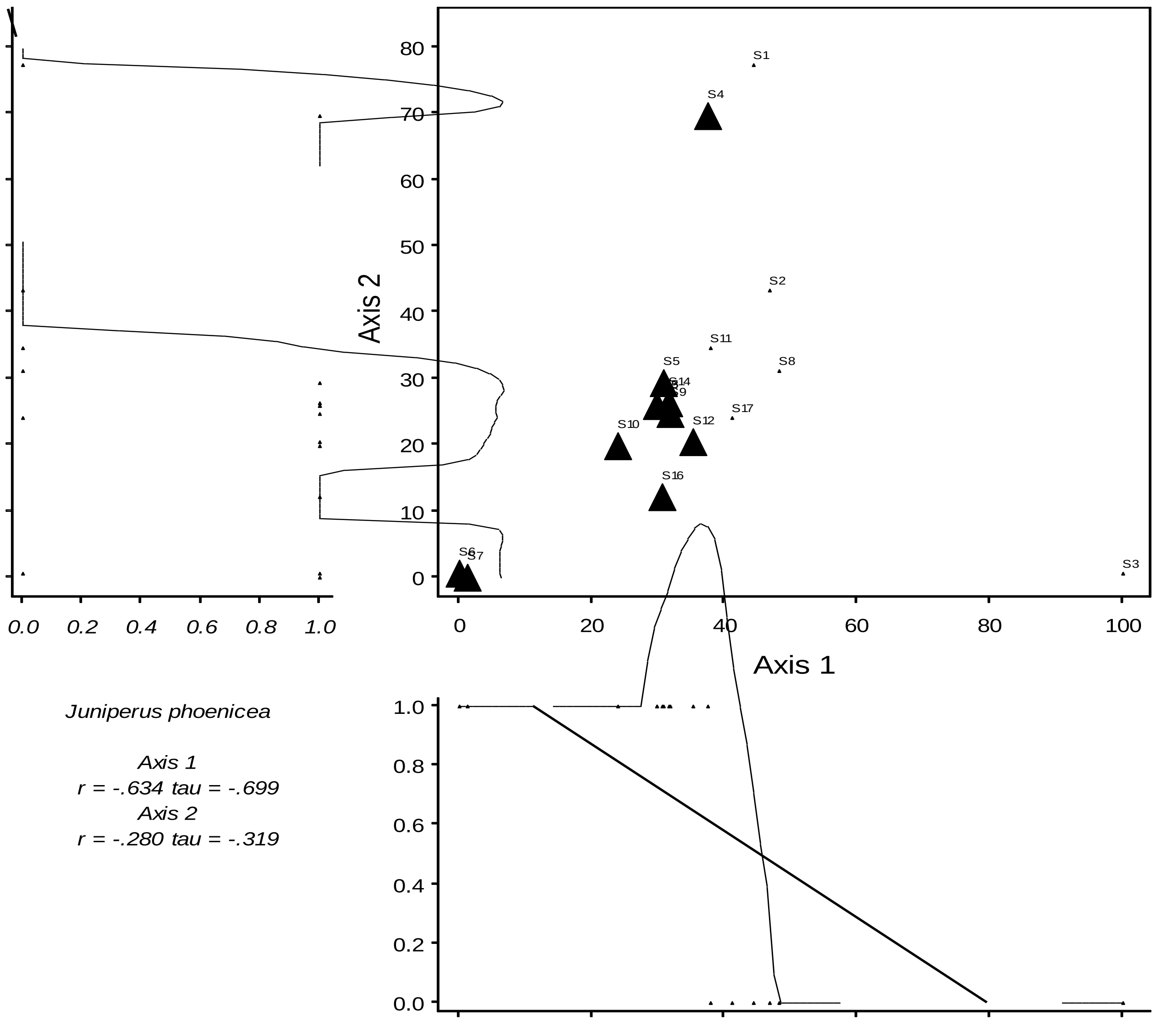

Fig. 7. Overlay diagram showing the distribution of *Juniperus phoenicea* with respect to the first and second axes. See Table 1 for explanation of the site numbers.

Direct gradient analysis: The ordinations of the study sites and species, overlaid with the relevant environmental variables, revealed a stronger eigenvalue and percentage of variance explained for axis 1 reaching 0. 723 and 15.9% respectively followed by axes 2 and 3 with a 38.3% variance explained by the three axes (Figs. 9 and 10, Table 3, and App. Table 1). Axis 1 reflects a gradient comprising sites on northern and southern sides; from coastal (group B), northern slope (group F) to wadis and southern side (group C and E) (Fig. 9). Alternatively, axis 2 reflects an altitudinal gradient from northern slope coastal rocky sites (group A) to the top of the mountain (group D).

