African Journal of Environmental Science and Technology Vol. 2 (7). pp. 157-171, July 2008
Available online at http://www.academicjournals.org/AJest
ISSN 1996-0786 © 2008 Academic Journals

Full Length Research Paper

Diversity and distribution of medicinal plants in North Sinai, Egypt

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Accepted 22 July, 2008

The present study aims to assess plant diversity and distribution of medicinal plants in relation to environmental factors at three geomorphological districts (Mediterranean coast, anticlines, and inland) and five main habitats (salt marshes, sand dunes, sand plains, wadis, and gorges) in North Sinai. The results revealed that North Sinai harbors 281 species with high taxonomic diversity (species/genera = 1.49) and high percentage of rare and very rare species (67%). Mediterranean coastal district and anticlines district are more diverse than inland district. Medicinal plants constitute 43% of North Sinai flora. Species richness, Shannon-Weiner *H*, and Margalef indices measurements indicated that gorges are the most diverse habitat in North Sinai followed by wadis. Plains have intermediate diversity followed by sand dunes. The lowest diversity indices were recorded at salt marshes habitat. Beta diversity measurements, using Wilson and Schmida index (β_T), indicated significant changes in floristic compositions between different habitats. The lowest changes were among sand plain, wadi, and gorge habitats. North Sinai habitats support about 100 to 120 medicinal plant associations. The main dominant species include *Artemisia monosperma*, *Arthrocnemum macrostachyum*, *Lycium shawii*, *Retama raetam*, *Stipagrostis scoparia*, *Tamarix nilotica*, *Zygophyllum album*, and *Zygophyllum dumosum*. Soil physical properties in addition to soil salinity and topographic variations are the main driving factors controlling the distribution of medicinal plants in North Sinai. About 60% of medicinal plants are threatened due to intensive collection and other human activities. The threatened medicinal plants including *Acacia pachyceras*, *Acacia tortilis*, *Anastatica hierochuntica*, *Asclepias sinaica*, *Capparis spinosa*, *Chiliadenus montanus*, *Citrulus colocynthis, Ephedra alata*, and *Juniperus phoenicea* along with their habitats should have the first priority in management and conservation plan of medicinal plants in North Sinai. Public and private involvement in management and utilization of medicinal plants in sustainable way is essential to combat human pressures on these valuable natural resources.

Key words: Conservation, diversity, habitats, human impacts, medicinal plants, vegetation.

INTRODUCTION

North Sinai is a part of the Saharo-Arabian deserts. Its flora is composed of a few common species that cover most of the area most of the time and many rare species that have limited distribution in time and/or space (Danin, 1986). Several studies have beendone on the floristic composition of North Sinai (Boulos, 1960; Täckholm, 1974; Danin et al., 1985; Gibali, 1988, 2000; Gazar et al., 2000). On the other hand, few studies have described the diversity indices between different habitats (Danin, 1978), and have provided qualitative assessment of North Sinai vegetation in relation to physiographic factors (Batanouny, 1964; Danin, 1986; El-Bana et al., 2000, 2002). North Sinai, in general, support 600 - 700 plant species (Täckholm, 1974; Danin et al., 1985; Kamel et al., 2008) of which 279 were recorded in the Mediterranean coastal district (Gibali, 1988), about 250 about 250 species in anticlines (Boulos, 1960; Gazar et al., 2000), and 119 species in the inland district (Gibali, 2000).

Sinai Peninsula is one of the important centers of medicinal plants in the Arabian deserts. Medicinal plants refer to species having medicinal (including veterinary),

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aromatic, and culinary importance. Distributions, utilization in folk medicine, and active constituents of medicinal plants in Sinai have attracted the attention of many ecologists, taxonomists and phytochemists (Bailey and Danin, 1981; Boulos, 1983; Bown, 1995; Batanouny et al., 1999; Hanafi and Abdel-Wahab, 2000; Abd El-Wahab et al., 2004). Environmental conditions and human impacts have a significant influence on diversity and distribution of threatened, endemic, and medicinal plants (Zaghloul, 1997; Moustafa et al., 2001; Abd El-Wahab et al., 2004). This influence is aggravated in arid ecosystems (Batanouny, 1983). The main threats that affect medicinal plants of North Sinai include continuous urbanization, land reclamation projects, and quarrying (Medicinal Plants Conservation Project, MPCP, 2006). Biodiversity is an important measurement that could contribute to management and conservation of natural resources. The rapid loss of species richness and viability are creating the need for understanding the biodiversity and its changes over time (UNEP, 1995).

The present study aims to provide required information for conservation and sustainable use of medicinal plants in North Sinai. In this study, we focus on (a) taxonomic diversity of medicinal plants at three main gomorphological districts, (b) diversity of medicinal plants at different habitats (c) floristic change between different habitats, and (d) distribution of medicinal plants associations in relation to environmental factors and human impacts at different habitats.

MATERIAL AND METHODS

Study area

North Sinai lies between 32° 20' and 34° 30' E and 30° 05' and 31° 10' N (Figure 1). Its area is about 27500 km^2. North Sinai, as a desert region, belongs to arid climate with hot summer, mild winter and annual rainfall of 20 – 100 mm (Ayyad and Ghabour, 1986). North of latitude 30°N, the topography comprises low alluvial plains, which are broken by large uplifted Mesozoic domes and anticlines, such as Gebel (G.) Maghara (738 m altitude), G. Halal (892 m), and G. Yi'allaq (1049 m). North of G. Maghara and extending nearly to the Mediterranean coast is a broad tract of sand dunes, some of which attain heights of 91 m above sea level (Said, 1990).

North Sinai is classified into three geomorphological districts; Mediterranean coastal district, anticlines district, and inland (transition) district. The Mediterranean coastal district extends 20 to 40 km southward from the Mediterranean coast. The main habitats in this district are open undulating sandy plain, sand dunes, and salt marshes. The open undulating sandy plains occupy most of the Mediterranean coastal district with coarse sand as soil surface. Different types of sand dunes are prominent in the district. Salt marshes are located at depressions and near the foothills of sandy dunes. The main anticlines are G. Maghara, G. Halal, and G. Yi'allaq.

These anticlines are characterized by limestone, chalk, dolmite, and marl outcrops. Large outcrops of smooth-faced limestone and dolomite are found at G. Halal, G. Maghara, G. Libni and G. Yi'allaq. The syncline valleys are filled with sand-covered alluvium (Said, 1990). The inland district is characterized by sandy plains with different types of sand dunes similar to those types at the Mediterranean coastal district. The second type of habitats is wadis mainly originated from the anticlines, then split and convert till pour in the plains surrounding the mountainous district.

Vegetation survey

Vegetation survey and assessing the ecological situation of medicinal plants, human activities and land use were carried out at five different habitats (salt marshes, sand dunes, sand plains, wadis, and gorges) in the three districts of North Sinai (Mediterranean coastal district, anticlines district, and inland district). Two hundred and sixty plots in 90 sites representing different habitats in different districts were selected in stratified random approach. The size of the plots varied from 10 x 10 m in habiats with dense vegetation to 20 x 20 m in habitats with widely spaced shrubs or trees. Geographic location (latitude and longitude), and altitude were recorded at each site using GPS receiver “Trimble model”. Distribution of these sites is as follow: Fifty-two sites were selected in the Mediterranean coastal district from Qantara to Rafah along twelve line transects, 2 km each. Twenty-eight sites were selected in anticlines district including four main mountains (G. Maghara (10 sites), G. Halal (6 sites), G. Lebni (4 sites), and G. Yi'allaq (8 sites). Ten sites were selected in inland district, the transition zone between the Mediterranean and anticlines, along four main roads; Ismailia-Gifgafa, Gifgafa-Bir El-Abd, Gifgafa-EL-Thamada, and Lehfen-Sad El-Rawafaa.

