

Sand Dune Vegetation in the Coast of Nile Delta, Egypt

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Abstract: The aim of the present study is to analyze the floristic elements and vegetation types of the black sand dunes of north Nile Delta in terms of species composition, diversity and behavior of the common species along the prevailing environmental conditions. Forty-four stands were selected to represent the apparent variation in the vegetation physiognomy and the micro-habitats of the black sand dunes (dune top, dune slopes and interdunes). Sixty-nine species belonging to 63 genera and 26 families were recorded. Therophytes represent 59.5% of the total species, followed by geophytes-helophytes (13.0%), hemicryptophytes (10.1%) and chamaephytes and phanerophytes (8.7%). The floristic categories of the recorded species showed that the bi-regional taxa had the highest contribution represented by 31.9% of the total species, followed by the monoregional (29.0%), pluriregional (27.5%) and cosmopolitan (11.6%). The application of TWINSpan and DCA on the plant cover data estimates of 69 species recorded in the 44 sampled stands in the black sand dunes, led to the recognition of 7 vegetation groups named after the first and occasionally the second dominant species: A) *Chenopodium murale*-*Mesembryanthemum crystallinum*, B) *Senecio glaucus* subsp. *coronopifolius*-*Cynodon dactylon*, C) *Rumex pictus*-*Cakile maritima*, D) *Nicotiana glauca*-*Cakile maritima*, E) *Rumex pictus*-*Silene succulenta*, F) *Elymus farctus*-*Silene succulenta* and G) *Asphodelus viscidulus*-*Elymus farctus*. *Senecio glaucus* subsp. *coronopifolius*-*Cynodon dactylon* group (VG B) had the highest species diversity, while *Nicotiana glauca*-*Cakile maritima* group (VG D) demonstrated the lowest value. The results obtained are extremely important to assess local conditions and future decisions on any proposed mining enterprise of the black sand dunes.

Key words: Black sand dunes • vegetation • plant life • Nile Delta

INTRODUCTION

The Mediterranean Basin integrates different ecosystems with climates vary from humid, semi-humid, arid, to hyper-arid. These ecosystems are under extreme and increasing pressure from direct human intervention [1]. Sand dune ecosystem types occupy a considerable district along the Mediterranean coast of the central Nile Delta. It extends about 60 km from Lake Burullus outlet in the west to Gamasa drain in the east. Burullus dune belt occupies the northwestern part of the central Delta dune occurrence. It contains the most extensive and high elevated dunes occupying a narrow coastal strip along the Mediterranean coast of Lake Burullus. The main geomorphologic features in the Central Delta dunes can be divided into three units; the coastal sand flat, the dune belt and the backshore sand flat [2].

The Egyptian black sand dunes along the Mediterranean coast are known to be originated from the

relatively fine detritus transported by the River Nile to the Mediterranean Sea. Most of these detritus are the weathering products, mainly by heavy rains, of the hard rocks located at the upper reaches of the River Nile in central Africa, especially the Ethiopian plateau. These dunes were deposited in discontinuous occurrences concentrated around the mouths of the present and old Nile distributaries. These deposits contain a number of heavy minerals of economic interest such as; magnetite, ilmenite, rutile, zircon and monazite [3].

The vegetation of the Mediterranean coastal dunes was investigated in many previous studies [4-9]. Many studies were carried out on the mineralogy and beneficiation of the black sand deposits in addition to their evaluation [3].

The aim of the present work is to investigate the floristic elements and vegetation types in terms of species composition, diversity and behavior of the common species along the prevailing environmental conditions in

the Nile Delta. The present work aims also at identifying the threatened plant species and communities as well as the environmental factors that affect their distribution in the black sand deposits in coastal sand habitats.

MATERIALS AND METHODS

Study area: El Burullus sand dunes are the most extensive dune belt between Port Said and Abu Qir. It occurs on the Mediterranean coast, between latitudes 30°58' and 31°12' N and 31°43' and 31° 36' E. The study area, covering the northern part of the Deltaic Mediterranean coast, is located in Kafr El-Sheikh Governorate (Fig. 1). It extends about 19 km from Burullus opening at the west to Gharbiya drain at the east. Its width ranges from 250 m to more than 1000 m. The dunes heights reach more than 34 m at the western part and decrease gradually eastward where their height reach about 20 m near Gharbiya drain. The Coastal International Road southward bound the western part of the area, while the eastern part is bounded by small farms. The area includes small villages, few settlements close to the dunes and the International Road.

