Vegetation-soil relationships in the Wadi Al-Hayat Area of the Libyan Sahara

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Vegetation-soil relationships in the Wadi Al-Hayat Area of the Libyan Sahara

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Abstract: Wadis are unique intrazonal landscapes in arid and semi-arid regions of the world. These wadis are undergoing rapid physical and socio-economic changes. The present study assesses the plant communities and soil factors that govern species distribution and richness of the Wadi Al-Hayat in the south-western area of Libya. Cluster analysis and Bray-Curtis ordination were used to classify and ordinate the vegetation in relation to soil factors. These analyses resulted in the recognition of seven vegetation groups that linked to a specific habitat. *Acacia tortilis* subsp. *raddiana* occupied the wadi channels, *Phragmites australis-Typha domingensis* inhabited the swamps, *Juncus acutus-Imperata cylindrica* represented the wet saline flats, *Alhagi graecorum-Tamarix nilotica* had the widest distribution and represented the dry saline flats, *Nitraria retusa-Tamarix nilotica* occupied the sand sheets, *Traganum nudatum-Zygophyllum album* and *Calligonum polygnoides-Stipagrostis plumosa* inhabited the stabilized and partially stabilized sand dunes, respectively. Cumulative variance detected for the three axes of the Bray-Curtis variance-regression ordination was substantial (77.3%). The first axis was positively correlated with soil salinity, moisture content, organic matter and altitude. The second axis represented mainly a soil texture; it was positively correlated with fine fractions, and negatively with gravel percentage. The third axis was negatively correlated to human disturbance (grazing and cutting intensities). These findings should guide conservation efforts to maintain species diversity at the study area.

Key words: Bray-Curtis ordination; cluster analysis, Libyan Sahara; salinity; sand formations; wadis

INTRODUCTION

A central goal of plant ecology is to understand the factors controlling local distribution of plant species and thus composition of plant communities (Barton 1993). Plant communities change gradually along environmental gradients (ter Braak and Prentice, 1988; Shaltout et al., 1995; Hegazy et al., 1998; Abd El-Ghani and Amer, 2003). The species distribution reflects the effects of several factors at different scales. Climate, topography and soil are thought to exert influences on the plant distribution at region and landscape (Ricklefs, 1990; Ringrose et al., 2003). Many authors have found that landscape or physiographic factors play an important role in community organization (Batanouny, 1979; O'Brien, 1993; McAuliffe, 1994). Others have demonstrated that soil characteristics are the most important factors in community organization (Bornkamm and Kehl, 1990; Shaltout et al., 1995; El-Bana et al., 2002).

In the arid regions of many Arab countries, there are considerable studies focused on the effects of environmental factors on plant communities (e.g. Kassas, 1957; Batanouny, 1979; Ayyad and El-Ghareeb, 1982; Halwagy et al., 1982; Bornkamm and Kehl, 1990; Zahran, 1997; Hegazy et al., 1998; Abd El-Ghani and Amer, 2003). However, detailed ecological and floristic accounts remain very scarce particularly for the arid and hyper-arid regions of Libya. Such information is crucial for developing strategies, programs or technical guidelines for the conservation and sustainable utilization of natural resources, particularly in the hyper-arid southwest region of the country. In this region, vegetation has been seriously degraded as a consequence of a long history of desertification, resulting from a combination of factors such as drought, overgrazing, overcutting and other political and social forces (di Lernia and Palombini, 2002; Brooks, 2004, 2006; Mercuri, 2008).

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The south-western area of Libya is unique with regard to its nature, landforms, and water availability (Cremaschi and di Lernia, 1999; Brooks et al., 2005; Mercuri, 2008). The area hosts an impressive number of wadis as well as the Erg Uan Kasa, Central Messak Settafet and Edeyen of Murzuq (White et al., 2003; Mercuri, 2008). However, no studies have been carried out on the distribution of vegetation in these geomorphologic features. The wadis are unique intrazonal landscapes in arid and semi-arid regions of the world (Fossati et al., 1998). The present study was carried out in the Wadi Al-Hayat (called Wadi al Ajal on older maps) which is currently undergoing considerable environmental changes under the extremely hyper-arid climate in the central Sahara (White et al., 2003; Brooks 2006). Until recently, cultivation was the principle way of life in the wadi as the irrigation water was only a couple of meters from the surface (Brooks 2006). Today, this cultivation has become more difficult due to changes in ground water availability and quality (saline intrusion) (Drake et al., 2004; Shaki and Adeloye, 2006). Some of the recently cultivated areas were abandoned and converted into salt marshes as soils are subjected to deterioration and salinization (Drake et al., 2004). The objective of this study was to examine vegetation-soil relationships, and to detect the main topographic and soil factors that control species distribution in the different habitats of Wadi Al-Hayat.