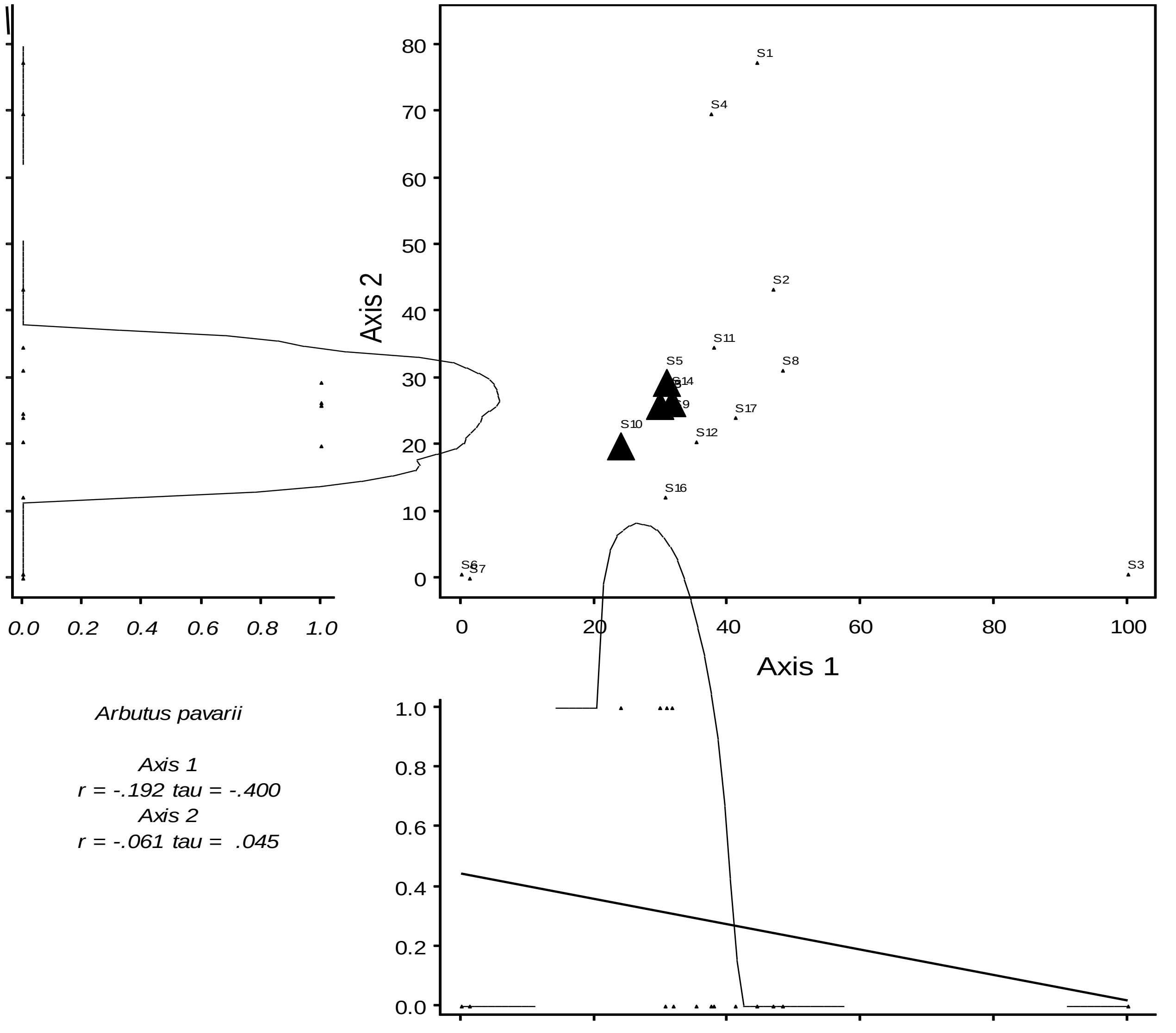

Fig. 8. Overlay diagram showing the distribution of *Arbutus pavarii* with respect to the first and second axes. See Table 1 for explanation of the site numbers.

Table 3. CA-ordination for 111 species and their relationships with the measured environmental variables.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.723	0.553	0.463
Variance explained (%)	15.9	12.2	10.2
Cumulative variance explained (%)	15.9	28.1	38.3

The most important variables which explain variations in the data set are elevation, organic matter percentage, iron concentration and sodium concentration. Elevation and iron concentration occupy intermediate positions with respect to axes 1 and 2. Significant positive correlations are detected between axis 1 and elevation, iron concentration and organic matter percentage (Table 4). Axis 2 is positively correlated with elevation and iron concentration, but negatively correlated with sodium concentration in the soil. Iron concentration is strongly correlated with axis 1, while elevation is strongly correlated with axis 2. Other soil mechanical and chemical variables show non significant correlation with both axes in the ordination diagram. The electrical conductivity is significantly correlated with axis 3. Sites with negative scores on axes 1 and 2 are correlated with magnesium, calcium and sodium concentrations. Sites with positive scores on axes 1 and 2 are correlated with fine sand, silt and clay, potassium concentration, pH and electrical conductivity.

As a major driving variable, elevation is selected to estimate the variation of species richness throughout the mountainous landscape. Species richness shows different patterns with altitude for the northern slope and southern side (Fig. 10). On the northern slope, the number of species slightly increases with altitude, up to about 350 m above sea level, reaching 32 species, then decreases towards the peak of the mountain (about 850 m) (Fig. 11a). On the southern side, the species richness decreases with increasing altitude from 26 species at 428 m, to 7 species at 537 m then increases with altitude where 34 species were recorded at about 750 m (Fig. 11b) which contrasts the low species richness recorded in the highest altitude.

Table 4. Correlation coefficients between environmental variables and ordination CCA-axes. Bold numbers are statistically significant at p<0.05.

