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Vegetation and Environment of Gebel Serbal, South Sinai, Egypt

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ABSTRACT

This study aimed to analyze the floristic composition and the distributional behavior of plant communities in relation to the main physiographic features and soil properties in Gebel Serbal. Canopy cover of plant species and altitude were measured in 58 stands (20 m x 20 m). Gravel percentage, soil texture, hygroscopic moisture, pH, electric conductivity, total carbonate, total nitrogen, available phosphorus, and soil organic matter were determined in each stand. The results revealed that Serbal Mountain is characterized by distinguished microhabitats and low to moderate human impact that result in unique floristic composition and vegetation patterns. One hundred and six species were identified in this study including 11 endemic species, and 36 characteristic species. Based on multivariate analyses, seven main plant communities were recognized in Gebel Serbal area. Distribution of the plant communities was more related to altitude, hygroscopic moisture, and gravel percentage rather than to sand, silt and clay fractions, soil organic matter, and total nitrogen. The present study indicates that Gebel Serbal is the most diverse area in South Sinai, and has a high conservation value. We recommend that Gebel Serbal, a part of St. Katherine Protectorate, should be declared as habitat/species management area.

Key words: Gebel Serbal, Mountainous habitats, plant communities, multivariate analysis, edaphic factors, endemic species, conservation.

INTRODUCTION

South Sinai is characterized by an arid to extremely arid climate, sparse vegetation of sub-shrubs restricted to wadis or growing on slopes of rocky hills and in sand fields, and paucity of trees (Danin, 1986). The flora of South Sinai comprises 520 species (Danin, 1983). Mountains in South Sinai support mainly Irano-Turanian steppe vegetation dominated by *Artemisia herb-alba*. They represent a great harbor of endemism where the area has wetter climate than the rest of Sinai and characterized by having large outcrops of smooth-faced rocks, which support rare species (Zohary, 1973; Danin, 1986; Moustafa and Klopatek, 1995).

Twenty-six endemic species are recognized at four main mountains; Gebel Cathrina, Gebel Serbal, Gebel Musa, and Gebel Umm Shomar (Moustafa *et al*., 2001). Gebel Serbal supports 143 plant species including 11 endemic species (Moustafa *et al*., 2001), 75 medicinal species, and 40 threatened species (Abd El-Wahab *et al*., 2004), which is represent about 14% of the threatened species in Sinai Peninsula (Boulos and Gibali, 1993).

Although, many ecological studies have provided quantitative assessment of vegetation of South Sinai (e.g., Ramadan, 1988; El-Ghareeb and Shabanna, 1990; Moustafa, 1990; Moustafa and Zaghloul, 1993; Helmy *et al*., 1996; Zaghloul, 1997; Abd El-Wahab, 2003), only general qualitative information about the vegetation of Gebel Serbal is known (Danin, 1983; Moustafa *et al*., 2001).

Due to its diversity and conservation value, and as a part of St. Katherine Protectorate, detailed information about the flora and vegetation of Gebel Serbal is essential for conservation and management purposes. This paper aimed to provide a quantitative analysis of the floristic composition and vegetation of Gebel Serbal, and to clarify the relationships between distribution of the characteristic vegetation units and environmental factors including topography, altitude and some soil factors.

MATERIALS AND METHODS

Site Description

Gebel Serbal (2070 m) lies in the middle of South Sinai close to the Gulf of Suez. It is mainly granite with some metamorphic rocks and alluvial deposits covering the wadi floor. The study area receives about 70 to 100 mm annual precipitation (Danin, 1983). Gebel Serbal area has a variety of landform types: gorges, terraces, slopes, wadis, and intermountain plains. It has two main basins; the first basin comprises Ain Lousa, Shaqq Shaarany gorge, Wadi Gohaier, and Wadi Aliyat, whereas the second basin comprises Wadi Ba'athran and Wadi Rem (Fig. 1).

(1) Wadi Aliyat

Wadi Aliyat, one of the main tributaries of Wadi Feiran, is characterized by hot climate and low amount of rainfall. It is about eight kilometer long. Its width varies between 150 and 200 m at the downstream and middle parts, and then becomes narrow (about 50 m or less) upward to the upstream. The wadi is surrounded by metamorphic mountains up to 200 m height, and filled with alluvial deposits of mainly large stones mixed with coarse to fine rock fragments. Low terraces are present at both sides of the wadi.

(2) Wadi Gohaier

It is a short (about 2 km length), narrow (20-50 m wide), and high gradient wadi. It is characterized by the presence of water pond called Ain Gohaier, a fissure

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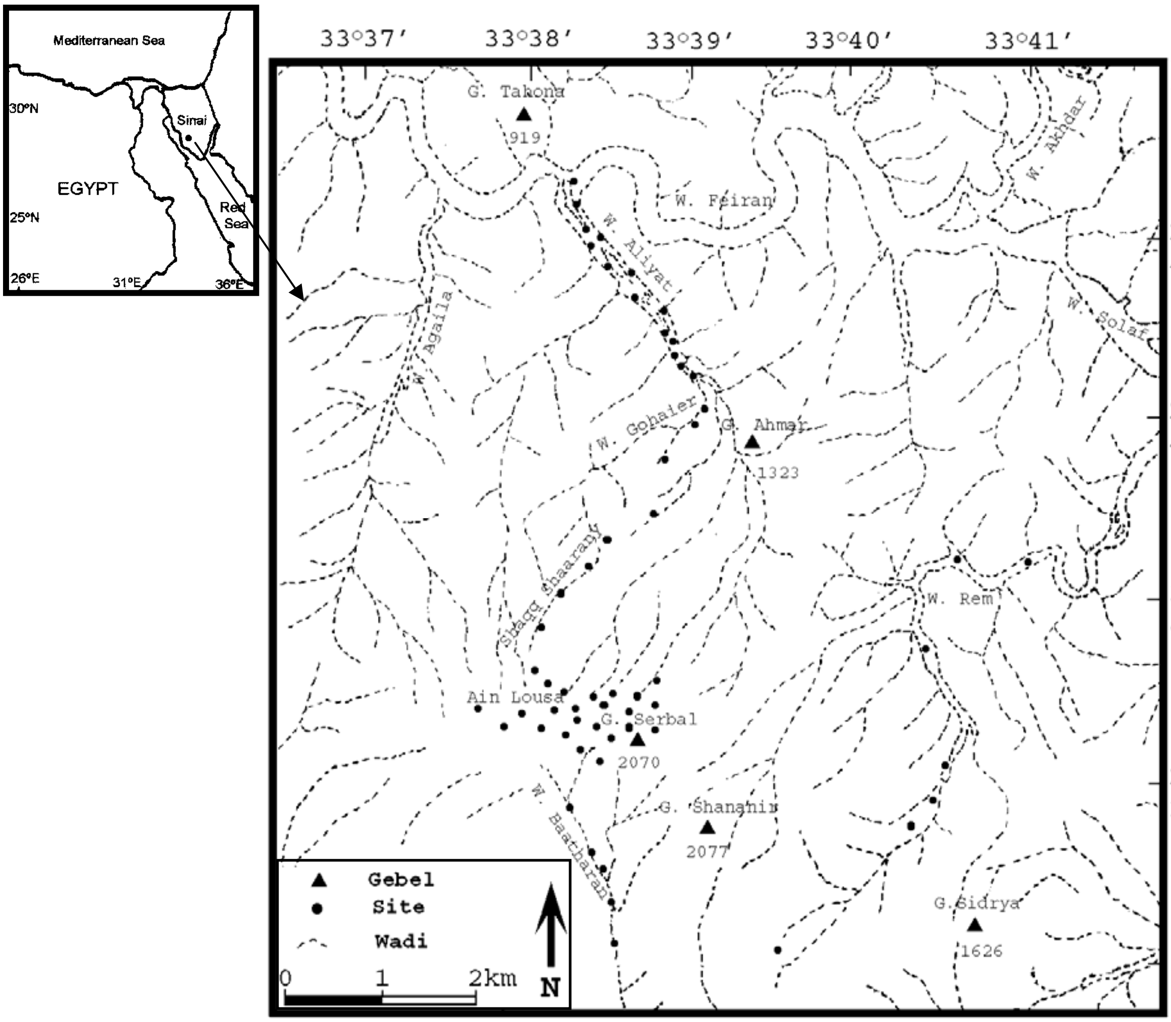