Plant cover as canopy cover of each species was measured at each plot (Gopal and Bhardwaj, 1981). Identification and nomenclature of plant species were according to Täckholm (1974), Boulos (1995), and Boulos (1999, 2000, 2002, 2005). Specimens of plants recorded in this study were deposited in Botany Department Herbarium, Suez Canal University. Abundance of each species was determined quantitatively based on presence percentage according to the following scale: dominant > 14%, local dominant 9 - 14%, associated 6 - <9%, rare 3 - <6%, and very rare <3%. Growth form was assigned following to Boulos (1995).

One-hundred and fifty two surface soil samples were collected as a mixture from zero to 25 cm in depth. They were air-dried and sieved through 2 mm sieve to obtain rpresentative sub-samples (fine soil) for physical and chemical analyses and to exclude large particles that are relatively less reactive (Robertson et al., 1999). The large particles (>2 mm) were weighed as a gravel percentage. Particle size distribution analysis was determined by dry sieving (Gee and Bauder, 1986) and soil electric conductivity was measured (Sparks et al., 1996).

Data treatment

The obtained data were statistically evaluated using SPSS software following to Zar (1984). Plant diversity indices included species richness, Shannon-Weiner diversity index (H′), and Margalef index. These diversity indices were eastimated for each plot in each habitat (Barbour et al., 1987). Taxonomic diversity including species/genera and genera/families ratios for North Sinai as a whole and for each district was determined. Beta diversity (β_T) (Wilson and Schmida, 1984) was also determined to represent the biotic change between different habitats. Diversity indices were determined using GenStat 10th Edition software (Payne et al., 2007).

RESULTS

Plant diversity in geomorphological districts

Species richness

Based on the current survey (2005 - 2006), North Sinai

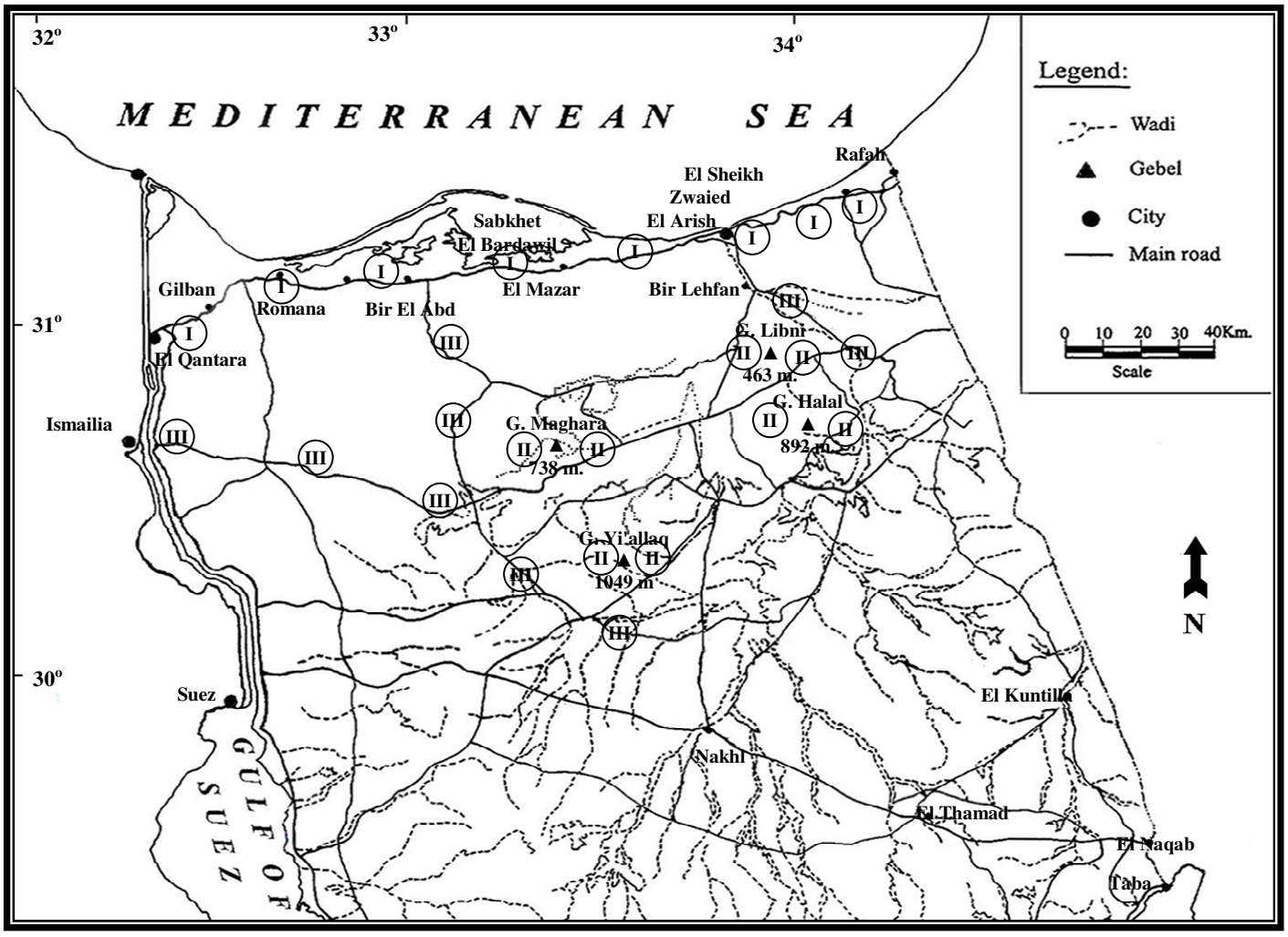

Figure 1. Location map of North Sinai showing the different sites selected at three main districts; Mediterranean coastal area (I), anticlines (II), and inland (III).

supports 281 species belonging to 189 genera and 52 families. Mediterranean coastal district harbors the highest number of species (188 species) followed by the anticlines district (131 species) and inland district (58 species). A total of 137 annuals species (49%) and 144 perennials (51%) was recorded in North Sinai. Mediterranean coastal district harbors the highest number of annuals 110 species followed by the anticlines district (37 species) and inland district (19 species). On the other hand, anticlines supports the highest richness of perennials (94 species) followed by Mediterranean (78 species) and inland (39 species) (Table 1).

Within these districts, the highest species richness was found at G. Maghara (92 species) followed by El-Sheikh Zewaied, G. Halal and Wadi El-Arish (70 - 80 species); and El-Arish- Wadi El-Akhdar, G. Yalleq, G. Libni, Wadi El-Akhdar, Nagila, Bir El-Abd - El-Arish, and Lehfen-Sad El-Rawafa (30 - 50 species). The total number of species recorded at Qantara, Balousa, Ismailia-Gifgafa, Gifgafa-Bir El-Abd, Romana, Romana - Nagila, and Rafah varied from 15 to 25 species whereas the lowest number of species was recorded at Gifgafa - El-Thamada (10 species) (Figure 2).

