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Vegetation Changes along a Geomorphological Gradient under Arid Bioclimate in North

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ABSTRACT

In north Africa the floristic richness and diversity are mainly due to its precarious bioclimate, geomorphology, soil and human activities. Ecosystem components have been formed and developed under these very different ecological conditions. Our study was conducted in a part of north Africa to analyze major relationships among vegetation distribution and landform in an protected ecosystems, case of Bou Hedma National Park (BHNP) in southern Tunisia.

Multivariate analysis of 200 vegetation plots along geomorphological gradient in the BHNP, allowed us to classify complex mosaics of landforms and plant communities. By assessing plant community distribution in the context of the different landform units and geomorphic processes, represented in detailed geomorphological schema, a sequence of landform-vegetation units and soil properties were identified. A total of fourty seven perennial species in four landform types were analyzed using correspondence analysis. Multivariate analysis identified five community types defined by physical soil properties and geomorphological conditions (A, B, C, D1 and D2).

Our results showed that the highest total number of species is recorded in the Glacis (20), whereas the lowest species numbers are recorded in the Mountain (13) and in the silty plain (15). Community C appears to be rather different, with 5 characteristic species (*Tricholaena teneriffae* L., *Raetama retam* Forssk, *Deverra chloranthus* Bent, *Periploca angustifolia* Labill. and *Rhus tripartita* Ucria). We can be also noted that organic matter, phosphorus and nitrogen attain their highest levels in the group of wadis and sandy plain, the low level of nutrients and low sand content on the glacis and mountain.

INTRODUCTION

Landforms provide information on the development of terrain over a long period of time as well as on its present condition, and vegetation is indicative, in the short term, of existing environmental conditions confounded by disturbance history [1,2]. Suggested that geomorphology may change the nature of the vegetation which can be supported across a landform [3].

The simultaneous analysis of landform and vegetation, known as phytogeomorphology, synthesizes a number of important land features indicative of vegetation distribution patterns as well as the current suitability for land restoration or other purposes [4]. Landform and vegetation are indicators of the influence of important environmental factors such as soil, water availability and climate [5].

The most pressing issues in north Africa are water, soil, and biodiversity. Protected areas are of particular concern, both in terms of the amount of land protected and the diversity of habitat types protected. Of all the African sub-regions, north Africa protects the least amount of land in the fewest number of sites. The aim of the Bou Hedma National Park (BHNP) is to conserve the biodiversity under arid bioclimate of southern of Tunisia. The vegetation of the park is one of particular scientific interest because it represents a transition between the vegetation of arid bioclimate and the savanian vegetation of the saharan-tropical bioclimate, corresponding to arid and saharan ecosystems in north Africa. The aim of this paper is to analyze major relationships among vegetation distribution and lanform types and to enrich the knowledge about the perennial vegetation of the BHNP. It attempts of portraying the relationship between the vegetation and the complex geomorphologic environment of the study area.

MATERIAL AND METHODS

Study Site

North Africa is bordered on the north by the Mediterranean Sea, and the climate of the coast is similar to that of the rest of the Mediterranean countries, the dominant feature of north Africa is the Sahara desert. The north African region is known for dry, hot summers, and wet winters. The changing temperatures and moisture affect what grows in the area. Since summer droughts and rainfall can vary drastically from year to year, indigenous plants are drought resistant. The most significant challenge to the region's environment is desertification and the lower biodiversity level.

The study area lies in Tunisian Bou Hedma National Park (BHNP) in northern African pseudo-savanna of *Acacia tortilis* ssp. *Raddiana* (Savi) (34º39′N and 9º48′E), protected since 1977 and since ranked by UNESCO as a biosphere reserve **(Figure 1).** Climatically, the study area is classified as a lower arid and characterized by hot summers, cool winters, and low unpredictable rainfall (annual rainfalls vary between 100 and 200 mm) [6]. Mean temperature varies from 32ºC to 36ºC in the summer and from 4ºC to 7ºC in the winter [7]. The soil of the experimental areas is composed of quaternary sandy deposits and covered by *Acacia tortilis* pseudo-savanna. *Acacia tortilis* subsp *raddiana* (Savi) is the most important tree species in the region. The lower vegetation layer (<1 m) is composed by perennial grasses (*Cenchrus ciliaris* L., *Digitaria nodosa* Parl. and *Stipagrostis ciliata* Desf.), two species of the genus Hammada (*Hammada schmittiana* Pomel and *Hammada scoparia* Pomel), which belong to Chenopodiaceae family and one Asteraceae of the arid and saharan region (*Rhanterium suaveolens* Desf.) [8,9].