Environmental variable	Axis 1	Axis 2	Axis 3
Coarse sand (%)	0.16	-0.358	0.109
Fine sand (%)	0.308	0.158	0.013
Silt and Clay (%)	0.321	0.324	-0.104
Fe^{+++} (ppm)	**0.462**	**0.436**	0.073
Mg^{++} (ppm)	-0.101	-0.159	0.07
Ca^{++} (ppm)	-0.189	-0.287	-0.252
K^{+} (ppm)	0.208	0.002	0.016
Na^{+} (ppm)	-0.238	**-0.470**	0.009
pH	0.134	0.028	0.331
Electrical Conductivity (EC, µs /cm)	0.164	0.016	**0.477**
Organic matter (OM, %)	**0.488**	0.266	-0.04
Elevation (Elev, m above sea level)	**0.366**	**0.578**	0.251

Discussion

The mountainous landscape of *Al-Jabal Al-Akhdar* is characterized by environmental heterogeneity throughout its altitudinal range, from coastal habitat types, through the northern and southern sides including the associated wadis, to the top of the mountain. As in many other mountains in arid regions of the world, this mountainous system is regarded as a humid 'island', in otherwise arid habitats extending southwards (Alford 1985). The habitat heterogeneity throughout this mountainous landscape greatly affects the plant community establishment and species richness.

App. Table 1. Correlation coefficients between plant species and ordination CCA- axes.

Species	Axis 1	Axis 2	Axis 3
Acacia karroo Hayne	**0.781**	-0.327	-0.18
Allium ampeloprasum L.	-0.045	-0.014	0.228
Allium erdelii Zuec.	**-0.613**	**-0.483**	-0.286
Allium roseum L.	-0.02	0.393	-0.35
Ammophila arenaria (L.) Link	0.139	0.195	-0.085
Anagallis arvensis L.	**-0.486**	-0.329	-0.247
Anthemis cyrenaica Cosson	-0.056	0.057	-0.135
Arbutus pavarii Pamp.	-0.192	-0.061	0.201
Arthrocnemum macrostachyum (Moric.) K. Koch	**0.781**	-0.327	-0.18
Arum cyrenaicum Hruby	-0.225	-0.175	0.064
Asparagus aphyllus L.	-0.042	-0.034	-0.16
Asparagus stipularis Forssk.	0.097	0.092	0.029
Asphodelus aestivus Brot.	**-0.592**	**-0.423**	-0.062
Asterolinon linum-stellatum (L.) Duby	**-0.613**	**-0.483**	-0.286
Atriplex halimus L.	0.17	**0.813**	-0.377
Atriplex portulacoides L.	**0.781**	-0.327	-0.18
Ballota pseudo-dictamnus (L.) Benth.	-0.392	-0.36	-0.007
Calicotome spinosa (L.) Link	-0.082	-0.023	0.283
Capparis spinosa L.	-0.573	-0.462	-0.142
Carduncellus pinnatus (Desf.) DC.	-0.051	-0.074	0.139
Carthamus glaucus M.Bieb.	0.1	**0.82**	-0.383
Centaurea cyrenaica Beguinot & Vacc.	-0.041	-0.15	0.753
Ceratonia siliqua L.	-0.089	0.004	-0.127
Cichorium spinosum L.	0.156	0.045	-0.043
Cistus parviflorus Lam	**-0.56**	**-0.501**	**0.477**
Cistus salvifolius L.	-0.151	-0.181	**0.769**
Clematis flammula L.	-0.054	0.024	-0.164
Convolvulus oleifolius Desr.	-0.5	-0.364	-0.18
Crucianella maritime L.	-0.042	-0.034	-0.16
Cupressus sempervirens L.	-0.13	-0.014	0.118
Cynara cornigera Lindl.	-0.082	-0.023	0.283
Cynodon dactylon (L.) Pers.	0.017	0.101	0.186
Cytinus hypocistis L.	**-0.613**	**-0.483**	-0.286
Dactylis glomerata L.	**-0.544**	**-0.429**	-0.34
Dichanthium annulatum (Forssk.) Stapf	**-0.413**	-0.334	-0.211
Echinops spinosus L.	0.139	0.195	-0.085
Echium angustifolium Mill.	-0.259	0.373	-0.414
Ephedra alata Decne.	**-0.517**	-0.226	-0.215
Erodium crassifolium L'He'r.	0.139	0.195	-0.085
Erodium glaucophyllum (L.) L'He'r.	-0.058	-0.185	0.253
Eryngium maritimum L.	-0.068	-0.018	-0.009
Euphorbia characias L.	-0.111	-0.031	0.233
Fagonia cretica L.	0.17	0.813	-0.377
Ferula marmarica Asch. & Taub.	**-0.503**	-0.406	**0.457**
Foeniculum vulgare Mill.	-0.089	0.004	-0.127
Frankenia hirsute L.	**0.552**	-0.195	-0.236
Fumana Arabica (L.) Spach	-0.139	-0.092	0.175

App. Table 1. (Cont'd.).