Figure (1): Location map showing the 58 sites selected at the six main localities in Serbal Mountain area.

spring issued from the jointed granite rocks and surrounded by steep sided of low hills (930 m a.s.l).

(3) Shaq Shaarany Gorge (700-1600 m a.s.l)

It is very rugged and narrow (about 20 m width) gorge. Partly, the gorge has steep slope but mostly it has high slope ranging from 75 to 80°. It mostly runs through granite of smooth faced outcrops and intercepted with few dykes. Boulders of large sizes are fallen along the main course of the gorge.

(4) Ain Lousa

It is a small intermountain plain (about 3750 m^2), lies near the summit of Gebel Serbal. It is characterized by a permanent water spring issued from fractured granitic rocks, and consequently, tourists use the area for camping. This small plain is formed as a result of intersection of more than two fault planes and filled up by gouge materials resulted by the movements along the fault planes. The area is a conjunction of many tracks or pathways of small wadis and gorges of rugged and narrow nature.

(5) Wadi Ba'athran

It is a very rugged and narrow wadi (about 10 m width) characterized by many faults and joints. The upstream of this wadi lies at elevation of 1710 m a.s.l. The floor of the wadi is mostly covered with cobbles and small stones.

(6) Wadi Rem (1230-1140 m a.s.l)

It is a long wadi (about 10 km long) running through smooth-faced granitic mountains. The wadi starts at the foothills of Serbal Mountain and pours into Wadi Solaf. Mean width of the wadi reaches about 50 to 75 m, and characterized by deep soil and loose surface in the mainstream parts. Towards the east, the aridity and slope of the wadi increase. In rainy years, it receives a considerable amount of water.

Vegetation and Soil Survey

Vegetation survey was carried out in six main localities at Serbal Mountain area through selection of 58 stands (20 m x 20 m) in a restricted random approach along wadi beds, slopes, and gorges. These localities are Wadi Aliyat, Wadi Gohaier, Shaqq Shaarany, Ain Lousa, Wadi Ba'atharan, and Wadi Rem (Fig. 1).

At each stand, canopy cover of each plant species was measured and ranked according to the following scale: <1% cover = 1, 1-5% = 2, 6-10% = 3, 11-20% = 4,

>20% = 5. Täckholm (1974) was followed for identification of plant species, while updating species names followed Boulos (1995, 1999, 2000, and 2002). Growth forms of plant species were described according to the following scale: annual, perennial herb, sub-shrub, shrub, and tree (modified after Boulos, 1999, 2000, and 2002).

Latitude, longitude and altitude (using GPS receiver "Trimble model") were recorded. The nature of soil surface was described using the following scale: sand < 2 mm, gravel 2-7.5 mm, cobbles 7.5-25 cm, stones 25-60 cm, and boulders > 60 cm (Hausenbuiller, 1985).

Surface soil samples, as a mixture from 0 to 20 cm depth, were collected under canopy of the dominant species. Soil analyses included hygroscopic moisture, particle-size distribution (Richards, 1954; Gee and Bauder, 1986), pH, EC, total carbonate, total nitrogen, soil organic matter, and available phosphorus (Sparks *et al*., 1996).

Data Treatment

Statistical analyses of the data involving Pearson correlation, multiple regression analyses, and analysis of variance (ANOVA) were carried out (Zar, 1984) using SPSS software version 10.

Multivariate analyses were carried out using PC-ORD software version 4 (McCune and Mefford, 1999). Rare species with presence less than 3% and/or plant cover less than 1% were excluded in order to mitigate noise and summarize redundancy (Gauch, 1982). Cover of 70 plant species measured in 58 stands were classified using Two-way Indicator Species Analysis (TWINSPAN) (Hill, 1979). Ordination using Canonical Corresponding analysis (CCA) (ter Braak, 1986) was employed to interpret the species/environment relationships.

RESULTS

Species Diversity and Floristic Composition

Gebel Serbal is characterized by a high richness of plant species (143 species). These 143 species belong to 39 taxonomic families and 112 genera. Compositae is the most represented family (23 species), followed by Labiatae (15 species), Gramineae (13 species), Leguminosae (10 species), and Scrophulariaceae (10 species). Flora of Serbal Mountain includes 21% annuals (30 species), 33% perennial herbs (48 species), 22% sub-shrubs (32 species), 18% shrubs (26 species), and 5% trees (7 species).

The recorded species in the 58 stands are 106 species including 11 endemic. Thirty-six species, having more than 15% presence and / or 10% cover, are considered as characteristic species of Gebel Serbal. The characteristic species include three trees (*Acacia tortilis* subsp.*raddiana, Colutea isteria,* and *Pistacia khinjuk*), nine shrubs, 11 sub-shrubs, and 13 perennial herbs (Table 1).

Table (1): Endemic and characteristic species of Serbal Mountain area. Occurrence numbers refer to the localities as follows: 1 = W. Aliat, 2 = W. Ghohaier, 3 = Shaqq Shaarany, 4 = Ain Lousa, 5 = W. Ba'tharan, and 6 = W. Rem.