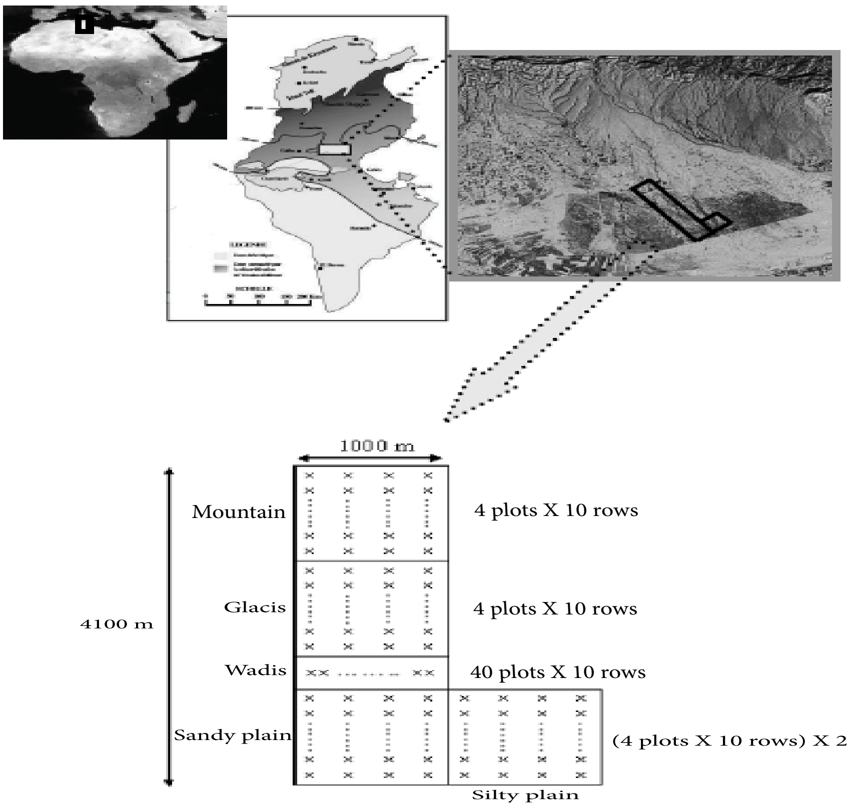

Figure 1. Location of the Bou Hedma National Park and experimental design.

Vegetation Sampling

The geomorphological type plays an important role in determining the distribution of plant communities [10]. Altitude across BHNP ranges from 106 m to 840 m. Our sampling method aimed to represent the plant communities of the BHNP, taking into account its large geomorphological variability. Four landform types were distinguished: mountain, glacis, wadis and plain **(Figure 2)**. A presence absence survey of the vegetation was carried out during 2008-2009 using a total of 200 plots (8-by-8 meter each). Each landform (the mountain A, glacis B and wadis C) were randomly sampled using 40 plots. The plain landform was sampled according to its soil composition: 40 plots were done in the sandy plain (D1), with a high sand content 75.8% and 40 other plots in the silty plain (D2), with a higher silt content 54.4% **(Figure 3).** Taxonomic nomenclature used is according to [11].