Species	Axis 1	Axis 2	Axis 3
Galium aparine L.	**-0.541**	**-0.525**	**0.567**
Halocnemum strobilaceum (Pall.) M. Bieb.	**0.781**	-0.327	-0.18
Helichrysum stoechas (L.) Moench	**-0.566**	-0.437	-0.209
Juniperus oxycedrus L.	-0.042	-0.034	-0.16
Juniperus phoenicea L.	**-0.634**	-0.28	-0.095
Limoniastrum monopetalum (L.) Boiss.	**0.684**	-0.206	-0.163
Limonium cyrenaicum (Rouy) Brullo	0.156	0.045	-0.043
Limonium pruinosum (L.) Chaz.	**0.781**	-0.327	-0.18
Lolium perenne L.	0.11	**0.608**	-0.211
Lonicera etrusca Santi	-0.068	-0.018	-0.009
Lotus creticus L.	-0.413	-0.334	-0.211
Lotus glaber Mill.	**-0.613**	-0.483	-0.286
Lycium europaeum L.	0.13	**0.712**	-0.427
Lygeum spartum Loefl. ex L.	-0.042	-0.034	-0.16
Malabaila suaveolens Delile ex Coss.	-0.101	-0.091	0.732
Marrubium vulgare L.	-0.089	0.004	-0.127
Melica minuta L.	-0.042	-0.034	-0.16
Micromeria juliana (L.) Benth. Ex Reichenb.	0.181	**0.721**	-0.35
Micromeria microhpylla (D'Urv.) Benth.	-0.042	-0.034	-0.16
Micromeria nervosa (Desf.) Benth.	**-0.572**	-0.405	-0.211
Moraea sisyrinchium (L.) Ker Gawl.	-0.042	-0.034	-0.16
Nitraria retusa (Forssk.) Asch.	0.139	0.195	-0.085
Olea europaea L.	-0.089	0.004	-0.127
Onopordum cyrenaicum Maire & Weiller	-0.068	-0.027	0.05
Origanum cyrenaicum Beg. ex Vaccari	-0.068	-0.018	-0.009
Pallenis spinosa (L.) Cass.	0.008	0.522	-0.243
Periploca angustifolia Labill.	0.1	**0.82**	-0.383
Phagnalon rupestre (L.) DC.	**-0.613**	-0.483	-0.286
Phillayrea latifolia L.	-0.089	0.004	-0.127
Phlomis floccosa D. Don	-0.48	0.228	-0.401
Pinus halepensis Mill.	-0.054	0.024	-0.164
Pistacia lentiscus L.	-0.438	0.176	**-0.458**
Polygala aschersoniana Chodat	-0.139	-0.092	0.175
Prasium majus L.	-0.054	0.45	0.375
Ptilostemon gnaphaloides (Cyr.) Sojak	**-0.613**	-0.483	-0.286
Reaumuria vermiculata L.	0.156	0.045	-0.043
Reichardia tingitana (L.) Roth	-0.613	**-0.483**	-0.286
Retama raetam (Forssk.) Webb & Berthel.	0.139	0.195	-0.085
Rhamnus lycioides L.	-0.56	-0.419	-0.143
Rhamnus oleoides L.	0.065	0.02	0.085
Rhus tripartite (Ucria) Grande	0.115	0.721	-0.344
Rosmarinus officinalis L.	-0.042	-0.034	-0.16
Salsola longifolia Forssk.	0.672	-0.097	-0.194
Salvia sp.	-0.177	-0.079	0.307
Salvia verbenaca L.	-0.17	**0.487**	**-0.454**
Sarcopoterium spinosum (L.) Spach	-0.526	0.281	**-0.437**
Satureja thymbra L.	-0.413	-0.334	-0.211
Scaligeria cretica (Mill.) Boiss.	-0.141	-0.05	0.008
Scirpoides holoschoenus (L.) Soja'k	0.139	0.195	-0.085
Scrophularia canina L.	-0.613	-0.483	-0.286
Sedum sediforme (Jacq.) Pau	-0.042	-0.034	-0.16
Seriphidium herba-album (Asso) Soj'ak	-0.042	-0.034	-0.16
Serratula cichoracea (L.) DC.	-0.068	-0.018	0.159
Smilax aspera L.	-0.042	-0.034	-0.16
Stachys tournefortii Poiret	-0.155	-0.076	0.347
Suaeda vera Forssk. ex J.F. Gmel.	**0.486**	0.422	-0.48
Tamarix arborea (Sieb. ex Ehrenb.) Bge.	**0.781**	-0.327	-0.18
Teucrium barbeyanum Aschers	**-0.521**	**-0.489**	-0.165
Teucrium polium L.	-0.015	-0.05	-0.017
Teucrium sp.	0.156	0.045	-0.043
Thapsia garganica Lag.	-0.126	-0.065	0.161
Thesium erythronicum Pamp.	-0.105	-0.134	0.395
Thymelaea hirsute (L.) Endl.	0.156	0.045	-0.043
Verbascum sinuatum L.	**-0.488**	-0.092	-0.397