MATERIALS AND METHODS

The study Area:

The study area lies along the Wadi Al-Hayat in the Fezzan region of south-western Libya at a latitude of approximately 26.5° (Figure 1). The wadi itself is a scarp foot oasis oriented approximately east-northeast – west-southwest. It is bounded by the Ubari or Al- Zallaf Sand Sea on the north, and by the high cliffs of the Messak Settafet plateau on the south (Brooks, 2006). The wadi is one of the largest and most fertile valleys in the Libyan Sahara (White et al., 2003). The surface is generally covered by sand.

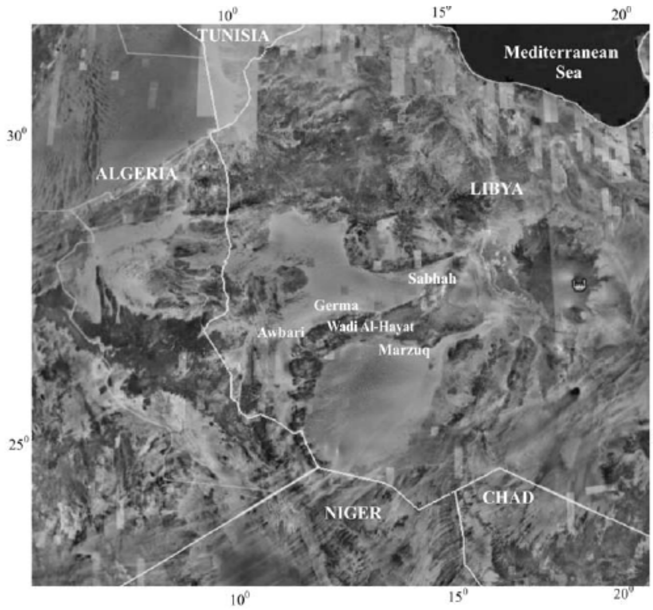


Fig. 1: Map showing the location of Wadi Al-Hayat in the south-western area of Libya.

Climatically, the study area is classified as an arid to extremely hyper-arid region (UNESCO, 1977). The climate of Sabha city is characterized by an annual mean temperature of 32.3°C, mean maximum temperature of 39.8°C, mean minimum of 11.2°C. Present day rainfall throughout the region is less than 20 mm per year on average, and exhibits high interannual variability (Brooks, 2004). The potential evaporation rate is about 2000mm a^{-1}, and the actual evaporation rate is negligibly less. The mean annual relative humidity ranges from 30 to 40%.

Vegetation and Soil Analyses:

In the spring of 2006, one hundred and twenty stands (each of approximately 1 0m x 1 0m) were selected to represent the main habitats in the study area. In each stand, the annual and perennial species were listed.

Plant nomenclature was according to Ali and Jafri (1976), and Latin names were updated following Boulos (1995). Plant cover for all species was estimated using the modified line intercept method (Etchberger and Krausman 1997). The altitude of each stand was obtained with a global positioning system device (model GPS 76, Garmin, Olathe, Kansas, USA).