Taxonomic diversity

Flora of North Sinai comprises 52 families of which Compositae, Gramineae, Leguminoseae, Cruciferae, and Chenopodiaceae harbor the highest number of species. Based on the number of families and genera, Mediterranean district has the highest diversity of families and genera (42 families and 145 genera) followed by anticlines district (42 families and 108 genera). On the other hand, inland district supports the lowest number of families and genera (24, 51, respectively) (Table 1). Taxonomic diversity indices in terms of species/genera and genera/families ratios indicate that the three districts are more diverse than North Sinai as a whole (Table 1).

Table 1. Taxonomic diversity, growth forms, and rarity of floristic elements in North Sinai as a whole and in its three main districts; Mediterranean, Anticlines, and Inland.

Taxonomic Diversity	North Sinai	Mediterranean	Anticlines	Inland
Family	52	42	42	24
Genus	189	145	108	51
Species	281	188	131	58
S/G	1.49	1.3	1.21	1.14
G/F	3.63	3.45	2.57	2.12
Growth Forms				
Perennial	144	78	94	39
Annual	137	110	37	19
Rarity				
Rare	44	25	20	6
Very rare	145	90	49	14

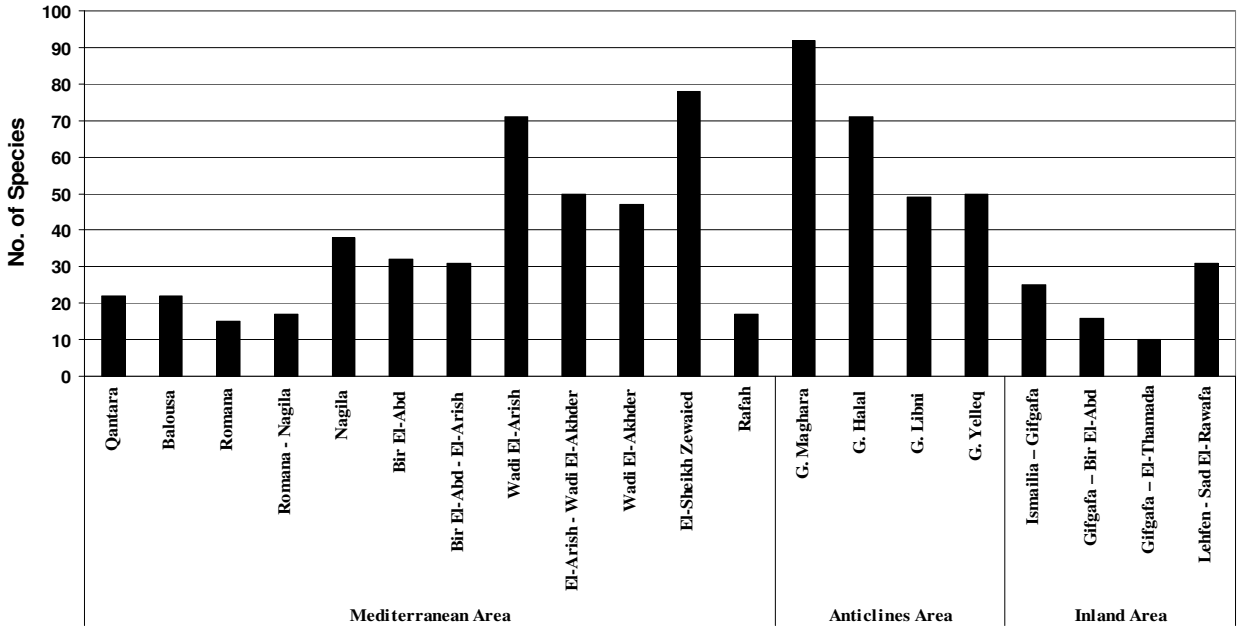

Figure 2. Species richness in different localities within the three main districts of North Sinai.

Taxonomic diversity of North Sinai is 1.49 for species/genera ratio and 3.63 for genera/families. Although inland district supports the lowest species richness, it is characterized by the highest taxonomic diversity (S/G = 1.14 and G/F = 2.12) followed by anticlines district (1.21 and 2.57, respectively) and Mediterranean district (1.30 and 3.45, respectively) (Table 1).

Species rarity

Most of the floristic elements of North Sinai (67%) are either rare (44 species) or very rare species (145 species). Percentages of rarity are 61% in Mediterranean coastal district, 52% in anticlines district, and 34% in inland district (Table 1).

Diversity of medicinal plants

North Sinai harbors about 121 medicinal species (43% of the total recorded flora) growing mainly in Mediterranean coastal district (84 species) and anticlines district (72 species). Inland district supports about 35 medicinal species. The recorded medicinal plants belong to 96 genera and 37 families. The most represented families are Compositae and Leguminosae (13 species), Chenopodiacea (11 species), Cruciferae, Caryophyllaceae, and

Table 2. Distribution, growth forms, and abundance of medicinal plants in North Sinai as a whole and in its three main districts; Mediterranean, Anticlines, and Inland.

Medicinal species	North Sinai	Mediterranean	Anticlines	Inland
Growth Forms				
Perennial	85	51	62	29
Annual	37	33	10	6
Abundance				
Dominant	12	12	12	9
Dominant Local	14	10	11	9
Associated species	35	28	22	9
rare	23	12	12	3
very rare	37	22	15	5
Total	**121**	**84**	**72**	**35**

Table 3. Distribution and abundance of medicinal plants in North Sinai. Uni-regional: plants growing in one district only, Bi-regional: plants growing in two districts, Pluri-regional: plants growing in all the three main districts of North Sinai.

Abundance	Uniregional	Biregional	Pluriregional
Dominant	-	3	9
Dominant Local	4	4	6
associated species	14	14	6
rare	20	2	1
very rare	33	4	0
Total	**72**	**27**	**22**

Graminae (8 species), and Labiatae and Zygophyllaceae (7 species) (Table 2).

Based on growth forms, medicinal plants of North Sinai consist of 39 annuals and 82 perennials. Most of the annuals are growing in Mediterranean coastal district (33 species) followed by anticlines district (10 species), whereas the highest number of perennials was recorded in anticlines district (62 species) followed by Mediterranean coastal district (51 species). Medicinal plants of inland district are 6 annuals and 29 perennials (Table 2). The most important districts of medicinal plants in North Sinai are G. Maghara (56 species), G. Halal (46 species), Wadi El-Arish (45 species), and G. Yi'allaq (43 species).

Sixty-one species of medicinal plants are either domi-nant or associated species. On the other hand, rare and very rare species constitute 60 species (50% of the total medicinal plants) mainly recorded in Mediterranean and anticlines districts (Table 2). Fifty-three of the rare and very rare medicinal plants are uniregional species (grow in Mediterranean, anticlines or inland district (uniregional). The uni-regional rare species include *Acacia pachyceras*, *Asclepias sinaica*, *Halocnemum strobilaceum*, *Juniperus phoenicea*, *Pulicaria undulata*, *Seriphidium herba-alba*, and *Teucrium polium*. The uni-regional very rare species include *Anastatica hierochuntica*, *Artemisia judaica*, *Capparis spinosa*, *Citrulus colocynthis*, *Ephedra alata,* and *Teucrium leucocladum* (Table 3). Medicinal plants growing in North Sinai, along with their distribution, growth forms, and conservation status arelisted in Table 4.