Statistically significant values ($p<0.05$) are bolded

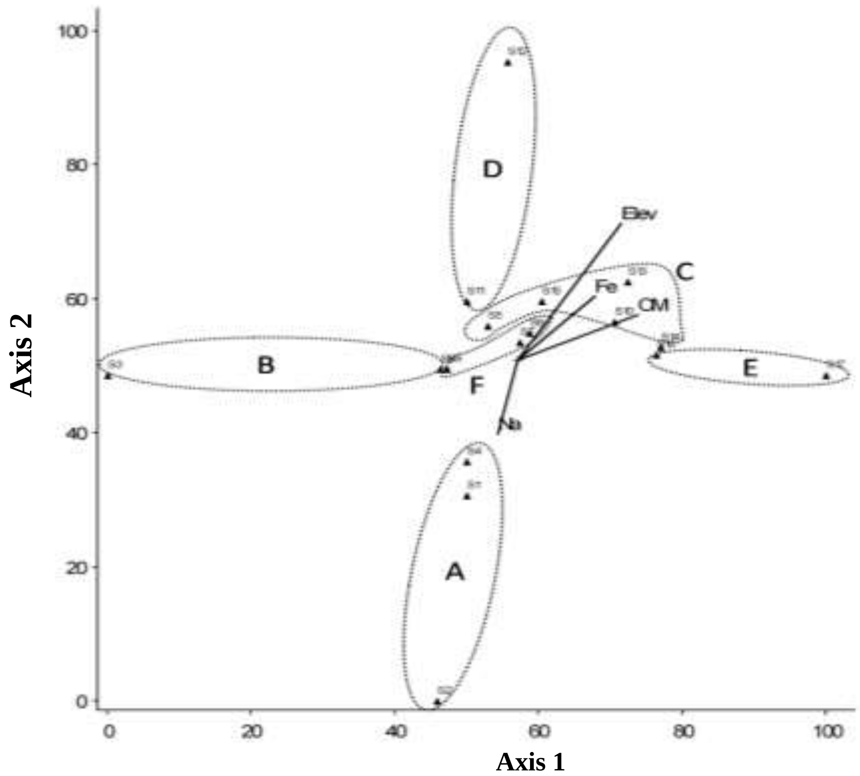

Fig. 9. CCA- ordination biplot of the study sites overlaid with relevant environmental variables (vectors). The cluster groups are indicated.

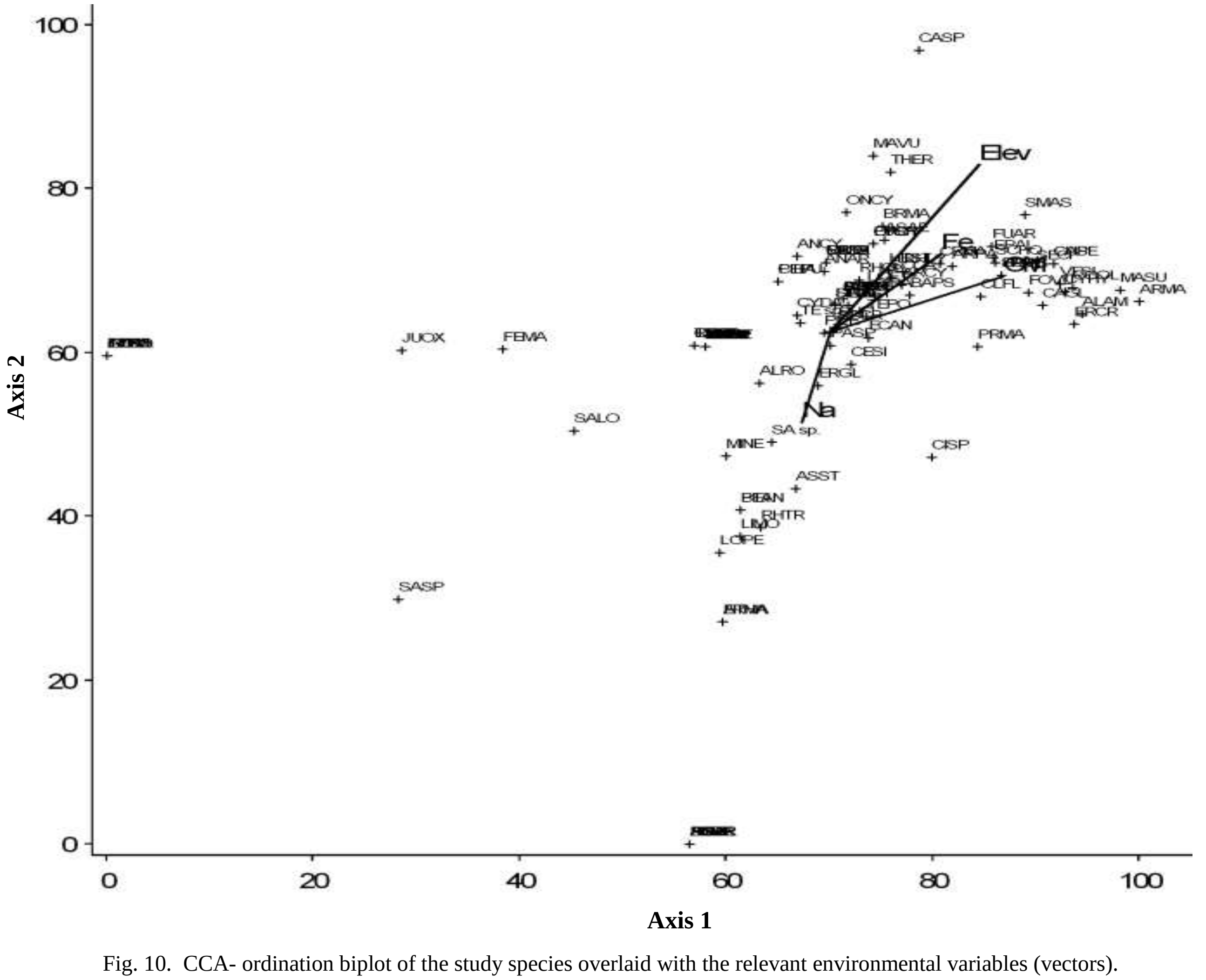

Fig. 10. CCA- ordination biplot of the study species overlaid with the relevant environmental variables (vectors).