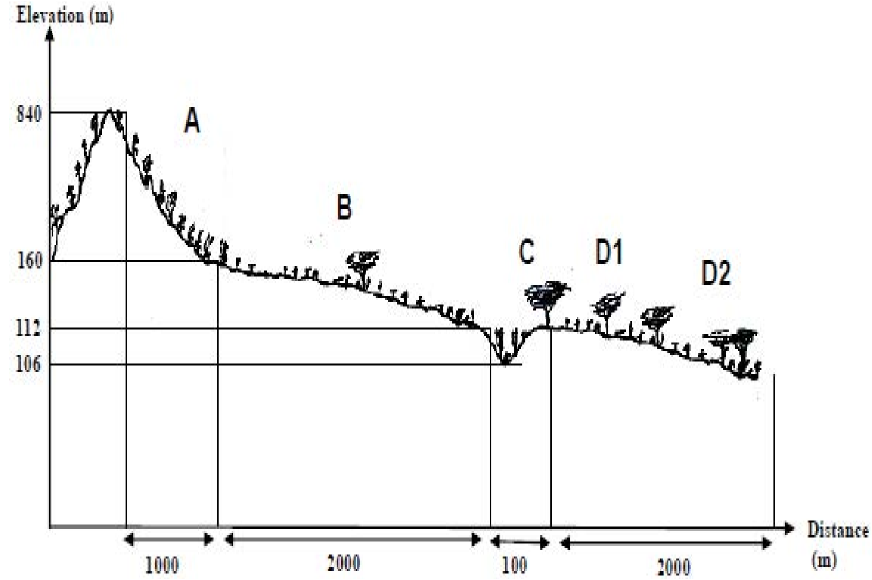

Figure 2. Geomorphological schema of the study area. A=Mountain, B=Glacis, C=Wadis, D1=Sandy plain, D2=Silty plain.

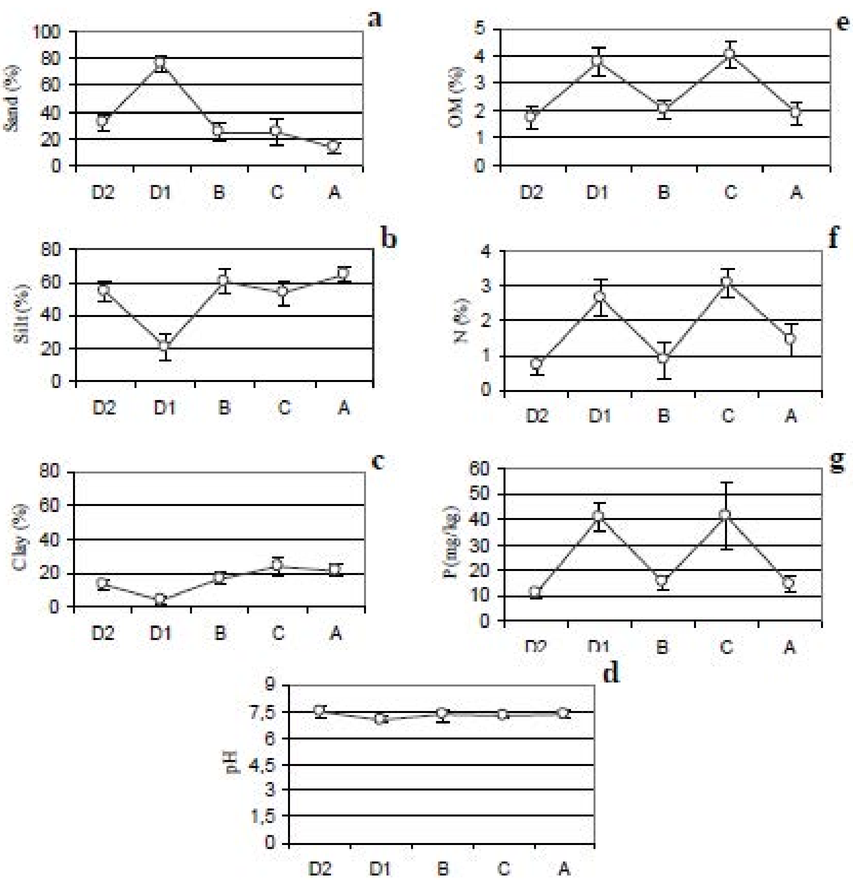

Figure 3. contents of sand (3a), silt (3b), clay (3c), concentrations of organic matter (OM) (3e), nitrogen (N) (3f), phosphorus (P) (3g) and pH values in the different sites (A=Mountain, B=Glacis, C=Wadis, D1=Sandy plain, D2=Silty plain).