In general, human activities in North Sinai that result in threatening the plant life and medicinal plants include urbanization and agriculture projects in the Mediterranean district, mining and quarrying in the anticlines district, and overcollection of medicinal plants and overcutting of woody species all over the North Sinai. Due to these human impacts in addition to natural hazards including aridity conditions and sand dune mobility, 17 medicinal plants are considered as either endangered or vulnerable species (in North Sinai). The endangered medicinal plants are *A. santolina*, *A. hierochuntica*, *A. sinaica*, *C. montanus*, *C. colocynthis*, *J. phoenicea*, *T. polium* and *T. leucocladum*. In addition, different species of fillose lichens growing on slopes of limestone anticlines are subjected to overcollection for their medicinal value. The availability of these medicinal plants at different herb shops in El-Arish City is a clear evidence of overcollection of these threatened species. *A. pachyceras* is another endangered medicinal and woody species growing mainly in limited populations in fan and wadi habitats around G. Maghara. Quarrying and mining activities for collecting sands and gravels in these habitats lead to declining the number of their populations and destroying their habitats. The vulnerable species are *A. tortilis*, *A. fragrantissima*, *A. judaica*, *A. stipularis*, *P. sickenbergeri*, *P.crispa*, *S. herba-*

Table 4. List of medicinal plants in North Sinai, their growth forms, distribution, abundance, and conservation status. M = Mediterranean area, Mg = G. Maghara, H = G. Halal, L = G. Libni, Y = G. Yi'allaq, In = Inland area.

Species	Growth form	Distribution	Abundance
***Acacia pachyceras* O. Schwartz var. *najdensis* (Chaudhry) Boulos**	**Perennial**	**Mg**	**Rare**
Acacia tortilis (Forssk.) Hayne	Perennial	M, Mg, H, Y, In	Dominant Local
Achillea fragrantissima (Forssk.)Sch.Bip.	Perennial	M, Mg, H, Y	Associated
Achillea santolina L.	Perennial	M, In	Associated
Adonis dentata Delile	Annual	M	Very Rare
Aerva javanica (Burm. f.) Juss. ex Schult.	Perennial	Mg	Very Rare
Agathophora alopecuroides (Delile) Fenzl ex Bunge	Perennial	Mg, H	Rare
Alhagi graecorum Boiss.	Perennial	M, In	Associated
Anabasis articulata (Forssk.) Moq.	Perennial	M, Mg, H, L, Y, In	Dominant Local
Anagallis arvensis L.	Annual	M	Rare
Anastatica hierochuntica L.	Annual	Mg	Very Rare
Andrachne aspera Spreng.	Perennial	Y	Very Rare
Artemisia judaica L.	Perennial	M	Very Rare
Artemisia monosperma Delile	Perennial	M, Mg, H, L, Y, In	Dominant
Asclepias sinaica (Boiss.) Muschl.	Perennial	Mg, H, Y	Rare
Asparagus aphyllus L.	Perennial	M, Mg	Associated
Asparagus stipularis Forssk.	Perennial	Mg, H, L, Y	Dominant Local
Astragalus peregrinus Vahl	Annual	M	Very Rare
Atriplex halimus L.	Perennial	M	Rare
Avena barbata Pott ex Link	Annual	M	Rare
Ballota undulata (Fresen.) Benth.	Perennial	Mg, H, Y	Associated
Bassia muricata (L.) Asch.	Annual	M, H, In	Associated
Calendula arvensis L.	Annual	M, In	Rare
Calotropis procera (Aiton) W. T. Aiton	Perennial	M, In, Y	Associated
Capparis spinosa L. var. *spinosa*	Perennial	In	Very Rare
Chenopodium album L.	Annual	M	Associated
Chenopodium murale L.	Annual	M	Associated
Chiliadenus montanus (Vahl) Brullo	Perennial	M, Mg, H, Y	Associated
Citrullus colocynthis (L.) Schrad.	Perennial	Mg, H	Very Rare
Cleome amblyocarpa Barratte & Murb.	Annual	M, Mg, H, L, Y, In	Dominant Local
Colutea istria Mill.	Perennial	M, Mg	Very Rare
Convolvulus oleifolius Desr.	Perennial	In	Very Rare
Cornulaca monacantha Delile	Perennial	M, Mg, H, L, Y, In	Dominant
Cymbopogon schoenanthus (L.) Spreng.	Perennial	H	Very Rare
Cynodon dactylon (L.) Pers.	Perennial	M, In	Dominant Local
Deverra tortuosa (Desf.) DC.	Perennial	M, Mg	Very Rare
Deverra triradiata Hochst. ex Boiss.	Perennial	Y	Very Rare
Diplotaxis acris (Forssk.) Boiss.	Annual	M	Very Rare
Diplotaxis erucoides (L.) DC.	Annual	M	Rare
Diplotaxis harra (Forssk.) Boiss.	Perennial	Mg, H, Y	Rare
Echinops spinosus L.	Perennial	M, Mg, H, Y	Dominant
Eminium spiculatum (Blume) Schott	Perennial	M	Very Rare
Ephedra alata Decne.	Perennial	H	Very Rare
Eruca sativa Mill.	Annual	M	Very Rare
Euphorbia peplis L.	Annual	M	Associated

Table 4. Cont.