Endemic species
Anarrhinum pubescence Fresen., Sub-shrub, 2,4,5,6
Ballota kaiseri Taekh., Perennial herb; 3
Buffonia multiceps Decne., Sub-shrub; 3,4
Hypericum sinaicum Boiss., Perennial herb; 1,2,4,5
Nepeta septemcrenata Benth., Perennial herb; 4
Origanum syriacum L. subsp. *sinaicum* (Boiss.) Greuter & Burdet, Perennial herb; 2,3,4
Phagnalon sinaicum Bornm. & Kneuck, Sub-shrub; 4,5
Phlomis aurea Decne., Perennial herb; 3,4
Polygala sinaica Botsch., Sub-shrub; 3,4,5,6
Silene leucophylla Boiss., Perennial herb; 1,3,4
Silene schimperiana Boiss, Perennial herb; 3,4
Tree species
Acacia tortilis (Forssk.) Hayne subsp. *raddiana* (Savi) Brenan; 1,2,6
Colutea istria Mill.; 3,4
Pistacia khinjuk Stocks v. glaberrima; 4,5
Shrub species
Anabasis articulata (Forssk.) Moq.; 2,3,6
Atraphaxis spinosa L.; 1,2,4
Cotoneaster orbicularis Schltdl; 1,3,4
Crateagus x sinaica Boiss.; 3,4
Deverra triradiata Hochst. ex Boiss.; 4
Ephedra alata Decne.; 3,4
Ficus palmata Forssk.; 2,3,4
Globularia arabica Jaub. & Spach; 1,3,4,5
Retama raetam (Forssk.) Webb & Berthel; 1,2,6
Sub-shrub species
Anarrhinum pubescence Fresen.; 2,4,5,6
Artemisia herba-alba Asso.; 2,4,5
Artemisia judaica L.; 1,6
Buffonia multiceps Decne.; 3,4
Fagonia mollis Delile.; 1,2,6
Heliotropium arbainense Fresen.; 1,2,3,4,5
Kickxia macilenta (Decne.) Danin; 2,3,4,5
Polygala sinaica Botsch.; 3,4,5,6
Pulicaria crispa (Forssk.) Oliv.; 2,4
Stachys aegyptiaca Pers.; 2,4,5
Varthemia montana (Vahl) Boiss.; 4,5
Perennial herb species
Ballota undulate (Fresen.) Benth.; 2,4,5
Echinops spinosissimus Turra; 3,4,5
Galium sinaicum (Delile ex Decne.) Boiss.; 1,4,7
Juncus rigidus Desf.; 1,2,4
Mentha longifolia (L.) Huds.; 2,4,5
Origanum syriacum L.subsp. sinaicum (Boiss.) Greuter & Burdet ; 2,3,4
Phlomis aurea Decne.; 3,4
Poa sinaica Steud.; 2,4
Polypogon viridis (Gouan) Breistr.; 2,3,4
Silene leucophylla Boiss.; 1,3,4
Silene linearis Decne.; 3,4
Tanacetum santolinoides (DC.) Feinbrun & Fertig ; 3,4
Verbascum sinaiticum Benth.; 2,4,5

Gorge and slope habitats represented by Shaq Shaarany and Ain Lousa are higher in number of genera, species richness, and number of endemic species than wadi habitats represented by Wadi Aliyat, Wadi Gohaier, and Wadi Ba'athran (Fig. 2). Ain Lousa supports the highest numbers of genera (60 genus), species richness (68 species), and endemic species (9 species). On the other hand, Wadi Rem shows the lowest numbers in these indices (14 genus, 15 species, and 2 endemic species).

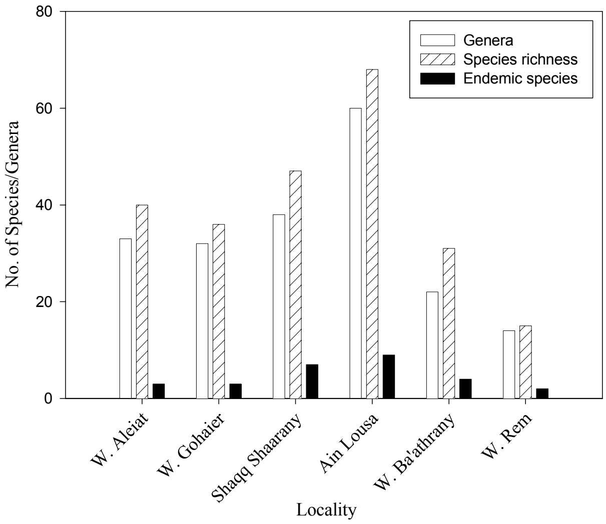

Figure (2): Number of genera, species richness and endemic sp. at different localities in Serbal Mountain area.

Distribution of growth forms of the recorded species within each locality is described in Figure 3. In general, the area is characterized by dominance of shrubs and sub-shrubs, and few number of tree species. Ain Lousa and Shaq Shaarany are richer in shrubs, perennial herbs and annuals than Wadi Aliyat, Wadi Gohaier, and Wadi Ba'athran. Wadi Rem supports the lowest numbers of sub-shrubs (five species), perennial herbs (two species), and no annuals.

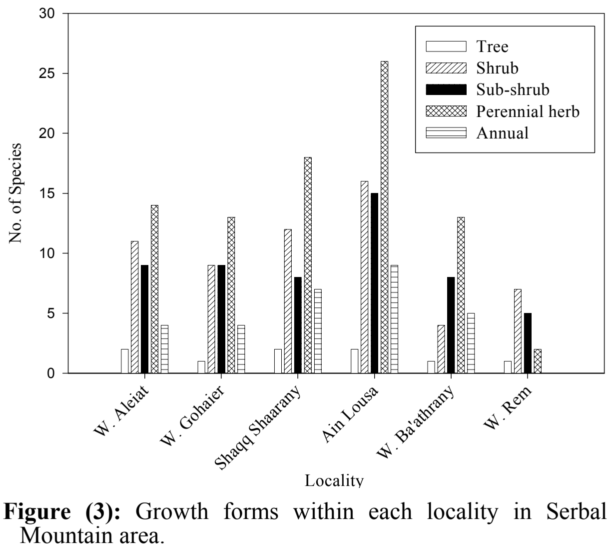

Figure (3): Growth forms within each locality in Serbal Mountain area.

Classification of Plant Communities

The TWINSPAN classification of 58 stands and 70 plant species resulted in seven main vegetation groups (Fig. 4). The main indicator species at the second and third level of classification are *Retama raetam*, *Pistacia khinjuk, Colutea istria*, and *Acacia tortilis*. These vegetation groups are named according to the dominant species based on their presence percentages in each group (Table 2). The seven vegetation groups in terms of dominant and associated species as well as edaphic conditions are described as follows:

Group I: Retama raetam – Anabasis articulata

This group is dominated by *Retama raetam* and *Anabasis articulata*. The main associated species are *Fagonia mollis* and *Zilla spinosa*. Wadi Rem represents the main habitat supporting this group. It is characterized by low total of plant cover that ranges between 1 and 5%. The wadi habitat supporting this vegetation group has relatively moderate elevation (1005 m a.s.l). Soils of this wadi are characterized by high percentages of total carbonate (6.5%) and sandy soil (94.6%), and low values of electric conductivity (0.51 m mhos/cm) and organic matter content (2.45%) (Table 3).

Group II: Pistacia khinjuk – Ephedra alata – Globularia arabica

Group II is dominated by *Pistacia khinjuk, Ephedra alata,* and *Globularia arabica*. The associated species include *Galium sinaicum, Helianthemum kahiricum, Heliotropium arbainense, Kickxia macilenta, Phlomis aurea, Poa sinaica,* and *Polygala sinaica*. This group is found mainly in slope and gorge habitats of Ain Lousa and surrounding area. Dense plant cover that varies between 25% on slopes and 35% in gorges characterizes these habitats. The characteristic and most dominant tree in these habitats is *Pistacia khinjuk,* which grows in hundreds forming forest-like vegetation. Soils supporting this community are fertile soils that range from sand to loamy sand with high percentage of gravel (60.55%), silt and clay (10.97%), organic matter content (4.96%), and total nitrogen (0.72 g/kg) (Table 3).