Several types of coastal dunes are present; uninterrupted belts of complex dunes, deformed barchans and longitudinal dunes. At the area near Burullus outlet, most of these dunes are of the barchan type, which are crescent-shaped sand mounds. They occur both as isolated dunes and in uninterrupted complex forms. On the other hand, east Baltim resort, most of the barchan dunes occur as isolated bodies. The interdunal areas are flat parts lie within the coastal dune belt. It is narrow areas at the western part and increase toward east. They have a supply of fresh water depending on rainfall, which can support vegetation.

The area is included in the coastal belt arid province characterized by a mild winter and a hot summer. It is under the maritime influence of the Mediterranean with rainfall of more than 100 mm/year and an attenuated dry period. The annual rainfall ranges between 8.9 mm at Damietta and 14.6 mm at Baltim, while the annual mean temperature from 20° to 25°C [10].

Data collection

Vegetation: Forty-four stands were selected to represent the apparent variation in the vegetation physiognomy and the micro-habitats of black sand dunes; dune tops (13 stands), dune slopes (15 stands) and interdunes (16 stands). The stand size was about 20 x 20 m in all microhabitats. Each stand was observed along two

seasons (spring and summer 2006). During each visit, the stands were surveyed and the following data were recorded: species list, the first and second dominant species and visual estimate of the total cover and the cover of each species (%). Identification and nomenclature were according to Boulos [11-14]. Life forms of the species were identified following the Raunkiaer scheme [15]. The global geographical distribution of the recorded species, in the study area, were gathered [16-19]. Voucher specimens were deposited in the Herbaria of Environmental Sciences Department, Alexandria University and Helwan University.

Soil analysis: Soil samples were collected from each stand as a profile (composite sample) at a depth of 0-50 cm below the soil surface. Soil water extracts of 1:5 were prepared for the determination of soil salinity (EC) using conductivity meter and soil reaction (pH) using pH meter. Chlorides were determined by direct titration against silver nitrate solution using 5% potassium chromate as an indicator. Bicarbonates were estimated by titration against 0.01N HCl and sulphates were determined turbidimetrically as barium sulphate at 500 nm. Calcium and Magnesium were determined by titration against 0.01N versenate solution using meroxide and erichrome black T as indicators. Sodium and potassium were determined using flame photometer. All these procedures are outlined by Jackson [20] and Allen *et al.* [21].

Data analysis: Two-way indicator species analysis (TWINSPAN) and Detrended Correspondence Analysis (DCA) were applied to the matrix of cover estimates of 69 species in 44 stands in the black sand dunes [22,23]. The relationship between the vegetation and soil gradients was assessed using the ordination diagram produced by principal component analysis (PCA) [24]. Species richness (alpha-diversity) for each vegetation group was calculated as the average number of species per stand. Species turnover (beta-diversity) was calculated as a ratio between the total number of species recorded in a certain vegetation group and its alpha diversity [25]. Relative evenness or equitability (Shannon-Weaver index) of the importance value of species was expressed as $H' = -\sum_{i=1}^S P_i (\log P_i)$, where S is the total number of species and P_i is the relative importance value (relative cover) of the i^{th} species. The relative concentration of dominance (Simpson index) is the second group of heterogeneity indices and is expressed by Simpson's index: $D = 1/C$ and $C = \sum_{i=1}^S (P_i)^2$, where S is the total number of species and P_i is the relative importance value (relative cover) of

species [26,27]. The simple linear correlation coefficient (r) was calculated for assessing the relationship between the estimated soil variables on one hand and the community variables, on the other hand. The variation in the soil variables in relation to the vegetation groups were assessed using one-way analysis of variance (ANOVA). These techniques were according to SPSS software [28].

RESULTS

Plant life: Three main micro-habitat types were recognized in the coastal sand dunes of the study area: the dune tops, dune slopes and interdunes. Sixty-nine species include 27 perennials and 42 annuals belonging to 63 genera and 26 families were recorded in these habitats (Table 1). Thirty-four species representing 49.3% of the total species were recorded along the dune tops, of them three were recorded only in this micro-habitat, namely *Calligonum polygonoides*, *Plantago squarrosa* and *Schismus barbatus*. Forty-four species representing 63.8% of the total species were recorded along the dune slopes, with three species namely *Cyperus capitatus*, *Frankenia pulverulenta* and *Nicotiana glauca*. The interdunes support 58 species representing 84.1% of the total species of them 21 species were exclusively recorded in this habitat such as *Herniaria hemistemon*, *Limbarda crithmoides* and *Solanum nigrum*.