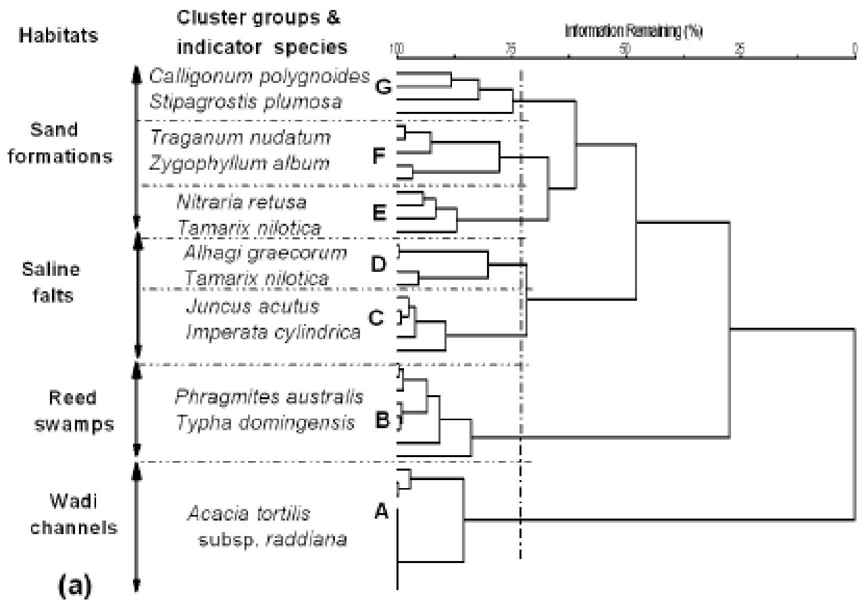
For each sampled stand, three soil samples were collected at profiles 0-50 cm. These samples are then pooled together to form one composite sample, air-dried, thoroughly mixed, and passes through a 2mm sieve to get rid of gravel and boulders. The weight of gravel in each sample plot is determined and expressed as a percentage of the total weight of the soil sample. Soil texture was determined with the Bouyoucos hydrometer, and the results were used to calculate the percentage of sand and fine fractions (silt and clay). Moisture content and organic matter were determined by drying and ignition at 600 °C for 3 h. Soil-water extract (1:5) was prepared for the estimation of electrical conductivity (EC in mS cm^{-1}) using a conductivity meter, and of soil reaction, using a pH meter. Disturbance index in each stand (the signs of grazing, cutting, digging, and trampling) was classified into three levels: high (level 1), medium (level 2), and low (level 3) as described by Naveh and Whittaker (1979).

Data Analysis:

In order to obtain an effective analysis of the vegetation and related soil factors, both classification and ordination techniques are employed. First, the floristic matrix of 42 species and 120 stands were subjected to cluster analysis using a similarity index (the Czekanowski coefficient; Ludwig and Reynolds 1988). Second, the matrix was analyzed with Bray-Curtis variance regression ordination, using the Sørensen coefficient as the distance measure, to check the magnitude of change in species composition along the soil gradients (McCune and Mefford, 1999). The Bray-Curtis variance regression ordination was used because it is considered an effective technique for community analyses and for revealing ecological gradients (Ludwig and Reynolds, 1988; McCune and Grace, 2002). These calculations were carried out using the PC-ORD 4.10 (McCune and Mefford 1999). Third, we measured the species richness in each vegetation cluster, in order to reveal their variation along the soil gradients. Species richness was calculated for each vegetation group as the average number of species per stand.

RESULTS AND DISCUSSION

Using cluster analysis, 120 stands were classified into seven groups (A-G), representing seven different types of communities belonging to four habitats: wadi channels, reed swamps, saline depressions and sand formations (Fig. 2a). The application of Bray-Curtis ordination indicates reasonable segregation between these vegetation groups (Fig. 2b).



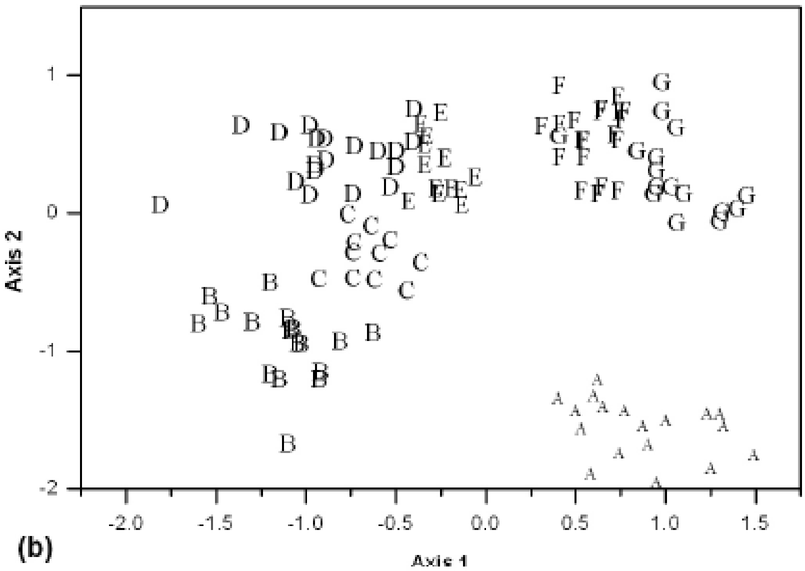


Fig. 2: The relationship between the seven vegetation groups generated after application of cluster analysis (a) and Bray-Curtis ordination (b). The cluster dendrogram showing the principal dominant species in each cluster with their habitats.