Group III: Pistacia khinjuk - Artemisia herba-alba- Echinops spinosus

Group III is characterized by *Pistacia khinjuk, Artemisia herba-alba,* and *Echinops spinosus* as dominant species, and *Bufonia multicepes*, *Devera triradiata*, and *Tanacetum santolinoides* as codominant species. The associated species include *Atraphaxis spinosus, Ephedra alata, Galium sinaicum, Kickxia macilenta, Phlomis aurea, Plantago sinaica,* and *Silene linearis*. This group is recognized at slopes, gorges and narrow wadis of Ain Lousa and surrounding area, Shaq Shaarany, and Wadi Baathran. Shaq Shaarany is characterized by dense vegetation (20-30% total plant cover). The area is characterized by a forest-like vegetation of few numbers of trees and shrubs including *Colutea istria, Pistacia khinjuk,* and *Crataegus x sinaica*. Vegetation cover of Wadi Ba'atharan ranges between 10 and 15%, dominated mainly by *Pistacia Khinjuk*. The number of *Pistacia* trees increases in

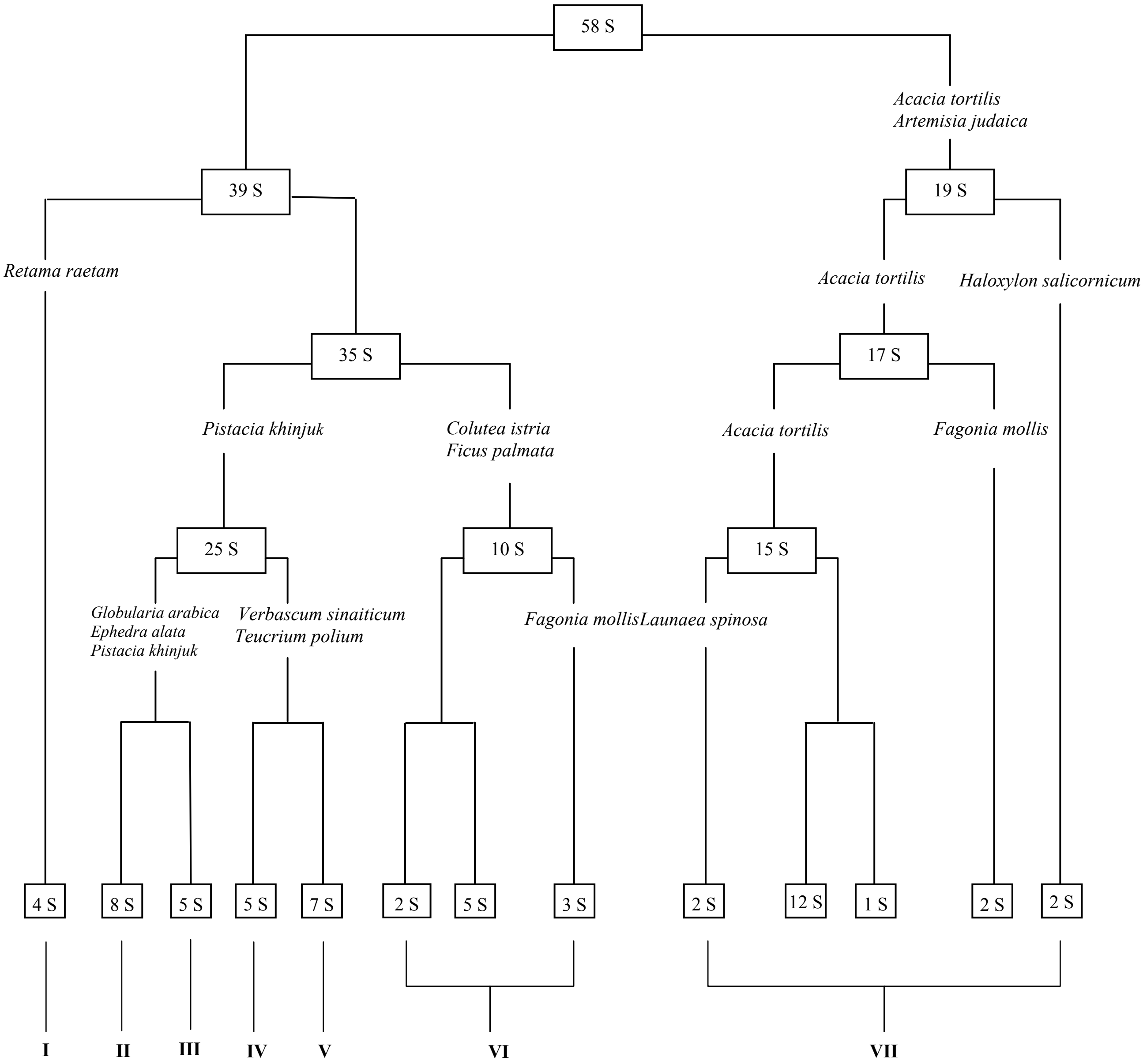

Figure (4): TWINSPAN results for the classification of 58 stands (S) based on the canopy cover of 70 plant species. The seven main vegetation groups, indicator species, and number of stands at each level are shown.

gorges and slopes and decreases in the main course of the wadi. Soils are shallow in depth but high in silt and clay content (12.15%) and as a result soils are characterized by high content of moisture and soil nutrients (Table 3).

Group IV: Tanacetum santolinoides - Pistacia khinjuk

This group is dominated by *Tanacetum santolinoides* and *Pistacia khinjuk*, and co-dominated with *Echinops spinosus* and *Silene linearis*. The associated species include *Artemisia herba-alba, Atraphaxis spinosus, Cotoneaster orbicularis, Ephedra alata, Galium sinaicum, Silene leucophyllua, Silene schimperiana, Verbascum sinaiticum*, and *Verbascum sinnuatum*. Ain Lousa and surrounding area is the main locality showing such group. High terraces, gorges, and narrow first and second order wadis (1700 m altitude) are the main habitats supporting this group.

Group V: Artemisia herba- alba

This group is dominated by *Artemisia herba- alba***.** The other species are growing as associated species including *Juncus rigidus, Mentha longifolia, Phlomis aurea, Stachys aegyptiaca, Tanacetum santolinoides, Teucrium polium Varthemia montana,* and *Verbascum sinaiticum*. This group is recognized in two main localities; Ain Lousa and Wadi Ba'athran. Landforms supporting this group are the high elevated terraces and slopes (1695 m a.s.l). Vegetation cover ranges between 20 and 25%. *Artemisia herba-alba* grows in pockets of fertile soils between the rocky and gravelly surface.

Table (2): Presence percentage of 70 species of the 6 vegetation groups resulted from the TWINSPAN analysis.