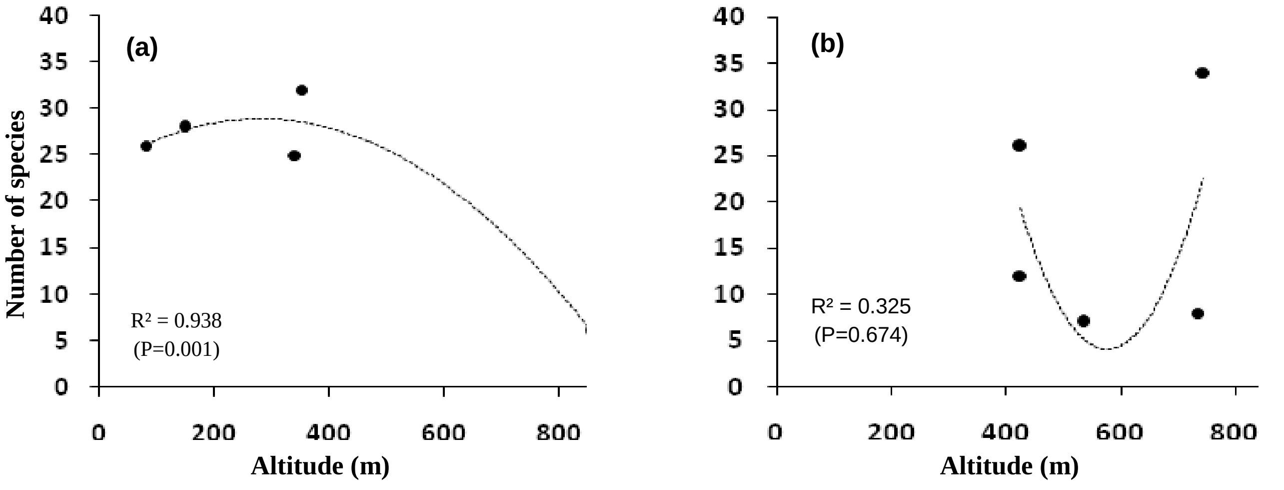

Fig. 11. Relationship between altitude (meter above sea level) and the total number of species in the sites on the northern (a; $y = -0.00007x^2 + 0.039x + 23.41$) and the southern sides (b; $y = 0.0007x^2 - 0.7593x + 223.35$) of the mountainous landscape. Note that wadis are not included in this relationship.

Elevation is admitted by several authors to be a key dominating factor determining the vertical distribution of species and communities in mountain areas (Day & Monk 1974; Busing *et al*., 1992; Hegazy *et al*., 1998, 2008; Hegazy & Amer, 2001; Doležal & Šrůtek, 2002; Jin *et al*., 2008). However, due to the complex topography in the GM; the environmental conditions are diverse and there is no distinct altitudinal pattern of vegetation. It is not surprising that there is no sharp altitudinal differentiation of vegetation and species distribution as the GM is rather a mountainous landscape dissected by wadis than a cone-shaped mountain.

The coastal landscape: Plant diversity in the coastal habitats are classified into two groups: group B, holds species in the coastal salt marsh habitats and rocky ridges along the sea coast; and group A holds species in the coastal sand dunes and low elevation sea-affected habitats on the northern side of the mountain. The coastal habitats are comparatively rich in the number of species, ranging from 38 to 43 species, belonging to more than 20 families. Among all study area, the highest percentage contribution of shrubs was recorded in the coastal habitats. The coastal habitats are separated from other study habitats in the CCA ordination biplot as the coastal vegetation is affected by magnesium, calcium and sodium concentrations contrary to other vegetation types. On the other hand, elevation, organic matter percentage and iron concentration are negatively correlated with sites in groups A and B.

The northern side landscape: Habitats on the northern side of *Al-Jabal Al-Akhdar* are more heterogeneous and occupy a wider range of elevation than those on the southern side. Plant diversity in the northern side of the mountain are separated from the species pool within four groups: group A including the lower parts of the mountain, group C including the wadis, group F characterizing the northern slopes habitat at mid elevation and group D characterizing the top of the mountain. The vegetation varies with altitude from the sea level habitat types (group A), through the mid elevation slope vegetation (group F) intersected by richer vegetation in the wadis (group C) to herbs and low shrub vegetation at the top of the mountain (group D).

The altitudinal patterns of plant species richness are mainly affected by the patterns of water and temperature conditions, altered along an altitude gradient which creates a variety of habitats (Hegazy *et al*., 1998; Zhao *et al*., 2005; Hegazy *et al*., 2008). The temperature decreases by an average of about 0.64 °C for each 100 m increase in elevation (El-Tantawi, 2005). Moreover, the aerological influence of the mountain on sea water vapour loaded winds, which pass over, increases the possibility and amount of precipitation at higher altitudes (El-Tantawi 2005; Grytnes *et al*., 2006). However, in the present study, the species richness did not differ substantially on the slope than on the mountain top, i. e. elevation did not affect the species richness of the northern slope vegetation. On the other hand, variations on the level of the life form and species diversity were obvious; the slope vegetation (group F) comprised a higher percentage of trees and shrubs, and lower one of herbs towards the mountain top (group D). Grytnes et al. (2006) stated that the vegetation composition responds more strongly to altitude than to species richness.

In tropical and cold temperate mountains, the species richness decreases with elevation, as the decrease in temperature with altitude limits the distribution of plant species (Zhao *et al*., 2005). In contrast, in *Al-Jabal Al-Akhdar*; as in mountains of subtropical regions, the highest species diversity lies at middle altitudes in group F and C. This may be explained by the positive effect of increased precipitation with elevation in subtropical regions. Meanwhile, the adverse effects of decreasing temperature were not met until high elevations near the top of the mountain (Grytnes *et al*., 2006).