Euphorbia retusa Forssk.	Perennial	M, Mg, H, L, Y, In	Associated
Fagonia arabica L.	Perennial	M, Mg, H, L, Y, In	Dominant
Fagonia glutinosa Delile	Perennial	Mg, In	Very Rare
Fagonia mollis Delile	Perennial	Mg, H, Y	Associated
Farsetia aegyptia Turra	Perennial	M, Mg, H, L, Y, In	Associated
Globularia arabica Jaub. & Spach.	Perennial	M, Mg, H, Y	Associated
Gypsophila capillaris (Forssk.) C. Chr.	Annual	Mg, H, Y	Rare
Halocnemum strobilaceum (Pall.) M. Bieb.	Perennial	M	Rare
Haloxylon salicornicum (Moq.) Bunge ex Boiss.	Perennial	Mg, Y, In	Dominant Local
Haloxylon scoparium Pomel	Perennial	M, H, Y	Associated
Haplophyllum tuberculatum (Forssk.) Juss.	Perennial	M, Mg, L	Associated
Heliotropium arbainense Fresen.	Perennial	Y, In	Rare
Herniaria hirsute L.	Annual	M, L	Associated
Hordeum vulgare L.	Annual	M	Very Rare
Hyoscyamus muticus L.	Perennial	M, Mg, In	Dominant Local
Imperata cylindrica (L.) Raeusch.	Perennial	M	Very Rare
Iphiona mucronata (Forssk.) Asch. & Schweinf.	Perennial	M	Very Rare
Juncus rigidus Desf.	Perennial	Mg	Rare
Juniperus phoenicea L.	Perennial	Mg, H, Y	Rare
Lavandula pubescens Decne.	Perennial	Mg	Very Rare
Lycium shawii Roem. & Schult.	Perennial	M, Mg, H, L, Y	Dominant
Malva parviflora L.	Annual	M, Mg, H, Y	Dominant Local
Melilotus indicus (L.) All.	Annual	M	Associated
Mesembryanthemum crystallinum L.	Annual	M	Dominant Local
Mesembryanthemum forsskaolii Hochst. ex. Boiss.	Annual	M	Very Rare
Mesembryanthemum nodiflorum L.	Annual	M, Mg	Associated
Moltkiopsis ciliata (Forssk.) I. M. Johnst.	Perennial	M, L, In	Associated
Nitraria retusa (Forssk.) Asch.	Perennial	M, Mg, H, In	Dominant Local
Noaea mucronata (Forssk.) Asch. & Schweinf.	Perennial	Mg, L	Very Rare
Ochradenus baccatus Delile	Perennial	Mg, Y	Associated
Orobanche cernua Loefl.	Perennial	M	Very Rare
Pancratium sickenbergeri Asch. & Schweinf.	Perennial	M	Associated
Panicum turgidum Forssk.	Perennial	M, Mg, H, L, Y, In	Dominant
Paronychia arabica (L.) DC.	Annual	M, H, L	Associated
Paronychia argentea Lam.	Annual	M	Rare
Peganum harmala L.	Perennial	Mg, H, L, In	Associated
Pergularia tomentosa L.	Perennial	Mg, H, L, Y	Associated
Phoenix dactylifera L.	Perennial	M	Associated
Phragmites australis (Cav.) Trin. ex Steud.	Perennial	M	Associated
Plantago afra L.	Annual	M	Very Rare
Plantago ovata Forssk.	Annual	M, In	Associated
Pluchea dioscorides (L.) DC.	Perennial	M	Very Rare
Polycarpaea repens (Forssk.) Asch. & Schweinf.	Perennial	M, In	Very Rare
Polycarpon succulentum (Delile) J. Gay	Annual	M	Very Rare
Pulicaria undulata (L.) C.A.Mey.	Perennial	Y	Rare
Reaumuria hirtella Jaub. & Spach	Perennial	M, Mg, H, Y, In	Associated

Table 4 Cont.

Reichardia tingitana (L.) Roth	Annual	M, L, In	Rare
*Retama raetam (*Forssk.) Webb & Berthel.	Perennial	M, Mg, H, L, Y, In	Dominant
Ricinus communis L.	Perennial	M	Associated
Salvia aegyptiaca L.	Perennial	Mg, H, L, Y	Associated
Salvia lanigera Poir.	Perennial	M	Very Rare
Senecio glaucus L. subsp. *coronopifolius* (Maire) C. Alexander	Annual	M, H, In	Dominant
Seriphidium herba-album (Asso) Soják	Perennial	Mg, L, Y	Rare
Silene succulenta Forssk.	Perennial	M	Very Rare
Silene villosa Forssk.	Perennial	M	Associated
Sisymbrium irio L.	Annual	M	Rare
Solanum elaeagnifolium Cav.	Perennial	M	Very Rare
Solanum nigrum L.	Annual	M	Very Rare
Stachys aegyptiaca Pers.	Perennial	M, Mg, H, L, Y	Associated
Stipagrostis scoparia (Trin. & Rupr.) De Winter	Perennial	M, Mg, H, In	Dominant
Tamarix aphylla (L.) H. Karst.	Perennial	Mg	Very Rare
Tamarix nilotica (Ehrenb.) Bunge	Perennial	M, Mg, H, In	Dominant
Tephrosia purpurea (L.) Pers. subsp. *apollinea* (Delile) Hosni & El-Karemy	Perennial	In	Very Rare
Teucrium leucocladum Boiss.	Perennial	Mg, L	Very Rare
Teucrium polium L.	Perennial	Mg, H, Y	Rare
Thymelaea hirsuta (L.) Endl.	Perennial	M, Mg, H, L, In	Dominant
Tribulus terrestris L.	Annual	M	Rare
Trifolium resupinatum L.	Annual	M	Rare
Trigonella stellata Forssk.	Annual	M	Dominant Local
Urginea maritima (L.) Baker	Perennial	M, H	Associated
Urtica urens L.	Annual	M	Rare
Vicia sativa L.	Annual	M	Very Rare
Zilla spinosa (L.) Prantl subsp. *spinosa*	Perennial	M, Mg, H, Y	Dominant
Zygophyllum album L.f.	Perennial	M, Mg, L, In	Dominant Local
Zygophyllum coccineum L.	Perennial	Y	Dominant Local
Zygophyllum dumosum Boiss.	Perennial	Mg, H, L, Y, In	Dominant Local

alba and *U. maritima*. Different types of human impacts including overcollection and overcutting have threatened these species.

Alpha and beta diversity in the main habitats

Five main habitats were recognized in North Sinai. These habitats are salt marshes, sand dunes, sand plains, wadis, and gorges. Alpha diversity indices within these habitats are described in Figures 3 and 4. Species richness in different habitats varies from 2.04 to 6.65 species per 100 m^2. Gorges are characterized by the highest species richness (6.65 ± 0.71 Standard error species/100 m^2) followed by wadis (4.37 ± 0.41 species/100 m^2). Sand plains and sand dunes are close to each other in species richness (3.08 ± 0.18 and 2.77 ± 0.30 species/100 m^2, respectively). The lowest species richness is recognized in salt marsh habitats (2.04 ± 0.22 species/100 m^2) (Figure 3). Similar to the trend in species richness, results of Shannon-Weiner *H* and Margalef indices measure-ments indicate that gorges are the most diverse habitats in North Sinai followed by wadis. Plains habitats have intermediate diversity followed by sand dune. Salt marshes have the lowest in both diversity indices in North Sinai (Figure 4). In general, plant diversity is positively correlated with altitude, silt and clay content and organic matter content. On the other hand, it is negatively corre-lated with salinity and fine sand.

To represent floristic change between different habitats along salinity and moisture gradients, beta diversity (β_T) was determined using Wilson and Schmida index. High values of β_T that varies from 0.49 to 0.74 indicate significant changes in floristic compositions between different habitats. The highest changes were recognized between sand dunes and gorge habitats ($\beta_T = 0.74$) and between