The vegetation cluster characterized by *Acacia tortilis* subsp. *raddiana* (A) occupied mainly the channels along the southern side of the wadi. The cluster dominated by *Phragmites australis – Typha domingensis,* (B) inhabited the swamps that collected the drainage fresh or brackish water from wells or irrigation lands. The cluster characterized by *Juncus acutus – Imperata cylindrica* (C) represented the wet saline flats of the abandoned cultivated fields. The *Alhagi graecorum – Tamarix nilotica* cluster (D) had the widest distribution along the wadi and represented the dry saline flats that covered with soil crust in many stands. The cluster (E) characterized by *Nitraria retusa - Tamarix nilotica* occupied the sand sheets deposited on dry saline flats. The *Traganum nudatum – Zygophyllum album* cluster (F) inhabited the stabilized sand dunes. However, the cluster (G) dominated by *Calligonum polygnoides – Stipagrostis plumosa* represented the stands of partially stabilized sand dunes.

Most of the identified vegetation groups have very much in common with that recorded in some wadis vegetation of the neighboring countries (Kassas and Girgis, 1965; Bornkamm and Kehl, 1990; Abd El-Ghani, 2000; Woldewahid et al., 2007). *Zygophyllum album* and *Nitraria retusa* community types were recorded by Kassas and Girgis (1965) in their study on the wadis vegetation in the eastern desert of Egypt. Some others (e.g. *Alhagi graecorum, Tamarix nilotica, Juncus rigidus, Typha domingensis* and *Phragmites australis* community types) were recorded by Abd El-Ghani (2000) in his study on the oases vegetation in the western desert of Egypt. However, the plant communities recorded in the present study are completely different to those of wadis in Al-Jabal Al-Akhadr area of Libya (Al-Sodany et al., 2003). This could be due to the differences in geomorphology and water availability in the wadis of the two areas. The wadis in Al-Jabal Al-Akhadr are characterized by their rocky substratum with crevices and developed prominent valleys (Shishov, 1980). While, the wadi of the study area is a scarp foot oasis that is generally covered by sand (Brooks, 2006).

Most of the characteristic species of the identified vegetation groups in the present study are salt tolerant plants. Shaltout et al. (2003) found that the growth of *Nitraria retusa* can tolerate wide salinity gradients. It grows in a pure community or mixed with *Tamarix nilotica,* and both species build huge sand hillocks in sandy flat habitats of the study area. The *Alhagi graecorum* and *Tamarix nilotica* species extend their occurrences all over the saline and sand formation habitats (Fig. 3), which indicating their wide ecological amplitudes (Kassas and Girgis, 1965; Zahran and Willis, 1992). They are also considered as groundwater-indicating plants (Girgis, 1972). *Tamarix nilotica* represents one of the main climax communities in the desert wadis (Zahran and Willis, 1992). In the study area, it is subjected to destructive cutting for fuel and other household purposes. The xero-psammophytes *Traganum nudatum, Zygophyllum album, Calligonum polygnoides* and *Stipagrostis plumosa* inhabited the sand dune formations where the soil is subjected to the drifting of sands. All these species are sand binding that accumulate wind-drifted sand and so build up sand mounds and hummocks within or around their canopies (Batanouny, 2001; El-Bana et al., 2007). These phytogenic mounds play an important ecological role in trapping-sand and maintaining plant diversity in degraded arid dunes (El-Bana et al., 2003, 2007).