Soil Sampling and Analysis

Five soil samples (0 cm to 50 cm) are collected from each site. The soil samples were kept in plastic bags, labelled, sealed and transported to the laboratory (Tunisia). Soils were air-dried and, and passes through a 2 mm sieve to get rid of gravel and boulders. The portion finer than 2 mm is kept for physical and chemical analysis according to [12]. Soil texture is determined by the hydrometer analysis, and the results used to calculate the percentages of sand, silt and clay. Soil reaction (pH) is evaluated using a glass electrode pH-meter. Total nitrogen (N) (Kjeldahl method), % of OM (Walkley-Black method), and phosphorus (calorimetric method) were also determined [12-14].

Geomorphological Gradient

Mountaneous landform are characterised by strong environmental gradients and unstable environments. These conditions

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lead to marginality in terms of human settlement due to steepness, poor soil and inaccessibility [15]. The glacis landform corresponds to an extension of the pediment composed of calcareous crust and covered by loamy soils (high silt content 60.6%, **(Figure 3)** that are generally not very deep. Abundant amount of water coming from the adjacent mountains are usually received by the glacis landform. The plain is a large area with a low slope and a low amount of streaming water. The wadis landform corresponds to wide depressions, accumulating flowing and streaming water and a high nitrogen content, organic matter and phosphorus **(Figure 3).**

Statistical Analyses

In each plot, the presence absence species relieves data were processed using correspondence analysis [16]. Landform type information was used a posteriori to illustrate species assemblage variations. Contributions of principal directions to species were computed as to emphasize landform type characteristic species compared to less representative ones.

Correspondence analysis, specific contributions and graphical representations were conducted via R using ade 4 and ade 4TkGUI packages [17-19].

RESULTS

Landform-Vegetation Physiognomy

In total, 47 perennial species representing 38 genus and 24 families are collected and identified in this study. The largest families are Poaceae, Asteraceae and Chenopodiaceae representing respectively 19%, 9% and 9% of the total flora of the BHNP. The best represented genus are Stipagrostis and Erodium with 3 species for each. None all of the 47 perennial species occurs at all the 5 sites **(Table 1).** Some of the recorded species have a wide ecological and phyto-sociological range of distribution, e.g. *Hammada schmittiana* Pomel, *Cenchris ciliaris* L., *Stipagrostis ciliata* Desf. and *Anabasis oropediorum* Maire with the highest species occurrence. Twenty-three species (49% of the total recorded species) demonstrated a certain degree of appearance, being confined to a certain geomorphologic unit and are not otherwise. These species are distributed as follows: 3 species in the Mountain (*Erodium arborescens* Desf., *Globularia alypum* L. and *Juniperus phoenicea* L.), 6 species in the Glacis (*Atractylis serratuloides* Cass., *Astragalus armatus* Willd., *Astragalus caprinus* L., *Erodium glaucophyllum* L., *Tetrapogon villosus* Desf. and *Teucrium polium* L.), 5 species in the Wadis (*Cleome amblyocarpa* Bar., *Farsetia eagyptiaca* Turra, *Periploca angustifolia* Labill., *Tricholaena teneriffae* L. and *Rhus tripartita* Ucria), 8 species in the Sandy plain (*Asparagus albus* L., *Dipcadi serotinum* L., *Echiochilon fruticosum* Desf., *Ephedra altissima* Desf., *Pergularia tomentosa* L., *Rhanterium suaveolens* Desf., *Salsola vermiculata* Aggr. and *Stipagrostis plumosa* L.) and one species in the silty plain (*Ziziphus lotus* L.). Floristic composition in the different geomorphologic landscape units showed differences in species richness. The highest total number of species is recorded in the Glacis (20), whereas the lowest species numbers are recorded in the Mountain (13) and in the silty plain (15).

Table 1. Summary table of species presence/absence data in the different landform types of BHNP. Abundant species are listed first (presence in more than one plot, 38 species) and rare species (presence in only one plot, 9 species) are listed at the bottom of the table. Most contributive species as demonstrated by correspondence analysis are represented in bold.