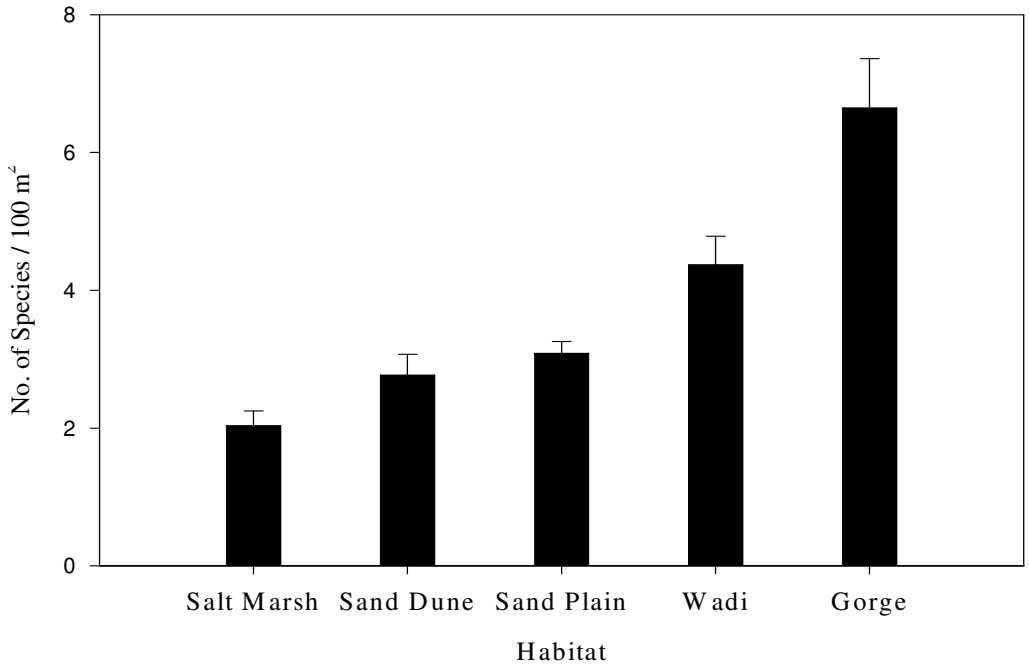

Figure 3. Number of species per 100 m^2 at different habitats in North Sinai.

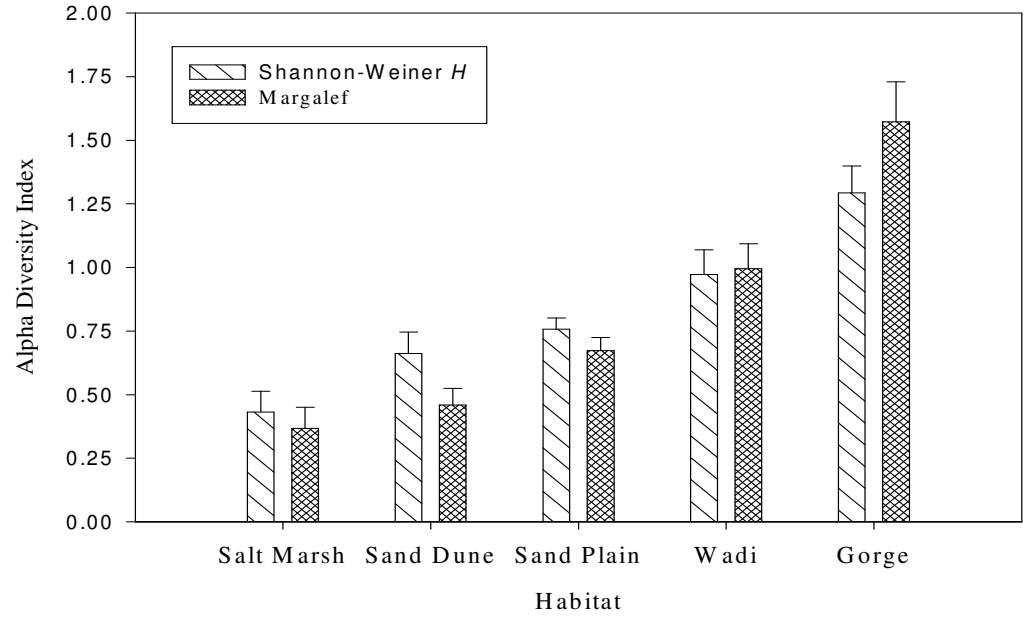

Figure 4. Shannon-Weiner *H* and Margalef indices at different habitats in North Sinai.

Table 5. Beta Diversity between five different habitats in North Sinai.

	Salt Marsh	Sand Dune	Sand Plain	Wadi
Sand Dune	0.67			
Sand Plain	0.71	0.57		
Wadi	0.69	0.66	0.49	
Gorge	0.65	0.74	0.54	0.50

salt marsh and sand plain habitats (β_T = 0.71). Salt marsh habitat supports limited number of halophytes rarely recognized in other habitats. Sand dune habitat shows some similarity in floristic composition with sand plain habitats (β_T = 0.57). The lowest changes were recognized among sand plains, wadis, and gorges habitats, where β_T varies from 0.49 to 0.54 (Table 5).

Vegetation and soil conditions

Based on vegetation analysis of 126 plant species growing in 260 plots randomly selected in different habitats, about 100 to 120 plant associations were recognized in different habitats of North Sinai. The total plant cover varies from 15 to 20%. The main plant associations at different habitats are listed in Table 6. Sand plains, wadis, and gorges are richer in plant associations than salt marshes and sand dunes. Gorges, wadis, and sand plains support high number of species richness that varies from 59 to 65 species. Sand dunes harbor low number of species (24 species) mainly recognized at the foothill of the sand dune. Salt marshes harbor the lowest number of species (18 species). Based on presence/absence of perennial species in different habitats in North Sinai, *A. monosperma*, *L. shawii*, *F. Arabica*, *T. nilotica*, *T. hirsuta* and *Z. album* are the most prominent species followed by *Asparagus stipularis, Cleome amblyocarpa, Cornulaca monacantha, Nitraria retusa, Panicum turgidum, Retama raetam,* and *Zygophyllum dumosum*. Species recorded in three different habitats only include *Acacia tortilis, Anabasis articulata*, *Centaurea pallescens*, *Fagonia mollis*, *Haloxylon salicornicum, Reaumuria hirtella*, *Stipagrostis scoparia*, and *Zilla spinosa*. On the other hand, the confined species to certain type of habitat include *Arthrocnemum macrostachyum, Halogeton alopecuroides,* and *Halocnemum strobilaceum* in salt marsh; *Convolvulus olifolius, Hyparrhenia hirta,* and *Neurada procumbens* in sand plain; and *A. herba-alba*, *Asclepias sinaica, Ballota undulata*, and *Teucrium polium* in gorge habitats. Statstical analysis of different soil properties showed high significant variations between different habitats (Table 7).

Vegetation of salt marshes

Salt marshes are located at coastal district and depressions. Soils of salt marshes are alkaline (pH = 8.3), strongly saline (EC = 11.04 dS m^{-1}), with coarse texture stable sand in surface, and low content of silt and clay (2.85%) and SOM (1.99%). The lowest species richness (18 species) is recorded in this type of habitats. According to the salinity gradients, different halophytic associations are recognized in these habitats. The average plant cover reaches 17.29%. The halophytic associations have the following dominant species: *A. macrostachyum*, *H. strobi-laceum*, *N. retusa*, *T. nilotica* and *Z.album. P.australis* and *J. rigidus* dominate the brackish parts of the salt marshes.

Vegetation of sand dunes

Different types of stable and mobile sand dunes are recognized in Mediterranean coastal district and inland district. Soils of sand dunes are mainly composed of fine sand (64.46%) with very low content of silt and clay (1.45%) and organic matter (0.34%). They harbor 24 plant species. The average plant cover reaches 14.22%. The dominant plant species of mobile sand dunes and sometimes the only species present is the perennial grass *Stipagrostis scoparia*. It grows in sites continuously covered by new accumulated sand dunes. At the foothills of the sand dunes and due to accumulation of water and stability of sands, dense vegetation dominated by *A. monosperma* are recognized with 20% as average plant cover. On the other hand, the upper parts of dunes are nearly bare of vegetation due to effect of high mobility of sand movement.