Species Name	Group No.						
	I	II	III	IV	V	VI	VII
Acacia tortilis (Forssk.) Hayne subsp. *raddiana* (Savi) Brenan	0	0	0	0	0	10	84.2
Agathophora alopecuroides (Delile) Fenzl ex Bunge	0	0	20	0	0	50	0
Alkanna orientalis (L.) Boiss.	0	12.5	0	0	28.6	20	5.3
Anabasis articulata (Forssk.) Moq.	100	0	0	0	0	40	5.3
Anarrhinum pubescence Fresen.	25	12.5	20	40	42.8	20	0
Arenarea deflexa Decne.	25	0	0	40	0	20	0
Artemisia herba-alba Asso	50	50	80	60	100	20	0
Artemisia judaica L.	0	0	0	0	0	0	63.2
Astragalus spinosus (Forssk.) Muschl.	25	25	40	40	0	0	5.3
Atraphaxis spinosa L.	0	0	60	60	28.6	20	0
Avena barbata L.	0	12.5	40	40	14.3	10	0
Ballota saxatilis C. Presl	0	0	0	0	0	50	0
Ballota undulata (Fresen.) Benth.	0	0	40	40	57.1	20	0
Buffonia multiceps Decne.	0	12.5	80	20	0	50	0
Capparis sinaica Veill.	0	0	0	0	0	30	15.8
Capparis spinosa L.	0	0	20	0	0	10	10.5
Centaurea eryngioides Lam.	0	37.5	0	0	28.6	0	0
Citrullus colocynthis (L.) Schrad	0	0	0	0	0	0	21.1
Colutea istria Mill.	0	0	40	0	0	60	0
Cotoneaster orbicularis Schltdl	0	50	20	60	14.3	30	0
Crateagus x sinaica Boiss.	0	37.5	0	0	28.6	30	0
Deverra triradiata Hochst. ex Boiss.	0	25	80	20	28.6	0	0
Echinops spinosissimus Turra	0	25	100	80	57.1	20	0
Ephedra alata Decne.	0	87.5	60	40	28.6	30	0
Fagonia mollis Delile	60	0	0	0	0	30	21.1
Farsetia aegyptia Turra	25	50	0	0	14.3	0	0
Ficus palmata Forssk.	25	0	0	0	14.3	60	0
Galium sinaicum (Delile ex Decne.) Boiss.	0	62.5	60	60	28.6	0	5.3
Globularia arabica Jaub. & Spach	0	75	40	0	42.8	0	0
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	25	0	0	0	0	0	21.1
Helianthemum kahiricum Delile	0	50	40	20	0	10	0
Heliotropium arbainense Fresen.	25	50	0	20	0	50	5.3
Hyoscyamus muticus L.	0	0	0	0	0	20	10.5
Hypericum sinaicum Boiss.	25	0	0	0	42.8	20	0
Iphiona scabra DC.	0	0	20	0	0	30	0
Juncus acutus L.	0	0	0	20	14.3	20	0
Juncus littoralis C. A. Mey.	0	0	0	0	28.6	30	0
Juncus rigidus Desf.	0	0	0	0	71.4	30	0
Kickxia macilenta (Decne.) Danin	0	50	60	0	28.6	40	0
Launaea spinosa (Forssk.) Sch. Bip. ex Kuntze	0	0	0	0	0	40	10.5
Lavandula coronopifolia Poir.	0	0	0	0	0	50	5.3
Lavandula pubescens Decne.	0	0	0	0	0	40	10.5
Melilotus messanensis (L.) All.	0	12.5	0	20	42.8	0	0
Mentha longifolia (L.) Huds.	25	0	0	0	57.1	40	0
Nepeta septemcrenata Benth.	0	0	0	20	42.8	0	0
Ochradenus baccatus Delile	20	0	0	0	14.3	20	5.3
Origanum syriacum L. subsp. *sinaicum* (Boiss.) Greuter & Burdet	25	12.5	0	20	28.6	60	0
Paronchyia sinaica Fresen.	0	12.5	20	40	28.6	10	0
Phlomis aurea Decne.	0	50	60	20	57.1	30	0
Phragmitus communis	0	0	20	0	14.3	0	0
Pistacia khinjuk Stocks v. *glaberrima*	0	75	80	80	42.8	0	0
Plantago sinaica (Barnéoud) Decne.	0	12.5	60	20	42.8	0	0
Poa sinaica Steud.	0	50	60	60	14.3	30	0
Polygala sinaica Botsch.	25	50	60	40	0	20	0
Polypogon viridis (Gouan) Breistr.	0	12.5	60	60	0	60	0
Pterocephalus sanctus Decne.	0	0	20	40	42.8	0	0
Pulicaria crispa (Forssk.) Oliv.	0	0	0	0	28.6	60	0
Retama raetam (Forssk.) Webb & Berthel	100	0	0	0	0	0	15.8
Schismus barbatus (L.) Thell.	0	0	20	0	28.6	30	0
Silene leucophylla Boiss.	0	0	40	60	28.6	50	0
Silene linearis Decne	0	0	60	80	42.8	40	0
Silene schimperiana Boiss	0	0	20	60	14.3	30	0
Solanum nigrum L.	0	0	20	0	0	50	0
Stachys aegyptiaca Pers.	25	25	0	0	71.4	20	5.3
Tanacetum santolinoides (DC.) Feinbrun & Fertig	0	25	80	80	71.4	50	5.3
Teucrium polium L.	0	0	0	20	71.4	0	5.3
Varthemia montana (Vahl) Boiss.	0	37.5	0	20	71.4	0	0
Verbascum sinaiticum Benth.	25	0	0	60	71.4	30	0
Verbascum sinuatum L.	25	0	0	60	14.3	30	0
Zilla spinosa (L.) Prantl	40	0	20	0	28.6	10	10.5

Table (3): Variation in altitude and soil properties along the seven main vegetation groups in Serbal Mountain area. *F* ratio and its significance are indicated in the last two rows. Mean values of each variable with similar letters indicate no significant variation according to Duncan's multiple range test.

Group	No of stands	Altitude (m)	pH	EC mmhos/cm	Total CO_3%	Soil Organic Matter%	Total Nitrogen (g/kg)	Available Phosphorus mg/kg	Hygroscopic Moisture%	Gravel %	Total Sand %	Silt & Clay%
I	4	1005b	8.16	0.51	6.50	2.45a	0.43b	0.32	0.37a	29.57a	94.62b	5.39a
II	8	1687d	8.28	0.69	5.18	4.96b	0.72bc	0.27	1.03b	60.55b	89.03a	10.97b
III	5	1660d	8.28	0.66	5.18	5.21b	0.79c	0.34	1.06b	61.32b	87.85a	12.15b
IV	5	1700d	8.29	0.69	5.18	4.81b	0.71bc	0.28	1.01b	60.43b	89.07a	10.93b
V	7	1695d	8.27	0.69	5.18	5.11b	0.73bc	0.26	1.05b	60.66b	88.99a	11.01b
VI	10	1189c	8.19	0.57	5.47	5.35b	0.74bc	0.37	1.00b	50.07b	86.65a	13.35b
VII	19	724a	8.26	0.72	5.37	2.43a	0.10a	0.30	0.31a	17.65a	94.46b	5.54a
	F	105.82	0.81	0.33	0.83	11.20	10.79	0.12	21.92	15.31	12.99	12.99
	Sig.	< 0.0001	0.565	0.916	0.55	<0.0001	<0.0001	0.994	<0.0001	<0.0001	<0.0001	<0.0001

Soils supporting this group are high in gravel content (60.66%), silt and clay (11.01%), and organic matter (5.11%) (Table 3).

Group VI: Colutea istria - Ficus palmata

This group is dominated by two characteristic tree species of gorges habitats; *Colutea istria* and *Ficus palmata*. Shaq Shaarany represents the main locality harborsing this group, which is co-dominated by *Origanum sriacum* subsp. *sinaicum*. The associated species include *Agathophora alopecuroides, Ballota saxatilis, Bufonia multiceps, Heliotropium arbainense, Lavandula coronopifolia, Polypogon viridis, Pulicaria crispa, Silene leucophyllua,* and *Tanacetum santolinoides*. Vegetation cover ranges between 20-30%. The mean elevation of sites supporting this group is 1189 m a.s.l. Soils of Shaq Shaarany have the highest means of silt and clay content (13.35%), organic matter (5.35%), total nitrogen (0.74 g/kg), and available phosphorus (0.37 mg/kg) (Table 3).