	Landform types		A	B	C	D1	D2
	Number of sample plots		40	40	40	40	40
	Total number of species		13	20	19	19	15
	Cover (%) ± standard error		24.75 ± 0.94	35.87 ± 1.11	40.62 ± 1.31	29.87 ± 1.19	15.12 ± 0.72
Abbr.	**Most Abundant Species**	**Families**					
Ear	*Erodium arborescens*	Geraniaceae	■	–	–	–	–
Etr	*Erodium triangulare*	Geraniaceae	▪	□	–	–	–
Gde	*Gymnocarpos decander*	Caryophyllaceae	▪	▪	–	–	–
Hse	*Helianthemum sessiliflorum*	Cistaceae	▪	–	□	□	–
Ste	*Stipa tenacessima*	Poaceae	▪	▪	–	–	–
Aor	*Anabasis oropediorum*	Chenopodiaceae	▪	▪	–	□	□
Ahe	*Artemisia herba alba*	Asteraceae	▪	▪	–	–	–
Aar	*Astragalus armatus*	Fabaceae	–	■	–	–	–
Dno	*Digitaria nodosa*	Poaceae	–	▪	▪	–	–
Fgl	*Fagonia glutinosa*	Zygophyllaceae	–	▪	▪	–	□
Hso	*Hammada scoparia*	Chenopodiaceae	□	▪	–	□	▪
Hka	*Helianthemum kahiricum*	Cistaceae	▪	▪	–	–	–
Sci	*Stipagrostis ciliata*	Poaceae	–	▪	□	□	□
Sob	*Stipagrostis obtusa*	Poaceae	–	▪	–	□	–
Tvi	*Tetrapogon villosus*	Poaceae	–	■	–	–	–
Sae	*Salvia aegyptiaca*	Lamiaceae	–	▪	▪	–	–
Cam	*Cleome amblyocarpa*	Capparaceae	–	–	■	–	–
Cda	*Cynodon dactylon*	Poaceae	–	–	▪	–	□
Dch	*Deverra chloranthus*	Apiaceae	–	–	▪	–	□

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Lmu	*Lavandula multifida*	Lamiaceae	–	–	■	–	□
Lsh	*Lycium shawii*	Solanaceae	–	–	■	■	□
Mar	*Moricandia arvensis*	Brassicaceae	□	–	■	–	–
Tte	*Tricholaena teneriffae*	Poaceae	–	–	■	–	–
Rre	*Raetama retam*	Fabaceae	–	–	■	□	■
Rtr	*Rhus tripartita*	Anacardiaceae	–	–	■	–	–
Pto	*Pergularia tomentosa*	Asclepiadaceae	–	–	■	□	–
Aal	*Asparagus albus*	Asparagaceae	–	–	–	■	–
Cci	*Cenchrus ciliaris*	Poaceae	–	■	□	■	–
Efr	*Echiochilon fruticosum*	Boraginaceae	–	–	–	■	–
Eal	*Ephedra altissima*	Ephedraceae	–	–	–	■	–
Hsc	*Hammada Schmittiana*	Chenopodiaceae	■	□	□	■	–
Rsu	*Rhanterium suaveolens*	Asteraceae	–	–	–	■	–
Sve	*Salsola vermiculata*	Chenopodiaceae	–	–	–	■	–
Spl	*Stipagrostis plumosa*	Poaceae	–	–	–	■	–
Aca	*Artemisia campestris*	Asteraceae	–	–	■	–	■
Dto	*Deverra tortuosa*	Apiaceae	–	–	–	□	■
Pha	*Peganum harmala*	Nitrariaceae	–	–	–	■	■
Zlo	*Ziziphus lotus*	Rhamnaceae	–	–	–	–	■
Abbr.	**Rare species**	**Families**	**A**	**B**	**C**	**D1**	**D2**
Gre	*Globularia alypum*	Globulariaceae					
Jph	*Juniperus phoenicea*	Cupressaceae					
Ase	*Atractylis serratuloides*	Asteraceae					
Acp	*Astragalus caprinus*	Fabaceae					
Egl	*Erodium glaucophyllum*	Geraniaceae					
Tpo	*Teucrium polium*	Lamiaceae					
Fea	*Farsetia eagyptiaca*	Brassicaceae					
Pan	*Periploca angustifolia*	Apocynaceae					
Dse	*Dipcadi serotinum*	Hyacinthaceae					
■=100%, ■=[20%;100%], □=[0%;20%], – =absence, A=Mountain, B=Glacis, C=Wadis, D1=Sandy plain, D2=Silty plain							