Vegetation of sand plains

Sand plain habitats are most prominent in the Mediterranean coastal and inland districts. Soils of sand plains are moderate to high alkaline (pH = 8.95), slightly saline (EC = 1.84 dS m^{-1}), and low in content of organic matter (SOM = 0.49%). Particle size distribution analysis showed that soils of sand plains are mainly composed of high content of coarse sand and medium sand (46%), fine sand (47.95%), and low content of silt and clay (6.17%). Sand plains at Mediterranean coastal district characterize by constant removal of sand by wind. The dominant plants are semi shrubs possessing taproots capable of resisting desiccation after being exposed. *A. monosperma* is the dominant species and forms nearly pure communities with 25 - 35 % as a total plant cover. The common associated species may include *T. hirsuta*, *C. lanatus*, *R. raetam*, *A. articulata* and *F. arabica*. Sand plains at inland region characterize by coarse-textured stable sands and very poor vegetation (10%) with few numbers of dominant species such as *A. articulata* and *A. monosperma*. Sand plains surrounding the anticlines district are dominanted with *A. articulata*, *P. turgidum*, *A. monosperma*, *S. scoparia*, and *T. nilotica*.

Vegetation of Wadis

Wadis habitats are most prominent in anticlines district. The main wadi in Mediterranean coastal district is W. El-Arish that originates from the plateau region in central Sinai and extends northward through the inland district and Mediterranean coastal district. Soils of wadi habitats are alkaline and slightly saline. Moderate content of silt and

Table 6. Main plant associations, plant cover, and number of species at different habitats in North Sinai.

Habitat	Plant Cover %	Number of Species	Main Associations
Salt Marsh	17.29	18	*Arthrocnemom macrostachyum – Zygophyllum album* *Halocnemum strobilaceum* *Nitraria retusa - Lycium shawii* *Tamarix nilotica - Juncus rigidus* *Tamarix nilotica - Zygophyllum album* *Zygophyllum album - Cornulaca monacantha* *Zygophyllum album - Nitraria retusa*
Sand Dune	14.22	24	*Artemisia monosperma* *Artemisia monosperma - Panicum turgidum* *Artemisia monosperma - Stipagrostis scoparia* *Artemisia monosperma - Zygophyllum album* *Stipagrostis scoparia* *Tamarix nilotica*
Sand Plain	14.54	59	*Artemisia monosperma* *Artemisia monosperma - Thymelaea hirsuta* *Artemisia monosperma - Haloxylon salicornicum* *Haloxylon salicornicum - Thymelaea hirsuta* *Haloxylon salicornicum - Zygophyllum album* *Retama raetam - Artemisia monosperma* *Retama raetam - Haloxylon salicornicum* *Thymelaea hirsuta - Panicum turgidum* *Tamarix nilotica - Nitraria retusa*
Wadi	22.68	65	*Acacia pachyceras* *Acacia tortilis* *Lycium shawaii – Fagonia scabra* *Retama raetam - Artemisia monosperma* *Retama raetam – Fagonia arabica* *Retama raetam – Panicum turgidum* *Zilla spinosa - Thymelaea hirsuta*
Gorge	18.37	62	*Chiliadenus montanus – Zilla spinosa* *Juniperus phoenicea - Achillea fragrantissima* *Juniperus phoenicea - Chiliadenus montanus* *Lycium shawaii - Zilla spinosa* *Zygophyllum dumosum* *Zygophyllum dumosum - Anabasis articulata* *Zygophyllum dumosum - Reaumuria hirtella* *Zygophyllum dumosum - Reseda arabica*

clay, and organic matter (1.11%) provide favorable conditions for water regime. Wadis and runnels support 65 plant species, which represent the highest recorded richness in the different habitats. The average plant cover in wadis reaches 22.68%. The dominant species in these habitats include *A. tortilis*, *L. shawii*, *A. monosperma* and *R. raetam*. *A. pachyceras* represents one of the local dominant species growing in limited and almost pure associations at anticlines district wadis. Severe disturbance due to mining and quarrying actvties have threa tened these associations.

Vegetation of Gorges

Gorge originates from joints and falults in the anticlines district. They are characterized by limestone, chalk, dolmite, and marl outcrops. Large outcrops of smooth-faced

Table 7. Soil Conditions at different habitats in North Sinai.

Habitat	pH	EC dS m^{-1}	Gravel%	Coarse Sand%	Medium Sand%	Fine Sand%	Silt & Clay%	SOM%
Salt Marsh	8.3a	11.04b	2.42ab	19.18b	30.82b	44.72a	2.85ab	1.99c
Sand Dune	8.80b	1.86a	0.02a	2.42a	31.65b	64.46b	1.45a	0.34a
Sand Plain	8.95b	1.84a	0.17a	13.17b	32.54b	47.95a	6.17bc	0.49a
Wadi	8.44a	1.97a	5.27ab	21.28b	21.56a	41.45a	9.89c	1.11b
Gorge	8.32a	2.06a	13.59c	13.38b	19.33a	36.51a	17.19d	2.22c
Mean	8.67	2.76	3.5	13.81	28.05	46.8	7.72	1.01
St. Dev.	0.45	3.64	7.77	14.27	15.96	19.74	8.62	1.16
St. Err.	0.04	0.31	0.66	1.21	1.35	1.67	0.73	0.1
F	22.02a	38.5	22.2	6.08	4.77	6.94	16.44	20.81
Sig.	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

limestone and dolomite are found at G. Halal, G. Maghara, G. Libni and G. Yi'allaq. Soils of gorge habitats are the richest soil in organic mater (2.22%), and silt and clay content (17.19%). These conditions support dense vegetation of shrubs and semishrubs. The average plant cover reaches 18.37%. Species richness of gorges reaches 62 species. The dominant species include *Z. dumosum*, *R. arabica*, *R. raetam*, *L. shawii*, and *J. phoenica*. The latter species represents the only conifer species known in the wild in Egypt. *J. phoenica* dominates many associations in G. Halal, G. Maghara, and G. Yi'allaq. The codominant species include *A. fragrantissima* and *C. montanus*. Almost all the trees of *J. phoenica* are suffering from overcollection and overcutting for medicinal uses.

DISCUSSION

Based on the edaphic and climatic conditions, North Sinai consists of three main districts; the Mediterranean coastal district, the anticlines district, and the inland district (Danin, 1986; Zahran and Willis, 1992; Gibali, 2000). These districts comprise five main habitats; salt marshes, sand dunes, sand plains, wadis, and gorges. The present study provides an assessment of diversity and distribution behavior of medicinal plants in North Sinai at different districts and habitats to help in management, and conservation of these natural resources.

Phytogeographical relations have a significant influence on species diversity as they largely determine the stock of species available in the past and present for inhabiting the area. North Sinai, as a bridge between Asia and Africa, harbors floristic elements from four phytogeographical regions; Saharo-Arabian, Irano-Turanian, Mediterranean, and Sudanian (Danin, 1986; Ayyad et al., 2000) Most of North Sinai belongs to Saharo-Arabian phytogeographical region. Irano-Turanian chorotype is represented in the limestone and chalk anticlines. The Mediterranean chorotype dominates the Mediterranean coastal district. Prominent Sudanian elements such as *Acacia* trees occur in wadis and gorges of anticlines district.