Group VII: Acacia tortilis

This group is characterized by *Acacia tortilis* as dominant species and by *Artemisia judaica* as co-dominant species. The associated species include *Citrullus colocynthis, Fagonia mollis, Capparis sinaica, Capparis spinosa* and *Haloxylon salicornicum*. This plant community is recognized mainly in low elevated wadis; Wadi Aliyat, Wadi Rem and Wadi Gohaier (724 m a.s.l). Vegetative cover ranges between 5-10% in Wadi Aliyat, and 1-5% in Wadi Gohaier and Wadi Rem. Soils are deep, poor in silt and clay content (5.54%), and have the lowest values of total nitrogen content (0.10 g/kg) (Table 3).

Generally, *Artemisia judaica* and *Citrullus colocynthis* occur only in group VII. On the other hand, certain species such as *Anarrhinum pubescence, Artemisia herba alba,* and *Tanacetum santolinoides* are recognized in six different groups. *Pistacia khinjuk* is one of the main indicator species characterizing four different vegetative groups either as dominant or co-dominant species (groups II, III, IV, and V).

Analysis of variance and Duncan multiple range test of altitude and soil properties between different vegetation groups are summarized in Table 3. Altitude, soil hygroscopic moisture, gravel as a soil surface fraction, total sand, silt and clay, soil organic matter and total nitrogen are highly significant. On the other hand, soil pH, EC, total carbonate, and available phosphorus were non-significant. Applying Duncan multiple range test resulted in classifying the vegetation groups into four subsets based on altitude. Subset *a* (724 m a.s.l.) represents group VII: *Acacia tortilis,* subset *b* (1005 m a.s.l.) represents group I: *Retama raetam – Anabasis articulata*, and subset *c* (1189 m a.s.l.) represents group VI: *Colutea istria - Ficus palmata*. Subset *d* includes four vegetation groups (II to V), and is characterized by narrow altitudinal range (1660 and 1700 m a.s.l.). Duncan multiple range test separates the vegetation groups into two main subsets based on the most significant soil properties. Soils of vegetation groups II to VI are shallow and formed between rocks and in crevices and have high percentage of gravels on soil surface (50-60%). These soils have high content of hygroscopic moisture (1%), silt and clay content (11-13%), organic matter (5%), and total nitrogen (0.7-0.8 g/kg). On the other hand, soils supporting vegetation groups I and VII are deep alluvial but have low content of hygroscopic moisture (0.3%), silt and clay (5%), organic matter (2.4%), and total nitrogen (0.1-0.4 g/kg) (Table 3).

Species – Environment relationships

Canonical corresponding analysis (CCA) shows the species-environmental variables relationships by calculating axes that are products of the species composition and linear combinations of the environmental variables (ter Braak, 1986). To explain these relationships, CCA axes number I and II, and number I and III are considered in the interpretation. The reason is that the eigenvalues of the CCA axis I is 0.674, and the CCA axis II (0.374) is not much higher than axis III (0.315). The percentages of variance accounted for by species-environment relations are 12.2% on axis I, 6.8% on axis II, and 5.7% on axis III. Intraset correlations may be helpful as indicators of

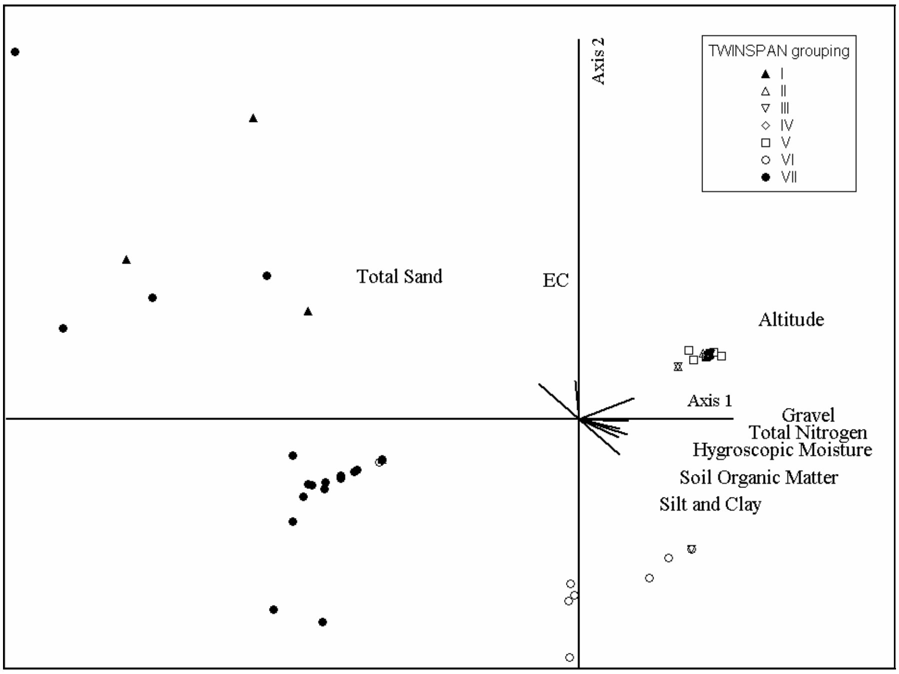

Figure (5): Biplot of CCA showing vegetation groups–environmental variables relationships along the axes 1 and 2.

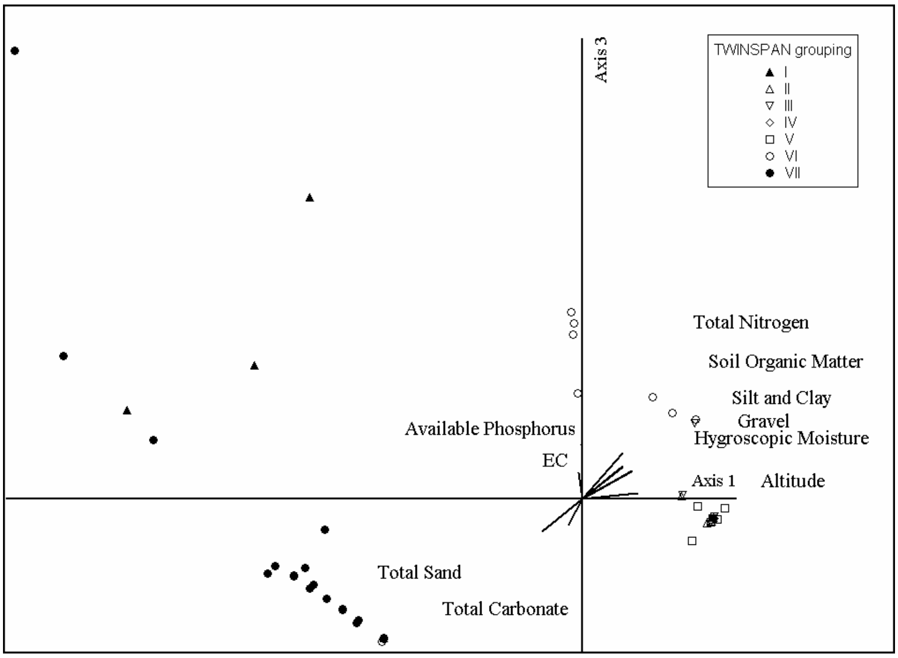

Figure (6): Biplot of CCA showing vegetation groups–environmental variables relationships along the axes 1 and 3