The life form spectrum indicated that 59.5% of the total species were therophytes, 13.0% geophytes-helophytes, 10.1% hemicryptophytes and 8.7% for chamaephytes and phanerophytes (Fig. 2). The floristic categories of the recorded species showed that the bi-regional taxa had the highest contribution represented by 31.9% of the total species (Fig. 3), followed by 29.0% monoregional, 27.5% pluriregional and 11.6% cosmopolitan species. Forty-two species include 28 annuals and 14 perennials are Mediterranean taxa, 30 species include 18 annuals and 12 perennials are Saharo-Arabian elements.

Vegetation: The application of TWINSpan on the cover estimates of 69 species recorded in the 44 sampled stands, led to the recognition of 7 vegetation groups (Fig. 4). The application of DCA on the same set of data indicates a reasonable segregation among these groups along the ordination plane of axes 1 and 2 (Fig. 5). The vegetation groups are named after the first and occasionally the second dominant species (Table 2). *Rumex pictus-Silene succulenta* group (VG E) mainly occupied the dune tops. Two vegetation groups inhabited the dune slopes: *Nicotiana glauca-Cakile maritima* and *Asphodelus viscidulus-Elymus farctus* groups (VG D & G). *Chenopodium murale-Mesembryanthemum crystallinum* group (VG A) occupied the interdunes, Three vegetation

Table 1: Floristic categories and presence (%) of the perennial species in relation to the micro-habitats of the black sand dunes. DT: Dune Top, DS: Dune Slope and ID: Interdunes, ME: Mediterranean, COSM: Cosmopolitan, SA-SR: Saharo-Arabian, Trop: Tropical, S-Z: Sudano-Zambezian, ER-SR: Euro-Siberian, IR-TR: Irano-Turanian, GC: Guineo-Congolese, PAL: Palaeotropical, PAN: Pantropical and NEO: Neotropical.

Species	Life form	Floristic category	DT	DS	ID
<i>Alhagi graecorum</i> Boiss.	Chamaephytes	ME+IR-TR+SA-AR+S-Z		26.7	31.3
<i>Amaranthus viridis</i> L.	Therophytes	COSM			6.3
<i>Archusa humilis</i> (Desf.) I. M. Johnst.	Therophytes	SA-AR			6.3
<i>Asphodelus viscidulus</i> Boiss.	Therophytes	SA-AR		20.0	6.3
<i>Astragalus fruticosus</i> Forssk.	Hemicryptophytes	SA-AR	7.7	6.7	6.3
<i>Beta vulgaris</i> L.	Therophytes	ME+ER-SR+IR-TR			6.3
<i>Brassica rapa</i> L.	Therophytes	COSM			6.3
<i>Bromus aegyptiacus</i> Tausch	Therophytes	ME		26.7	6.3
<i>Cakile maritima</i> Scop.	Therophytes	ME+IR-TR	76.9	80.0	68.8
<i>Calendula arvensis</i> L.	Therophytes	ME+ER-SR+IR-TR+SA-AR			6.3
<i>Calligonum polygonoides</i> L.	Phanerophytes	IR-TR+SA-AR	7.7		
<i>Carthamus lanatus</i> L.	Therophytes	ME+IR-TR+ER-SR+S-Z			12.5
<i>Chenopodium murale</i> L.	Therophytes	COSM		6.7	25.0
<i>Convolvulus arvensis</i> L.	Hemicryptophytes	Trop		6.7	18.8
<i>Cutandia memphitica</i> (Spreng.) K. Richt.	Therophytes	ME+SA-AR+IR-TR	76.9	60.0	37.5
<i>Cynanchum acutum</i> L.	Phanerophytes	ME+IR-TR	7.7	20.0	6.3
<i>Cynodon dactylon</i> (L.) Pers.	Geophytes-Helophytes	COSM	23.1	6.7	43.8
<i>Cyperus capitatus</i> Vand.	Geophytes-Helophytes	ME+GC		6.7	
<i>Cyperus conglomeratus</i> Rottb.	Hemicryptophytes	ME	46.2	66.7	25.0
<i>Daucus syrticus</i> Murb.	Therophytes	ME	30.8	20.0	18.8
<i>Echinops spinosus</i> L.	Hemicryptophytes	ME+SA-AR	76.9	20.0	18.8

Table 1: Continue.