According to Täckholm (1974), Danin et al. (1985), El Hadidi et al. (1989) and Kamel et al. (2008), flora of North Sinai comprises about 700 plant species of which 281 species are only recorded in the current study. On geomorphological districts scale within North Sinai, about 30 - 40% of the recorded species in the last fourty years are considred as lost species in the current survey (Boulos, 1960; Gibali, 1988) including 10 endemic species (Danin, 1986; Boulos, 1995). Different types of human impacts including urbanization, agriculture, mining and quarrying, overcollection, and overcutting of woody species threaten biodiversity of North Sinai.

Pielou (1975) and Magurran (1988) point out that taxonomic diversity will be higher in an area in which the species are divided among many genera as opposed to one in which most species belong to the same genus, and still higher as these genera aredivided among many families as opposed to few. Taxonomic diversity in terms of species/genera and genera/families ratios indicates that North Sinai is more diverse as compared with South Sinai or Sinai Peninsula as a whole (Ayyad et al., 2000). On the other hand, percentages of rare and very rare species in North Sinai and South Sinai are close to each others (67 and 62%, respectively) (Ayyad et al., 2000), which indicate that biodiversity in both regions are suffering from similar level of impacts of aridity conditions and human activities.

North Sinai is considered an important region of medicinal plants (Batanouny et al., 1999; Hanafi and Abdel

Wahab, 2000; MPCP, 2006). Medicinal plants constitute 43% of North Sinai flora. They are mainly growing in Mediterranean and anticlines districts, which characterize by habitat heterogeneity. In agreement with Cramer and Willig (2005), increase in the number of habitats leads to an increase in species diversity in a landscape. Sinai Peninsula, in general, has higher percentage of medicinal plants (about 40%) as compared with the average percentage of the earth as stated by Farnsworth and Soejarto (1991) that only 14 - 28% of plants on earth have been used ethnomedically. Only 20% of the medicinal plants in North Sinai are either dominant or local dominant. On the other hand, about 50% of the medicinal plants are threatened. Human activities in North Sinai that result in threatening the plant life and medicinal plants include urbanization and agriculture projects in the Mediterranean district, mining and quarrying in the anti-clines district, and overcollection of medicinal plants and overcutting of woody species all over the North Sinai. In agreement with (Bolous and Gibali, 1993) most of the threatened species in North Sinai are mainly growing in Mediterranean coastal district and anticlines district. South Sinai medicinal plants are suffering from similar human impacts (Moustafa et al., 2001). The threats of human impacts will not only cause the loss of important medicinal species and unique habitats but also create new ecosystems (El-Bana et al., 2000).

Correlation between alpha diversity and environmental factors has attracted many ecologists (Ayyad et al., 2000; Moustafa et al., 2001; Acar et al., 2004; Willner et al., 2004; Cramer and Willig, 2005). Species richness, Shannon-Weiner *H*, and Margalef indices measurements showed significant differences among habitats. Gorges are the most diverse habitats in North Sinai followed by wadis. Plains have intermediate diversity followed by sand dunes. The lowest diversity indices were recorded at salt marsh habitats. These results indicate that altitudinal gradient and edaphic conditions that control soil moisture and salinity gradients have significant influences on species diversity. In agreement with Whittaker (1972), arid conditions with high s alinity and poor drainage limit the number of taxa able to survive, and decrease species diversity. In contrary with the hypothesis that species richness decreases with increasing altitude (Stevens, 1992; Colwell and Hurtt, 1994; Acar et al., 2004), the results of this study indicated that, in desert habitats, spe-cies richness increases with increasing altitude (Moustafa et al., 2001).

Beta diversity (β_T) results showed significant changes in floristic compositions between different habitats. The highest floristic changes between sand dunes and gorge habitats (β_T = 0.74) and between salt marsh and sand plain habitats (β_T = 0.71) may reflect rapid and ecological significant change in environment of these habitats (Ayyad et al., 2000). Intermediate change was between sand dunes and sand plains. The lowest changes were among sand plain, wadi, and gorge habitats. Salt marsh habitat supports limited number of halophytes rarely recognized in other habitats.

About 100 to 120 plant associations were recognized in North Sinai. These associations are mainly dominanted with medicinal species including *A. monosperma*, *A. macrostachyum*, *L. shawii*, *R. raetam*, *S. scoparia*, *T. nilotica*, *Z. album*, and *Z. dumosum*. Contracted vegetation type in gorges, wadis, runnels and depressions charac-terized by sufficient moisture for plant growth is the prominent type in North Sinai. This type of vegetation has been recorded and described in deserts and dry lands by many researchers (Kassas, 1966; El-Ghareeb and Sha-bana, 1990; Abd El-Ghani and Amer, 2003; Abd El-Wahab et al., 2006). Vegetation of North Sinai is charac-terized by sparseness of plant cover, limited number of dominant and associated species, paucity of trees, and high percentage of rare and very rare species. Soil phy-sical properties in addition to soil salinity and topographic variations are the main driving factors controlling the distribution of medicinal plants in North Sinai. This con-clusion is in agreement with many researches in desert vegetation (Ayyad and Ammar, 1974; El-Ghareeb and Shabanna, 1990; Moustafa and Klopatek, 1995; Abd El-Ghani and Amer, 2003).

A. monosperma, *L. shawii*, *F. Arabica*, *T. nilotica*, *T. hirsute* and *Z. album* are the most prominent species growing in different habitat types. On the other hand, other species are confined to certain type of habitat such as *A. macrostachyum*, *H. alopecuroides*, and *H. strobe-laceum* in salt marsh; *C. olifolius*, *H. hirta* and *N. procum-bens* in sand plain; and *A. herba-alba*, *A. sinaica*, *B. undulata*, and *T. polium* in gorge habitats.

In conclusion, North Sinai harbors an important stock of medicinal plants. Sixty species of medicinal plants are threatened due to severe impacts of human activities. The uniregional threatened species along with their habitats and localities should have the first priority in conservation plan of medicinal plants in North Sinai. These species include *A. pachyceras*, *A. tortilis*, *A. hiero-chuntica*, *A. sinaica*, *C. spinosa*, *C. montanus*, *C. colo-cynthis*, *E. alata*, *J. phoenicea*, *S. herba-alba*, *T. leucocla-dum*, and *T. polium*. *A. fragrantissima*, *A. Santolina*, *A. tortilis*, *A. stipularis*, *P. sickenbergeri*, *U.maritima*, and *Z. dumosum*. Slopes of limestone anticlines harbor uni-que diversity of lichens that are subjected to overcool-lection for their medicinal value. These habitats should be considered also in conservation strategy of natural resources in North Sinai. Public and private involvement in management and utilization of medicinal plants in sustainable way is essential to combat human pressures on these valuable natural resources.

ACKNOWLEDGEMENTS

The authors would like to express thanks to Mr. Hamada El-Sayed and Mr. Ahmed Hussein for technical assis-tance in soil analysis.

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