Wadis dissecting the northern side of the mountain landscape have specific topograpgy creating localized microclimate favourable for richer vegetation, as regards the number of species and percentage of shrub and tree composition in the community (El-Bana & El-Mathnani 2009). In contrast to the northern slope, which is exposed to direct wind coming from the sea, the wadi vegetation is protected within the wadi channels. Possible temperature inversion in wadis, created by the altered topography on the northern slope at the location of wadis, contributes to the production of variation between the slope and wadi vegetation. Furthermore, the mountain slope serves as catchment area attracting extra rain to the wadi vegetation.

The southern side landscape: Habitats on the southern side of the mountain landscape are affected by the topographic effect on the wind and precipitation creating varied habitat types in the way that a simple linear relationship between species richness and altitude would be unreliable. Generally, elevation is an important factor affecting the amount of precipitation along a mountain range (Dhar & Rakhecha 1980; Al-Sodany *et al*., 2003). But other authors as Alpert (1985) and Buytaert (2006) found that the correlation between elevation and precipitation is weak, because other factors are strongly involved as slope and aspect. Consequently, elevation is not the sole determinant of species distribution but other variables as aspect, wind direction and slope may determine, to a large extent, the microclimate such as radiation, precipitation, and temperature, thus controlling the spatial distribution and pattern of vegetation (Allen & Peet, 1990; Busing *et al*., 1992; Holten, 1998; Körner, 1999; Stage & Salas, 2007).

The species on the southern side may be recognized into three groups: group E characterizing habitats on the southern slope, group C including other habitats with rich vegetation on the same side, and group D characterizing the top of the mountain. Groups C and E do not show distinct altitudinal discrimination throughout the southern side of the mountain. Different elevations on the southern side may show locations at similar latitudes, but differing in elevation, varying greatly in temperature and rainfall and consequently in species composition (El-Tantawi, 2005; Grytnes *et al*., 2006; Hegazy *et al*., 2008).

The percentage of herbs decreases from the mountain peak (50%) to the slope (37-44%). The opposite is observed for the tree species, where the percentage increases from 7% on the peak to 13-15% on the slope. The decrease in species richness towards the top of the mountain may be explained by the more dry and harsh conditions (Grytnes *et al*., 2006). Similarly, Zhao *et al*., (2005) found that the altitude is negatively correlated with plant species diversity along the mountainous altitudinal gradient.

The northern versus southern side landscape: Aspect is among the main topographic factors that control the species distribution and patterns of vegetation in mountain areas, both attitudinally and horizontally, through control of the microclimate, slope weathering, erosion, and deposition processes (Burnett 2008; Jin *et al*., 2008). Slopes on mountain side aspects show contrasting microclimate which varies on north- and south-facing side of a mountain (Branson & Shown 1989; Kirkby *et al*., 1990; Burnett, 2008). Obviously, the same vegetation type may develop on both sides of *Al-Jabal Al-Akhdar* at higher elevations along the southern side, as compared to the northern side. Along the northern side, group C comprising the richest of the study habitats, is confined to the wadis at an elevation ranging from 316.69 m at Wadi El-Akar to 643.74 m at Wadi Algharega. However, on the southern side, group C characterize habitats at an elevation ranging from 425.50 m at the dry slope of Al-Marj-Al-Baida motorway to 734.87 m at Slanta. This variation may be explained by the mountain climate which is characterized by spatial and temporal variability. Usually, windward slopes (northern and northwestern, in case of the *Al-Jabal Al-Akhdar*) receive significantly more rains than the leeward slopes (southern, in case of *Al-Jabal Al-Akhdar*) receiving warmer air masses and greater amount of insolation (Cantlon 1953; Smith, 1977; Gommes, 2002). As air approaches the mountain landscape, it rises upwards along the mountain producing clouds and precipitation on the northern and northwestern side, then descends downwards along the southern side where precipitation decreases because its situation in the rain shadow (El-Tantawi 2005; Jin *et al*., 2008). Probably the slopes of Qandulah and Al-Marj-Al-Baida motorway (sites 13 and 14) lying east and west of the southern side and belonging to group C, are more influenced by the precipitation climate on the northern and northwestern sides of the mountain. In this case, richer vegetation turn up, with higher percentage of shrubs and trees, compared to other sites on the southern slope belonging to group E. The southern side may hold better vegetation than the northern side depending, not only on the elevation range, but on the prevailing microclimate (Cantlon, 1953; Jin *et al*., 2008).

Common species in different habitat types: *Al-Jabal Al-Akhdar* faces the sea from its northern and northwestern sides. The coastal belt of the mountain landscape varies between salt marsh, sand dune and rocky ridge habitats. The characteristic species in the salt marshes communities (site 3, Birccess) are: *Limoniastrum monopetalum*, *Arthrocnemum macrostachyum*, *Suaeda vera*, *Atriplex portulacoides*, *Limonium pruinosum*, *Tamarix arborea*. The sand dune vegetation (site 2, Birccess) is dominated by *Ammophila arenaria*, *Scirpoides holoschoenus*, *Lycium europaeum*, *Asparagus stipularis* and *Nitraria retusa*. The community types in the coastal rocky ridge vegetation (Site 8 to 9, Susah to El Fadel Abu-Omar) are dominated by *Cichorium spinosum*, *Limonium cyrenaicum*, *Arum cyrenaicum*, *Asparagus stipularis*, *Frankenia hirsuta*, *Teucrium polium*, *Ballota pseudo-dictamnus*, *Micromeria juliana*, *Herniaria glabra*, *Reaumuria vermiculata*, *Thymelaea hirsuta*, *Sedum sediforme*, *Sarcopoterium spinosum*, and *Crucianella maritime*.