important environmental variables in structuring the ordination (ter Braak, 1986). Intraset correlations between 11 variables and different axes are described in table 5. In CCA biplot diagram, environmental variables are represented as lines radiating from the centroid of the ordination. The longer the environmental line, the stronger the relationship of that variable with the community (Fig. 5 and 6). The positions of species/sites points relative to the environmental lines interpret their relationships (ter Braak, 1986). Altitude, hygroscopic moisture, and gravel percentage have higher positive correlation on axis I than soil organic matter, total nitrogen, and clay (Table 4). On the other hand, EC and total sand have a positive correlation with axis II, whereas, available phosphorus and total nitrogen have negative correlation with CCA axis III (Table 4).

Based on these results, CCA axes could be explained as follow:

CCA axis I: Altitude gradient

The distribution of vegetation groups along the altitude gradient (724-1700 m a.s.l.) exhibits significant variation. Of the seven common vegetation groups, group VII: *Acacia tortilis* attains maximum occurrence in low altitude wadis (724 m a.s.l), followed by group I: *Retama raetam – Anabasis articulata* that is recognized in wadi habitat also but at higher elevation (1005 m a.s.l) than group VII. *Colutea istria - Ficus palmata* (group VI) dominates the gorges habitats that attain a moderate elevation within the study area (1189 m a.s.l). At high elevation (1660 and 1700 m a.s.l), the other four TWINSPAN vegetation groups were recognized (groups II to V). These groups are close to each other in the ordination space and attain a relatively similar distance to altitude line, which indicates similarity between these communities relative to altitudinal gradient.

Table (4): Intraset correlations (ter Braak, 1986) for 11 variables and different axes of CCA.

Variable	Correlations		
	Axis 1	Axis 2	Axis 3
Altitude m	0.938	0.300	-0.088
pH	0.184	0.085	0.352
EC m mhos/cm	-0.058	0.545	-0.372
Total Carbonate %	-0.247	-0.119	0.370
SOM %	0.682	-0.266	-0.472
TN g/kg	0.693	-0.136	-0.650
P mg/kg	-0.016	0.069	-0.777
Hygroscopic Moisture %	0.829	-0.224	-0.390
Gravel %	0.841	-0.027	-0.407
Total Sand %	-0.685	0.513	0.462
Silt & Clay %	0.685	-0.513	-0.462

CCA axis II: EC and total sand gradients

EC gradient characterized by narrow range (0.51-0.72 m mohs/cm) is directly related to axis II and indirectly related along the other axes. CCA axis II is affected also by total sand, which exhibits a relatively wide range (87.9-94.6%). The habitats characterized by high sand fraction and low EC are dominated with group I: *Retama raetam – Anabasis articulata* (Fig. 5). Groups II to VI have relatively similar distances to the EC gradient. Soils supporting these communities are characterized by narrow EC range (0.57 and 0.69 mmohs) revealing the resemblance of these groups. Group VII: *Acacia tortilis* is characterized by high EC value (0.72 m mohs) and high sand percentage (94.46%).

CCA axis III: Available Phosphorus and Total Nitrogen gradient

Available Phosphorus and Total Nitrogen are negatively correlated with Axis III and directly correlated with Axis I (Table 4). This gradient could be considered as a soil fertility index (Fig. 6). Even though, groups: II to VI dominate the mountainous habitats characterized by shallow soils, they are highly correlated with soil fertility indicators; phosphorus (0.26-0.34 mg/kg), total nitrogen (0.71-0.79 g/kg), SOM (4.81-5.35%), and silt and clay content (10-13.35%). On the other hand, Group I: *Retama raetam – Anabasis articulata* and Group VII: *Acacia tortilis* located far from these variables (Fig. 6) are indicators of low soil fertility that characterized by high percentages of gravel and sand and low content of soil organic matter (2.45%), total nitrogen (0.10-0.43 g/kg), and silt and clay (5.39-5.54%) (Table 3).

DISCUSSION

South Sinai has five main mountains attaining altitude more than 2000 m a.s.l. These mountains are Gebel Serbal, Gebel Musa, Gebel Tarbush, and Gebel Umm Shaumar, consisting of granite rocks, and Gebel Cathrina consisting of old black volcanic rocks (Said, 1990). Relatively wet climate and landform diversity in mountainous habitats result in diversity in floristic composition, and diffuse vegetation of shrubs and sub-shrubs (Moustafa *et al*., 2001). Danin (1978) assumed that in mountainous habitats, floristic richness is more related to edaphic factors than the climatic ones. In this study, we focused on the quantitative analysis of flora and vegetation of Gebel Serbal in relation to environmental factors.

In agreement with Moustafa *et al*. (2001), Gebel Serbal is characterized by more rich and unique flora than other mountains in the upper Sinai massif. The flora of Gebel Serbal represents about 28% of the flora of South Sinai recorded by Danin (1983) and El-Hadidi (1989), and about 44% of the flora of St. Katherine Protectorate recorded by Moustafa *et al*., 2001. More than 57% of the medicinal plant species in South Sinai (Abd El-Wahab *et al*., 2004), and 14% of the threatened species in Sinai Peninsula (Boulos and Gibali, 1993) are represented in Gebel Serbal. Thirty six of the flora of Gebel Serbal are considered as characteristic species including *Pistacia khinjuk, Acacia tortilis* subsp. *raddiana,* and *Colutea isteria*. They cover most of the area and dominate many of plant communities. This number is more than that of other mountains of the upper Sinai Massif including Cathrina Mountain (Moustafa, 1990).

South Sinai Mountains are rich in endemic species (Migahid, *et al*., 1959; Zohary 1973; Danin, 1986; Moustafa and Zaghloul, 1996). Gebel Serbal is considered one of the important centers of endemism in South Sinai. It harbors more than 30% of the endemic species recorded in Sinai (Boulos and Gibali, 1993). Most of endemic species are also recorded in Gebel Musa and Gebel Catrina. *Phagnalon sinaicum* is nearly endemic to Gebel Serbal. On the other hand, *Primula boveana*, the endemic species previously recorded in Gebel Serbal and other mountains in South Sinai (Danin, 1986; Moustafa *et al*. 2001) was not recorded in the current study in Gebel Serbal.

The rock types of Serbal Mountain area are mainly of igneous and metamorphic varieties and have intensively rugged topography dissected by a complicated drainage system of deep wadis with different landforms.

In addition, gorges and slope habitats are characterized by smooth-faced granite outcrops. This unique geomorphologic nature radically modifies the plant water resources (Kassas, 1960), and results in differentiation of a number of microhabitats spaced few meters apart. Each of them has its peculiar environmental conditions and plant cover (Batanouny, 1973). Even though, soils accumulated on the slopes and the talus are shallow soils, they contain a higher percentages of silt and clay, organic matter, total nitrogen content, and water holding capacity than deep alluvial soils in wadis. These conditions; cool and relatively wet climate, diversity in landforms, and geologic structures give Serbal area the merit to have such rich and unique flora and elucidate why gorge and slope habitats in Shaq Shaarany and Ain Lousa are higher in species richness and number of endemic species than wadi habitats in Wadi Aliyat, Wadi Gohaier, and Wadi Ba'athran (Fig. 2).