<i>Elymus farctus</i> (Viv.) Runemark ex Melderis	Geophytes-Helophytes	ME		20.0	18.8
<i>Emex spinosa</i> (L.) Cambd.	Therophytes	ME+SA-AR			12.5
<i>Erodium laciniatum</i> (Cav.) Willd.	Therophytes	ME	38.5	26.7	43.8
<i>Eruca sativa</i> Mill.	Therophytes	ME+ER-SR+IR-TR+SA-AR			6.3
<i>Frankenja pulverulenta</i> L.	Therophytes	ME+ER-SR+IR-TR		6.7	
<i>Herniaria hemistemon</i> J. Gay	Therophytes	SA-AR			6.3
<i>Hordeum marinum</i> Huds.	Therophytes	ME+ER-SR+IR-TR	7.7		25.0
<i>Hordeum murinum</i> spp. <i>leporinum</i> (Link) Arcang.	Therophytes	ME+IR-TR		26.7	12.5
<i>Iflago spicata</i> (Forssk.) Sch.Bip.	Therophytes	ME+SA-AR			6.3
<i>Imperata cylindrica</i> (L.) Raeusch.	Geophytes-Helophytes	ME+SA-AR+IR-TR	23.1	40.0	25.0
<i>Juncus rigidus</i> Desf.	Geophytes-Helophytes	ME+SA-AR+IR-TR	7.7	6.7	
<i>Leptochloa fusca</i> (L.) Kunth	Geophytes-Helophytes	Trop			6.3
<i>Limbarda crithmoides</i> (L.) Dumort.	Chamaephytes	SA-AR			6.3
<i>Lobularia arabica</i> (Boiss.) Muschl.	Therophytes	SA-AR	7.7	6.7	
<i>Lolium perenne</i> L.	Therophytes	ME+ER-SR+IR-TR	30.8	13.3	18.8
<i>Lotus creticus</i> L.	Therophytes	SA-AR+S-Z			6.3
<i>Lotus glaber</i> Mill.	Hemicryptophytes	ME+ER-SR+IR-TR	23.1	20.0	18.8
<i>Malva parviflora</i> L.	Therophytes	ME+IR-TR	7.7	6.7	31.3
<i>Melilotus indicus</i> (L.) All.	Therophytes	ME+SA-AR+IR-TR	7.7	33.3	25.0
<i>Melilotus messanensis</i> (L.) All.	Therophytes	ME+IR-TR			12.5
<i>Mesembryanthemum crystallinum</i> L.	Therophytes	ME+ER-SR	7.7	13.3	37.5
<i>Mesembryanthemum nodiflorum</i> L.	Therophytes	ME+ER-SR+SA-AR			12.5
<i>Moltkiopsis ciliata</i> (Forssk.) I. M. Johnst.	Chamaephytes	SA-AR	23.1	13.3	12.5
<i>Neurada procumbens</i> L.	Therophytes	SA-AR	15.4	6.7	12.5
<i>Nicotiana glauca</i> R. C. Graham	Phanerophytes	NEO		20.0	
<i>Ononis serrata</i> Forssk.	Therophytes	ME+SA-AR	15.4	13.3	
<i>Phoenix dactylifera</i> L.	Phanerophytes	SA-AR+S-Z		26.7	12.5
<i>Phragmites australis</i> (Cav.) Trin.ex Steud	Geophytes-Helophytes	COSM	7.7	20.0	50.0
<i>Plantago squarrosa</i> Murray	Therophytes	ME	7.7		
<i>Polygonum equisetiforme</i> Sm.	Geophytes-Helophytes	ME+IR-TR			31.3
<i>Polypogon monspeliensis</i> (L.) Desf.	Therophytes	COSM			12.5
<i>Raphanus raphanistrum</i> L.	Therophytes	ME+ER-SR		13.3	12.5
<i>Reichardia tingitana</i> (L.) Roth	Therophytes	IR-TR+SA-AR	15.4	6.7	18.8
<i>Ricinus communis</i> L.	Phanerophytes	PAN	7.7	20.0	12.5
<i>Rumex pictus</i> Forssk.	Therophytes	ME+SA-AR	92.3	80.0	87.5
<i>Salsola kali</i> L.	Therophytes	COSM	23.1	13.3	18.8
<i>Schismus barbatus</i> (L.) Thell.	Therophytes	ME+SA-AR+IR-TR	7.7		
<i>Senecio glaucus</i> subsp. <i>coronopifolius</i> (Maire)					
C. Alexander	Therophytes	ME+SA-AR+IR-TR	92.3	80.0	87.5
<i>Senecio vulgaris</i> L.	Therophytes	ME+ER-SR+IR-TR	15.4	46.7	37.5
<i>Setaria viridis</i> (L.) P.Beauv.	Therophytes	ME+ER-SR+IR-TR			6.3
<i>Silene succulenta</i> Forssk.	Hemicryptophytes	ME	84.6	46.7	25.0
<i>Solanum nigrum</i> L.	Chamaephytes	ME+ER-SR+IR-TR			6.3
<i>Sonchus oleraceus</i> L.	Therophytes	COSM		6.7	12.5
<i>Stipagrostis plumosa</i> (L.) Munro ex T. Anderson	Hemicryptophytes	IR-TR+SA-AR	15.4	20.0	
<i>Suaeda pruinoso</i> Lange	Chamaephytes	ME+SA-AR			6.3
<i>Symphyotrichum squamatum</i> (Spreng.) Nesom	Chamaephytes	Trop		6.7	12.5
<i>Tamarix nilotica</i> (Ehrenb.) Bunge	Phanerophytes	SA-AR+S-Z	7.7	6.7	
<i>Typha domingensis</i> (Pers.) Poir.ex Steud	Geophytes-Helophytes	ME+IR-TR			6.3