Correspondence analysis of the 200 relieves × 47 species table allows us to distinguish five plant communities **(Figure 4)**: Mountain community (A) mainly represented by *Erodium arborescens* Desf. and *Erodium triangulare* Cav., Glacis community (B) characterized by *A. oropediorum* Maire, *T. villosus* Desf. and *Helianthemum kahiricum* Del., Wadis community (C) as exemplified by *Cynodon dactylon* L., *Deverra chloranthus* Bent., *Retama raetam* Forssk. and *Moricandia arvensis* Desf. taxons, Sandy plain community (D1) where *C. ciliaris* L., *H. Schmittiana* Pomel and *R. suaveolens* Desf. are most characteristic, and Silty plain community (D2) with presence of *Artemisia campestris* L.

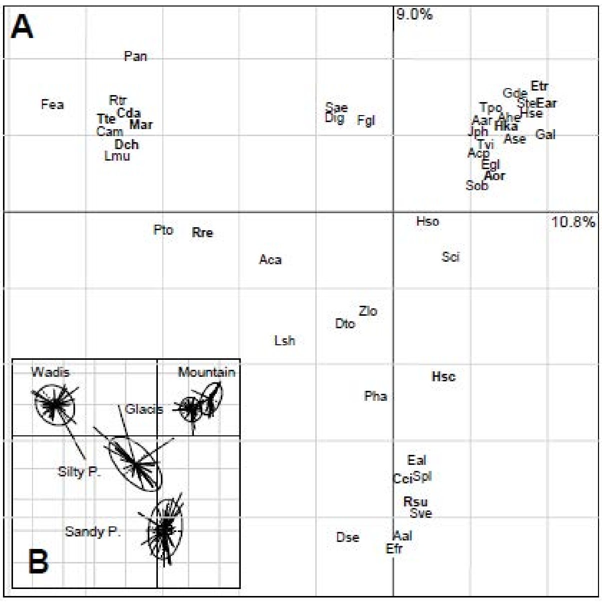

Figure 4. Correspondence analysis of presence-absence data (200 relevés and 47 species). A: Axis 1 (horizontal) and 2 (vertical) representation of vegetation species (most contributive species in bold). B: Axis 1 and 2 representation of relevés. Relevés are categorised according to 4 landform types : Wadis, Plain (sandy or silty), Glacis and Mountain. Landform types are represented as inertia ellipses. Mean and individual situation of the relevés per each landform type are represented by stars.

Community C appears to be rather different, with 5 characteristic species (*T. teneriffae* L., *R. retam* Forssk., *Deverra chloranthus* Bent., *P. angustifolia* Labill. and *R. tripartita* Ucria). These two plant communities as well as communities C, D1 and D2 are well spread over the two first principal directions showing distinct assemblages of species **(Figure 4B).** D1 and D2 communities appear to be intermediate between "A, B" and C communities. A and B look rather homogeneous compared to B, D1 and D2 which are the most heterogeneous.

Floristic composition and structure of communities field surveys showed that A community consisted of 13 species, 10 genera and 9 families of perennial plants, while B community was composed of 20 species 16 genera and 10 families. There were 19 species, 19 genera and 14 families of perennial plants in C community, and 19 species, 16 genera and 12 families of perennial plants in D1 community, and 13 species, 13 genera and 11 families of perennial plants in D2 community **(Table 1).**

Communities B, C and D1 appear to be sources of species richness having respectively 6, 5 and 7 characteristic species (species that exists only in this community). Community A and D2 have relatively poor species richness with the lowest levels of nitrogen, phosphorus and organic matter **(Figure 3).** Community A shares most of its species with the B community due to the similarity of the physical and chemical properties of soil **(Table 1 and Figure 3).** Community D2 shares species with most of the other communities having only one characteristic species. According to ellipses sizes **(Figure 4B)** it could be noticed that communities are of various heterogeneity: As a consequence of its intermediate situation, heterogeneity of plots is high for the D2 community. The same comment is true for D2. Plots of the A, B and C landform types are relatively homogeneous.