Application of multivariate analysis indicated that Gebel Serbal is characterized by distinct vegetation represented in seven main vegetation groups. In general, distribution of these vegetation groups or plant communities were more related to altitude, hygroscopic moisture, and gravel percentage rather than to sand, silt and clay fractions, soil organic matter, and total nitrogen. These findings are in agreement with many previous studies indicated that distribution of plant communities in arid ecosystems are controlled by edaphic conditions, physiographic features, and topographical irregularities, which all act through modifying the amount of available moisture (Kassas, 1960; Ayyad and Ammar, 1974; Whittaker, 1975; Kassas and Batanouny, 1984; El-Ghareeb and Shabanna, 1990; Moustafa and Klopatek, 1995). Vegetation group I, *Retama raetam* – *Anabasis articulate,* is a unique association recognized in Wadi Rem. In other wadis and plains in Sinai and other parts in Saharo Arabian desert, *Retama raetam* or *Anabasis articulata* was recorded as a pure community or associated with different co-dominant species. In general, distribution of *Retama raetam* or *Anabasis articulata* have been described by many researchers (Kassas, 1952; Migahid *et al*., 1959; Zohary, 1973; Ramadan, 1988; Moustafa, 1993; Moustafa and Zayed 1996; Abd El-Wahab, 2003). Vegetation groups number II to VI are dominated mainly by Irano-Turanian species such as *Pistacia khinjuk, Ephedra alata, Artemisia herba-alba,* and *Tanacetum santolinoides* (Zohary, 1973). These vegetation groups are almost restricted to Gebel Serbal and dominate slopes and gorges habitats forming forest-like vegetation. The vegetation group V represented by *Artemisia herba-alba* is quite similar to an association recorded by Moustafa and Zaghloul (1996) on the slopes of Gebel Cathrina. Group VII dominated by *Acacia tortilis* was previously recorded in wadis mainly at margins and at foothills in South Sinai (Migahid *et al*., 1959; Danin, 1983; Ramdan, 1988, Abd El-Wahab, 1995; Moustafa *et al.,* 2001).

Pistacia khinjuk is the main significant species characterizing four different vegetative groups either as dominant or co-dominant species. Thousands of *Pistacia khinjuk* trees occur on slopes and gorges of Gebel Serbal (2070 m), which consists of smooth-faced red granite. On the other hand, Gebel Musa (2285 m), Gebel Umm Shoumer (2586 m), and Gebel Cathrina (2641 m) do not support a single *Pistacia khinjuk* tree, whereas Gebel Tarboush (2190 m) supports tens of these trees (Moustafa *et al*., 2001).

The prominent rock type in Gebel Cathrina is old black volcanic rocks, whereas the rock type of Gebel Musa, Gebel Tarbush, and Gebel Umm Shummer is similar to that of Gebel Serbal. Danin (1983) assumed that rock structure has a greater influence on the distribution of vegetation than dose the elevation. Due to its rugged topography, Gebel Serbal is subjecting to relatively low to moderate human impact. Low tourism pressure, and low grazing intensity were recognized (Moustafa *et al*., 2001; Abd El-Wahab, 2004). On the other hand, Gebel Musa and Gebel Cathrina are subjecting to severe human impact including tourism, urbanization, overcollection, and overgrazing (Abd El-Wahab, 2003). Therefore, we believe that in addition to environmental conditions, human activities and land use history have a substantial impact on floristic composition and distributional behavior of characteristic species growing at each area. These conditions may interpret why Gebel Serbal supports more rich and unique flora, and distinct vegetation than neighboring mountains sharing similar environmental conditions. We assume that the rich flora and climax vegetation at Gebel Serbal represented by forest like vegetation dominated by *Pistacia khinjuk* were the case at the other mountains in South Sinai especially those similar in geomorphic structures few hundred years ago. The substantial human impact on other mountains, especially Gebel Musa and Gebel Cathrina, aggravated the present prevalence of aridity (Abd El-Wahab, 2003) and resulted in retardation to sparse vegetation dominated by chasmophytes and sub-shrubs (Mousafa, 1990).

The present study indicates that Gebel Serbal is the most diverse area in South Sinai and has a high conservation value. We recommend that Gebel Serbal, a part of St. Katherine Protectorate, should be declared as habitat/species management area (IUCN, 1994) that will be managed mainly for conservation. The main objectives of the proposed protected area are the following: (1) to secure and maintain the habitat conditions necessary to protect (a) distinctive vegetation, (b) significant species such as *Pistacia khinjuk, Colutea istria*, *Acacia tortilis*, and (c) endemic and other characteristic species; (2) to facilitate scientific research and environmental monitoring as primary activities associated with sustainable resource management; and (3) to develop limited areas for public education and appreciation of the characteristics of the habitats/species concerned (IUCN, 1994).

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الكساء الخضرى والبيئة فى جبل سربال، جنوب سيناء، مصر

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الملخص العربــى

تهدف هذه الدراسة إلى تحليل التركيب الفلورى، والسلوك التوزيعى للمجتمعات النباتية فى جبل سربال وعلاقة ذلك ببعض العوامل الطبوغرافية، وخصائص التربة.

تم تقدير الغطاء النباتى فى 58 موقع مساحة كل منهم 400 م^2. كذلك تم قياس كل من الإرتفاع عن سطح البحر، وطبيعة سطح التربة. وتم تحليل العوامل الآتية فى عينات التربة التى تم جمعها من هذه المواقع. وهذه التحاليل هى قوام التربة، والرطوبة الهيجروسكوبية، والأس الهيدروجينى، والتوصيل الكهربائي، والكربونات الكلية، والنيتروجين الكلى، والفسفور المتاح، والمادة العضوية. تم تحليل النتائج إحصائيا وكذلك بالتحليلات متعددة المتغيرات.

أوضحت النتائج أن جبل سربال يتميز بالتنوع فى البيئات والمواطن الموقعية، وكذلك بانخفاض التأثيرات الإنسانية والتى بدورها أدت إلى وجود تركيب فلورى وغطاء نباتى مميز. تم رصد عدد 106 نبات داخل المواقع المدروسة، منهم 11 نباتاً متوطناً، و36 نباتاً سائداً. بناءً على التحليلات متعددة المتغيرات، تم رصد 7 مجتمعات نباتية مميزة لمنطقة جبل سربال. أظهرت النتائج ارتباط توزيع هذه المجتمعات بعامل الإرتفاع عن سطح البحر، والرطوبة الهيجروسكوبية، ونسبة الحصى، ويلى ذلك ارتباطها بنسبة الطين والغرين، والمادة العضوية، والنيتروجين الكلى.

أكدت الدراسة على أهمية جبل سربال حيث يعتبر أكثر الجبال تنوعاً فى جنوب سيناء، ويعد من أكثر المناطق أهمية من ناحية الصون الحيوى. لذا نوصى باعتبار منطقة حبل سربال منطقة محمية خاصة لتنوع الأنواع النباتية والمواطن البيئية. Habitat/Species Management Area.