The northern slopes (sites 4 and 6, Al-Dercya) community type is characterized by *Juniperus phoenicea*, *Cistus parviflorus*, *Phlomis floccosa*, *Teucrium barbeyanum*, *Globularia alypum*, *Pistacia lentiscus*, *Rhamnus lycioides*, *Calicotome spinosa*, *Ephedra alata*, *Scrophularia canina*, *Ballota pseudo-dictamnus*, and *Dactylis glomerata*. At higher elevation in Shahat area (site 7) the common species in the community types are *Juniperus phoenicea*, *Satureja thymbra*, *Cistus parviflorus*, *Phlomis floccosa*, *Verbascum sinuatum*, *Calicotome spinosa*, *Ephedra alata*, *Cistus parviflorus*, *Sarcopoterium spinosum*, *Arum cyrenaicum*, *Rhamnus lycioides* and *Pistacia lentiscus*. Similarly, the slopes in Al Fadel Abou-Omar (site 9) are dominated by *Rosmarinus officinalis*, *Juniperus phoenicea*, *Juniperus oxycedrus*, *Ephedra alata*, *Teucrium* sp., *Micromeria microhpylla*, *Calicotome spinosa*, *Asparagus aphyllus*, *Convolvulus oleifolius*, *Seriphidium herba-album*, *Cistus parviflorus*, *Pistacia lentiscus*, and *Sarcopoterium spinosum*.

The top of the mountain in Sidi Al-Hemery (site 11) is characterized by *Sarcopoterium spinosum*, *Thapsia garganica*, *Tragopogon porrifolius*, *Echium angustifolium* and many other ruderal herbs, while the mountain top in Slanta (site 12) communities are characterized by *Juniperus phoenicea*, *Sarcopoterium spinosum*, *Asphodelus aestivus*, *Onopordum cyrenaicum*, and *Thapsia garganica*.

Vegetation on the southern dry slopes (sites 13, 14, 16 and 17) is characterized by *Juniperus phoenicea, Arbutus pavarii, Cynara cornigera, Phlomis floccosa, Capparis spinosa, Globularia alypum, Pistacia lentiscus, Cupressus sempervirens, Ferula marmarica, Cistus parviflorus, Cistus salvifolius, Sarcopoterium spinosum, Serratula cichoracea, Rhamnus lycioides, Euphorbia characias, Ephedra alata, Teucrium barbeyanum, Calicotome spinosa, Convolvulus oleifolius,* and *Malabaila suaveolens.*

The wadi vegetation (sites 5, 10, and 15) is characterized by *Arbutus pavarii*, *Pistacia lentiscus*, *Phillayrea latifolia*, *Ceratonia siliqua*, *Olea europaea*, *Marrubium vulgare*, *Cupressus sempervirens*, *Juniperus phoenicea*, *Phlomis floccosa*, *Cistus parviflorus*, *Cistus salvifolius*, *Stachys tournefortii*, *Micromeria nervosa*, *Polygala aschersoniana*, *Pistacia lentiscus*, *Asparagus stipularis*, *Onopordum cyrenaicum*, *Calicotome spinosa*, *Phillayrea latifolia*, *Eryngium maritimum*, *Thapsia garganica*, *Lonicera etrusca*, *Anthyllis vulneraria* , *Origanum cyrenaicum*, *Euphorbia characias*, *Sarcopoterium spinosum* and *Globularia alypum*.

The microclimate determines the species composition and richness along both sides of the mountain landscape. Variation in species diversity is not always affected by the slope aspect (Zhao *et al.* 2005). Some of the studied species exhibit broad ecological amplitude by occurring in several habitat types along both northern and southern sides of the mountainous landscape. These species are recorded in more than 50% of the study sites, including: *Sarcopoterium spinosum*, *Phlomis floccose*, *Echium angustifolium*, *Juniperus phoenicea*, *Cistus parviflorus*, and *Globularia alypum*. In contrast, other species are endemic and have restricted distributions. Four perennial species are recorded as endemic to *Al-Jabal Al-Akhdar*. These species are *Arbutus pavarii* Pamp., *Arum cyrenaicum* Hruby, *Origanum cyrenaicum* Beg. ex Vaccari, and *Thapsia garganica* Lag. Endemism is fairly low in Libya; out of about 1825 native plant species 134 species are endemic (7.3%). *Al-Jabal Al-Akhdar* is one of the four major centers of endemism which holds about 50% of the total endemic species in Libya (Boulos, 1997; Davis *et al*., 1994).

The fact that elevations above the sea level, aspect and soil parameters do not explain the majority of variance in the data, leaves the diverse local conditions and habitat types as the main determinant of vegetation variation. Another explanation may be the disturbance of vegetation due to overgrazing or over collecting of firewood and other human activities that always influence the pattern and distribution of vegetation negatively or even destroy old vegetation types and creating new ones (Zunni, 1977; Aquiteen, 1985; Fekete *et al*., 2000; Hegazy *et al*., 2004). Accordingly, more varied vegetation cover was found in wadis and in probably remote sites. Al-Idrissi *et al*., (1996) recorded extreme degradation of tree species through mismanagement and overexploitation for making fire wood and clearing natural vegetation for reclamation of cropping lands.

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