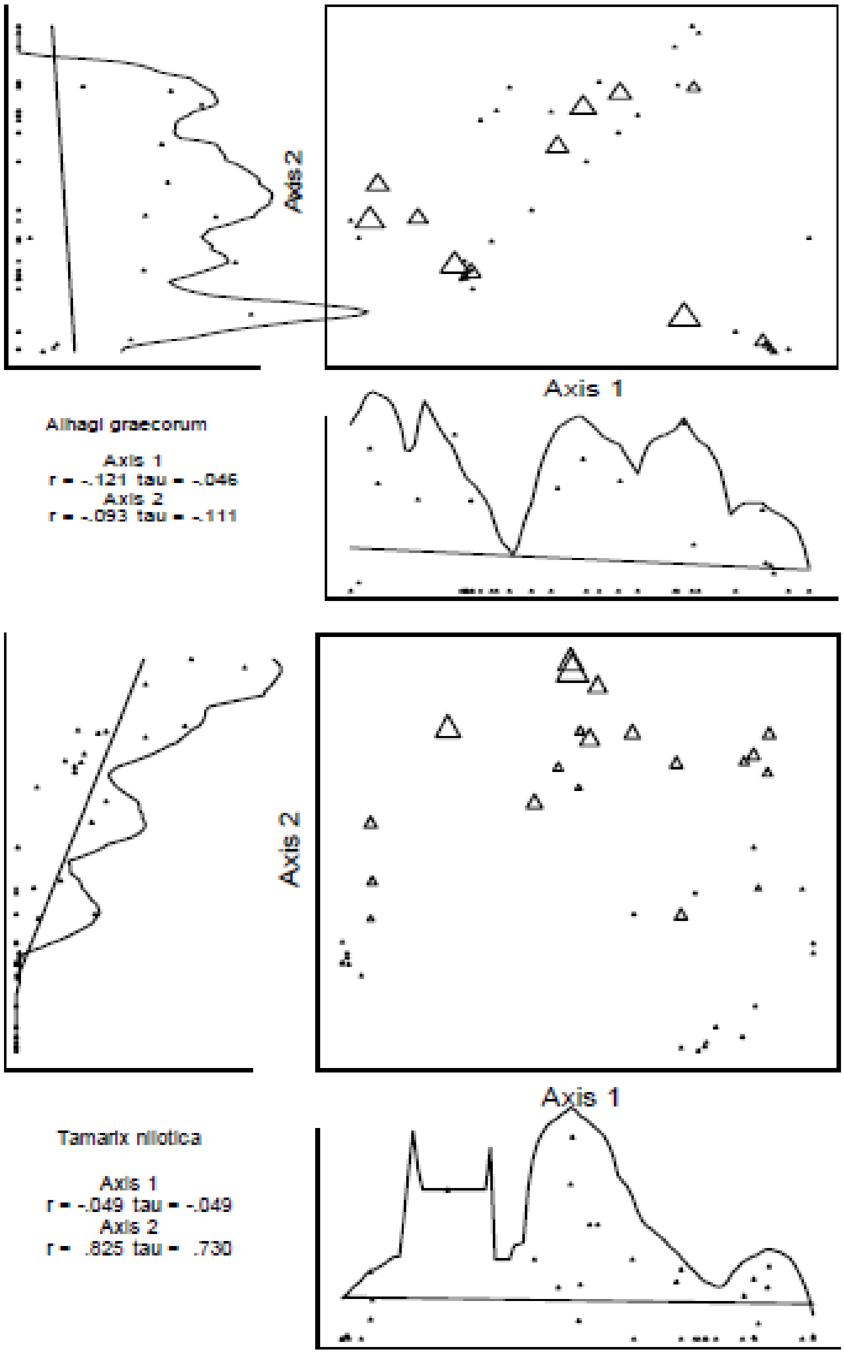


Fig. 3: Overlay diagram showing the distribution of *Alhagi graecorum* and *Tamarix nilotica* with respect to the first and second axes of Bray-Curtis ordination, bigger triangles indicate higher cover values of the cited species.

The dominance of *Acacia tortilis* subsp. *raddiana* in wadi channels has been reported in many parts of the arid Middle East (Ward and Rohner, 1997; Abd El-Ghani and Amer, 2003; Robinson, 2004; Woldewahid et al., 2007; Abdallah et al., 2008), and is supported by this study. It is a very important tree as fodder for livestock and as a source of fuel wood for the Bedouin people. A recent evaluation of the conservation status of this species has pointed to massive mortality of mature trees and a corresponding lack of recruitment by young trees (Ward and Rohner, 1997; Rohner and Ward 1999). Therefore, it is believed to be endangered in many parts of the Middle East (Ward and Rohner, 1997; Wiegand et al., 1999).

The variation in the soil variables in relation to the seven vegetation clusters (Table 1) indicated that the soils supporting clusters B-E tend to be more saline, and have higher contents of fine fractions (silt and clay) and organic matter than other clusters (Table 1). The soil of wet saline flats *(Juncus acutus – Imperata cylindrica)* had the highest contents of fine fractions (13.1%) and moisture content (8.4%). However, the soil of dry saline flats *(Alhagi graecorum – Tamarix nilotica)* had the highest salinity (45.5 mS cm^{-1}).