Soil characteristics of each of the five vegetation groups are summarized in **Figure 3.** Of the measured soil parameters, pH, organic matter, phosphorus, nitrogen and fine soil fraction showed differences between groups. It can be also noted that organic matter, phosphorus and nitrogen attain their highest levels in the group of wadis and sandy plain, the low level of nutrients and low sand content on the glacis and mountain. Results from **Figure 3** showed that the soil variables are largely uncorrelated, with few noteworthy exceptions. Significant correlations occurred between the organic matter, phosphorus, nitrogen content and soil texture. pH values are similar for all groups, about 7.5 in the different landforms.

DISCUSSION

Our results showed well the relative positions of species and sites along the most important ecological gradients, both physical and chemical properties are the most important factors for the distribution of the vegetation pattern in BHNP. The soil texture gradient that exists from the sandy plains to fine-textured flats in the alluvial plains and wadis channels in arid environments results in gradients of available soil moisture [20]. The organic matter content plays an important role as a key element in soil fertility, as shown for other desert ecosystems in Egypt and in Saudi Arabia [21-24].

The flora of the BHNP is composed by a group of very common species (*H. scoparia* Pomel, *H. schmittiana* Pomel, *A. oropidiorum* Maire, *Gymnocarpos decander* Forssk., *A campestris* L.) that covers most of the area and dominates many of the sub-shrub communities. Also, many rare species have a limited distribution in the BHNP. There are some rare endemic species such as *Tricholaena teneriffae* L. and *Digitaria nodosa* Parl. and species that are threatened by grazing of wild animals in the park (e.g. *Juniperus phoenicea* L., *T. polium* L., *A. caprinus* L. and *Stipagrostis sp.*).

The wadis vegetation depends on the prevailing water regime and is highly influenced by livestock [25,26]. In this study the main indicator species of the vegetation group on wadis sites were *Periploca angustifolia* Labill. and *Rhus tripartita* Ucria, which were previously described by as typical phanerophytes present in the wadis. The plant life in the study area is restricted to microenvironments (as in wadis) where runoff water collects and provides sufficient moisture for plant growth [20,27].

This study and our previously published results are the first quantitative attempt to classify the vegetation of the BHNP, using a range of complementary sampling methods and current best-practice statistical techniques [9]. Under arid bioclimate, vegetation patterns are determined by environmental factors that exhibit heterogeneity over space and time, such as rainfall, temperature, topography, geology and soil characteristics [28] also showed strong relationships between relief and the vegetation structure [29]. These geomorphologic parameters have been described as indirect variables according to which usually replace a combination of different trophic resources and direct gradients in a simple way, such as climatic and moisture conditions [30]. The present study concentrated on plant communities in differents landform types. As in any other arid zones, low-lying sites and wadis sites receive runoff water and water sediments, resulting in deeper soil layers, which provide a continuous supply of organic matter and moisture for the perennials [31]. By contrast, elevated sites always have limited water resources and more shallow soils. Hence, the vegetation cover of shrubs is greatly affected by the landform and was significantly higher on wadis sites. The total cover, as a better indicator of plant community health [32]. In the BHNP, the low vegetation cover in the silty plain is influenced by physical properties of soil [8].

CONCLUSION

Under the conditions of low and irregular rainfall in the study area, local geomorphology is one of the overriding factors controlling physical and chemical properties of soil and vegetation in the local landscape.

The vegetation structure in the present study showed different vegetation communities along a significant geomorphological gradient. As such it mirrors particularly the effects of relief and landform on plant species composition and diversity. In our precedent work we investigated the effect of grazing in the plain of the Bou Hedma region [9]. Grazed area is still poorly documented and future work is needed to study the distributions of plant communities and threatened species in more detail, particularly in relation to geomorphological gradient on vegetation physiognomy and structure.

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