groups extend their occurrence in the three microhabitats: *Senecio glaucus* subsp. *coronopifolius*-*Cynodon dactylon*, *Rumex pictus*-*Cakile maritima* and *Elymus farctus*-*Silene succulenta* groups (VG B, C & F).

Senecio glaucus subsp. *coronopifolius*-*Cynodon dactylon* group (VG B) had the highest species richness represented by 11.2 species stand⁻¹, while *Rumex pictus*-*Cakile maritima* group (VG C) had the highest species

Table 2: Characteristics of the 7 vegetation groups derived after the application of TWINSpan on the 44 stands of the black sand dunes. VG: Vegetation Group; N: Number of stands; NS: Number of species per group; P: Presence of species. RC: Relative cover, DT: Dune top, DS: Dune slope and ID: Interdunes. Diversity indices are also shown.

VG.	N	NS	Micro-habitat			1st Dominant	P (%)	C (%)	2nd Dominant	P (%)	C (%)	richness	Species turnover	Shannon index	Simpson index
			DT	DS	ID										
A	4	33			100	<i>Chenopodium murale</i>	100	21.8	<i>Mesembryanthemum crystallinum</i>	100	19.5	17	1.9	3.4	25.8
B	5	20	40	20	40	<i>Senecio glaucus</i> subsp. <i>coronopifolius</i>	100	8.2	<i>Cynodon dactylon</i>	100	4.8	11.2	1.8	2.9	15.9
C	12	38	17	42	42	<i>Rumex pictus</i>	100	14.3	<i>Cakile maritima</i>	91.7	10.5	9.8	3.9	3.2	19.3
D	2	5		100		<i>Nicotiana glauca</i>	100	50.0	<i>Cakile maritima</i>	100	2.5	3.5	1.4	1.5	4.5
E	13	33	69	15	15	<i>Rumex pictus</i>	100	6.1	<i>Silene succulenta</i>	92.3	4.2	10.9	3.0	3.1	18.9
F	4	22		50	50	<i>Elymus farctus</i>	75	12.5	<i>Silene succulenta</i>	75	11.5	10.3	2.1	2.9	16.9
G	4	23		75	25	<i>Asphodelus viscidulus</i>	100	8.8	<i>Elymus farctus</i>	50	7.5	8.8	2.6	3.0	17.6

Table 3: Means (upper line) and standard deviations (lower line) of soil characteristics of the 7 vegetation groups recorded for the black sand dunes. The F-value and its probability (P) are indicated. * P< 0.05, ** P< 0.01, *** P<0.001.