Table 1: The mean ± standard deviation (S.D.) of the soil and vegetation variables of the seven vegetation groups

	Vegetation groups						
Variable	A	B	C	D	E	F	G
Soil variables							
Sand (%)	54.3±8.3	82.9±4.2	83.4±3.7	82.2±5.4	86.4±3.4	89.1±6.7	92.3±14.2
Fine fractions (%)	11.2±3.1	14.3±4.2	13.1±2.4	9.7±1.8	8.8±2.1	8.2±3.1	4.6±1.4
Gravel (%)	34.5±17.5	2.8±0.8	3.5±1.1	8.8±0.3	5.8±1.8	3.7±1.6	3.1±2.1
Moisture content (%)	2.3±1.2	6.6±4.5	8.4±3.1	5.5±4.1	5.4±2.3	1.7±0.6	0.89±0.7
Organic matter (%)	0.56±0.2	4.6±2.2	4.2±3.1	3.2±1.8	2.8±1.2	0.83±0.4	0.45±0.3
EC (mS/cm)	1.49±2.3	7.66±3.7	27.42±11.4	45.5±18.2	20.4±23.3	8.57±4.2	4.62±3.5
pH	7.7±0.5	8.1±1.3	7.9±0.4	7.3±0.3	7.1±0.1	8.2±0.7	7.7±0.3
Vegetation variables							
Total species	18	7	5	6	9	11	14
Species richness	7.3±2.1	4.6±1.3	3.2±0.8	5.2±2.4	4.8±0.9	5.8±0.4	6.2±3.4

The species-environment correlation indicates that the species data are strongly related to the measured soil variables (Table 2). Bray-Curtis ordination of the main matrix showed that cumulative variance explained by the first three axes was 47.86%, 67.49% and 77.23% (Table 2). The first axis was positively correlated with soil salinity, moisture content, organic matter and altitude. The second axis represented mainly a soil texture; it was positively correlated with fine fractions, and negatively with gravel percentage. The third axis was negatively correlated to human disturbance. These findings agree with the hypothesis that the heterogeneity of local topography and soil properties are important determinants of plant species distribution and communities over a small geographic area in arid regions (Bornkamm and Kehl, 1990; Shaltout et al., 1995; Hegazy et al., 1998; Abd El-Ghani, and Amer, 2003; El-Bana et al., 2007). In addition, the present study found that other factors such as human disturbance (e.g. heavy grazing and cutting) can also influence the vegetation in a wadi corridor (Zahran and Willis, 1992; Fossati et al., 1998).

Table 2: The extracted and cumulative variance of Bray-Curtis ordination, and correlation coefficients between soil variables coefficients and ordination axes. Bold indicates statistical significance at $p<0.05$.

Factor	Axis 1	Axis 2	Axis 3
% Extracted variance	47.86	19.63	9.87
% Cumulative variance	47.86	67.49	77.23
Sand (%)	-0.23 1	0.341	0.656
Fine fractions (%)	0.324	**0.542**	-0.121
Gravel (%)	0.214	**-0.644**	-0.034
Moisture content (%)	**0.687**	**0.494**	0.019
Organic matter (%)	**0.586**	0.312	-0.232
Electrical conductivity (mS/cm)	**0.873**	0.254	-0.315
pH	0.2 12	**0.488**	0.087
Altitude	**0.724**	0.321	0.261
Disturbance	-0.243	-0.254	**-0.574**

Acacia tortilis subsp. *raddiana* cluster (A) had the highest total number of species (18 species), and species richness (7.3 species/stand) (Table 1). On the other hand, *Juncus acutus – Imperata cylindrica* cluster (C) had the lowest total number of species (5 species) and richness (3.2 species/stand). The high species richness in the wadi channels characterized by *Acacia tortilis* subsp. *raddiana* could be related to the considerable amounts of runoff water that received by channels. In addition, the canopy shade of *A. tortilis* subsp. *raddiana* is essential for the water and energy conservation of several animal and plant species (Wiegand et al., 1999; Robinson, 2004). Ward and Rohner (1997) documented that the disappearance of *Acacia tortilis* subsp. *raddiana* from Negev desert has lead to the loss of many of perennial plants growing in its vicinity. On the other hand, the low species richness in the vegetation groups of wet and dry saline flats may be attributed to the soil salinity and crust that inhabit the germination and growth of intolerant salt plants (Grime 1979; Shamsudinov, 1997)

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