Environmental variable	A	B	C	D	E	F	G	F-value
pH	7.15 0.17	7.24 0.11	6.12 2.67	7.11 0.01	7.07 0.08	7.03 0.05	7.00 0.12	0.667
E.C (mS/cm)	0.90 58.00	0.42 0.02	1.56 2.59	0.51 0.01	0.43 0.05	0.45 0.06	0.40 0.01	0.892
HCO ₃ ⁻ mg 100 gm ⁻¹	0.51 0.01	0.50 0.01	0.50 0.01	0.50 0.01	0.81 0.25	0.63 0.25	0.50 0.01	5.27***
Cl ⁻	2.75 0.29	1.88 0.52	1.10 0.19	2.00 0.14	0.95 0.20	0.63 0.25	0.50 0.01	44.33***
SO ₄ ⁻	2.88 3.02	1.03 0.28	1.29 0.10	1.25 0.07	1.23 0.32	1.63 0.48	1.55 0.06	2.09
Ca ⁺⁺	1.73 0.89	0.87 0.17	0.96 0.04	1.00 0.14	1.02 0.07	0.95 0.07	0.85 0.06	5.33***
Mg ⁺⁺	1.45 1.10	0.51 0.09	0.69 0.23	0.95 0.01	0.78 0.23	0.75 0.23	0.60 0.06	2.99*
Na ⁺	2.50 1.73	1.08 0.08	1.02 0.04	1.00 0.14	1.01 0.06	1.00 0.08	1.00 0.12	5.39***
K ⁺	0.15 0.06	0.10 0.01	0.13 0.05	0.10 0.01	0.10 0.01	0.10 0.01	0.10 0.01	1.99

turnover with a value of 3.9 (Table 2). On the other hand, *Chenopodium murale-Mesembryanthemum crystallinum* group (VG A) had the highest relative evenness and relative concentration of species dominance represented by 3.4 and 25.8, respectively. *Nicotiana glauca-Cakile maritima* group (VG D) had the lowest species richness represented by 3.5 species stand⁻¹, species turnover: 1.4, relative evenness: 1.5 and relative concentration of species dominance: 4.5.

Soils of *Senecio glaucus* subsp. *coronopifolius-Cynodon dactylon* group (VG B) had the highest pH value: 7.24, but the lowest of sulphate: 1.03 mg 100 gm⁻¹ and magnesium: 0.51 mg 100 gm⁻¹ (Table 3). On the other hand, *Rumex pictus-Cakile maritima* group (VG C) had the lowest pH value: 6.12, but the highest of salinity: EC = 1.56 mS cm⁻¹. The lowest values of salinity: 0.40 mS cm⁻¹, chlorides: 0.50 mg 100 gm⁻¹ and calcium: 0.85 mg 100 gm⁻¹ were recorded in *Asphodelus viscidulus-Elymus farctus* groups (VG G). *Chenopodium murale-*

Table 4: Simple linear correlation coefficient (r) between some soil variables and the cover of the common species. * P< 0.05, ** P< 0.01, *** P<.001. *C mur*: *Chenopodium murale*, *M cry*: *Mesembryanthemum crystallinum*, *C dac*: *Cynodon dactylon*, *S gla*: *Senecio glaucus* subsp. *Coronopifolius*, *R pic*: *Rumex pictus*, *M par*: *Malva parviflora*, *C mar*: *Cakile maritime*, *N pro*: *Neurada procumbens*, *A vis* *Asphodelus viscidulus* and *N gla*: *Nicotiana glauca*.

	Soil variables									Common species								
	pH	E.C	HCO ₃ ⁻	Cl ⁻	SO ₄ ⁻	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	C mur	M cry	C dac	S gla	R pic	M par	C mar	N pro	A vis
E.C	-0.87*																	
HCO ₃ ⁻	0.17	-0.32																
Cl ⁻	0.32	0.16	-0.39															
SO ₄ ⁻	0.18	0.19	-0.17	0.49														
Ca ⁺⁺	0.19	0.27	-0.08	0.73	0.92**													
Mg ⁺⁺	0.20	0.21	-0.07	0.70	0.86**	0.95***												
Na ⁺	0.23	0.24	-0.21	0.737*	0.93**	0.97***	0.88**											
K ⁺	-0.34	0.73	-0.32	0.58	0.77*	0.83*	0.73	0.84**										
<i>C mur</i>	0.22	0.24	-0.20	0.72	0.94***	0.98***	0.89**	0.99***	0.83**									
<i>M cry</i>	0.22	0.24	-0.19	0.71	0.95***	0.98***	0.89**	0.99***	0.83**	0.99***								
<i>C dac</i>	0.39	0.08	-0.26	0.79*	0.74*	0.82*	0.65	0.90**	0.67	0.89**	0.88**							
<i>S gla</i>	0.18	0.14	-0.30	0.60	0.13	0.29	0.06	0.42	0.35	0.38	0.36	0.74*						
<i>R pic</i>	-0.86**	0.79*	0.07	-0.18	-0.28	-0.16	-0.27	-0.19	0.32	-0.19	-0.20	-0.19	0.18					
<i>M par</i>	0.26	0.22	-0.28	0.79*	0.85**	0.92**	0.78*	0.98***	0.81*	0.97***	0.96***	0.97***	0.59	-0.15				
<i>C mar</i>	-0.91	0.89	-0.33	0.01	-0.25	-0.13	-0.17	-0.16	0.38	-0.17	-0.18	-0.21	0.13	0.87**	-0.13			
<i>N pro</i>	0.33	-0.25	-0.24	0.26	-0.37	-0.27	-0.44	-0.12	-0.25	-0.16	-0.17	0.31	0.81*	0.02	0.09	-0.03		
<i>A vis</i>	0.05	-0.27	-0.24	-0.48	-0.01	-0.29	-0.31	-0.18	-0.25	-0.17	-0.16	-0.27	-0.38	-0.29	-0.22	-0.29	-0.17	
<i>N gla</i>	0.18	-0.17	-0.23	0.31	-0.21	-0.08	0.18	-0.19	-0.25	-0.17	-0.18	-0.27	-0.35	-0.39	-0.23	-0.02	-0.17	-0.17

Mesembryanthemum crystallinum group (VG A) had the highest values of chlorides: 2.75 mg 100 gm⁻¹, sulphates: 2.88 mg 100 gm⁻¹, calcium: 1.73 mg 100 gm⁻¹, magnesium: 1.45 mg 100 gm⁻¹, sodium: 2.5 mg 100 gm⁻¹ and potassium: 0.15 mg 100 gm⁻¹. The highest value of bicarbonates: 0.81 mg 100 gm⁻¹ was recorded in *Rumex pictus-Silene succulenta* group (VG E).

The correlation between the identified vegetation groups and the soil characteristics is indicated on the ordination diagram produced by Principal Component Analysis (Fig. 6). It is clear that salinity, calcium, sodium and potassium are the most effective variables. *Rumex pictus-Cakile maritime* group (VG C) occupies a high level along salinity gradient, an intermediate level along calcium and chloride gradients and low level along sodium gradient. *Chenopodium murale-Mesembryanthemum crystallinum* (VG A), *Senecio glaucus* subsp. *coronopifolius-Cynodon dactylon* (VG B) and *Nicotiana glauca-Cakile maritime* (VG D) groups occupy high level along bicarbonate gradient, intermediate levels along magnesium and chloride gradients and low level along salinity gradient. On the other hand, *Asphodelus*

viscidulus-Elymus farctus groups (VG G) extends along high level of sulphate gradient, an intermediate level along bicarbonate gradient and a low level along pH gradient. *Elymus farctus-Silene succulenta* group (VG F) occupies a high level along pH gradient, an intermediate level along bicarbonate gradient and low levels along sulphate and potassium gradients.

Some soil variables have significant positive correlation with each other (Table 4) such as sulphate with calcium, magnesium and sodium (r = 0.92, 0.86 and 0.93) and calcium with magnesium and sodium (r = 0.95 and 0.97). Some other variables have significant negative correlation such as pH with salinity (r = -0.87). On the other hand, some of the common species have significant positive correlation with some soil variables such as *Chenopodium murale* with sulphate, calcium and sodium (r = 0.94, 0.98 and 0.99) and *Malva parviflora* with chlorides and sulphate (r = 0.79 and 0.85). Some other species have significant negative correlation with some soil variables such as *Rumex pictus* with pH (r = -0.86). Regarding the correlation between the common species, some species are positively correlated such as

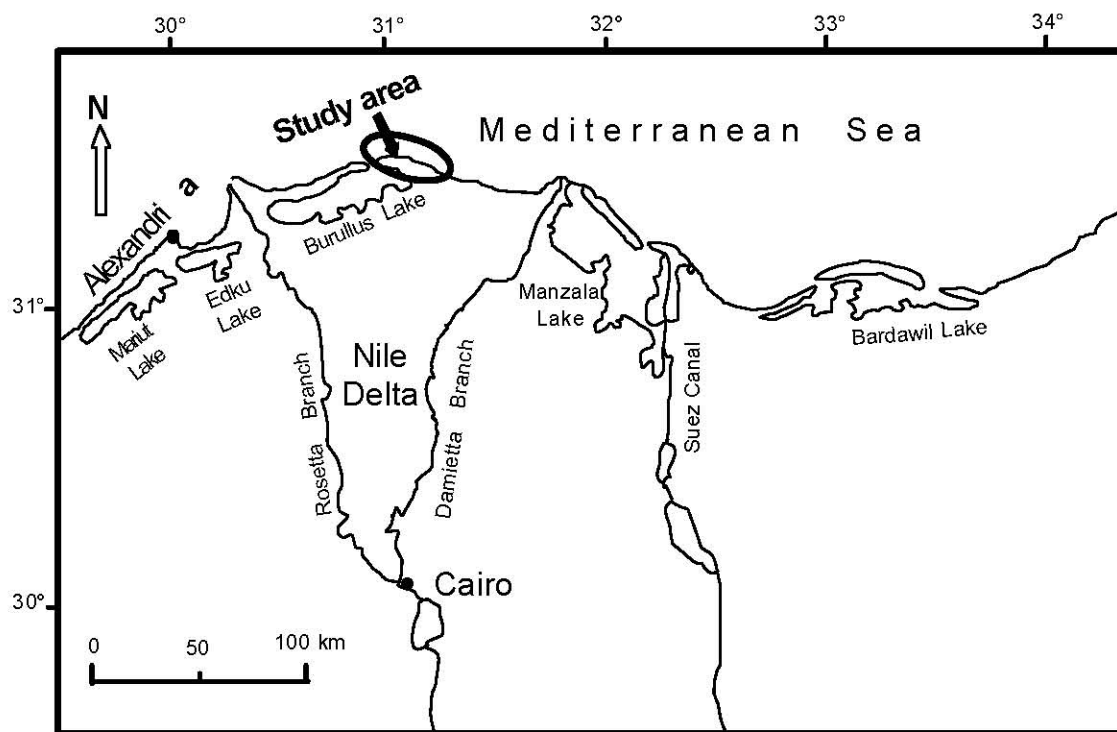


Fig. 1: Location map of the study area.

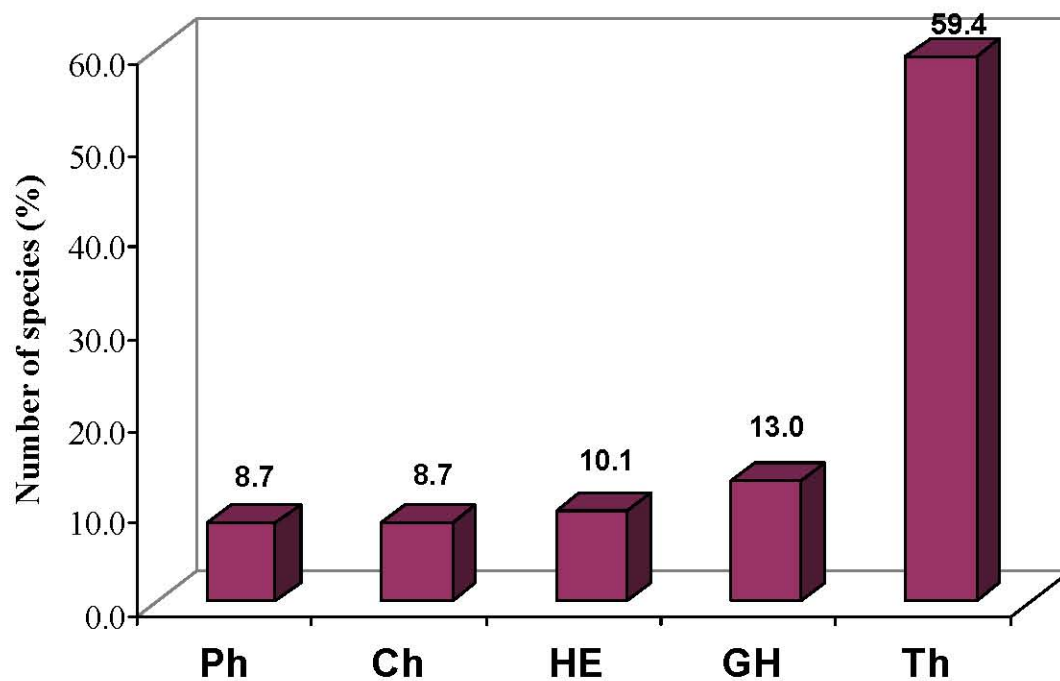


Fig. 2: Life form spectrum of the species recorded in the black sand dunes of the Nile Delta coast. Ph: Phanerophytes, Ch: Chamaephytes, HE: Hemicryptophytes, GH: Geophytes-helophytes and Th: Therophytes.

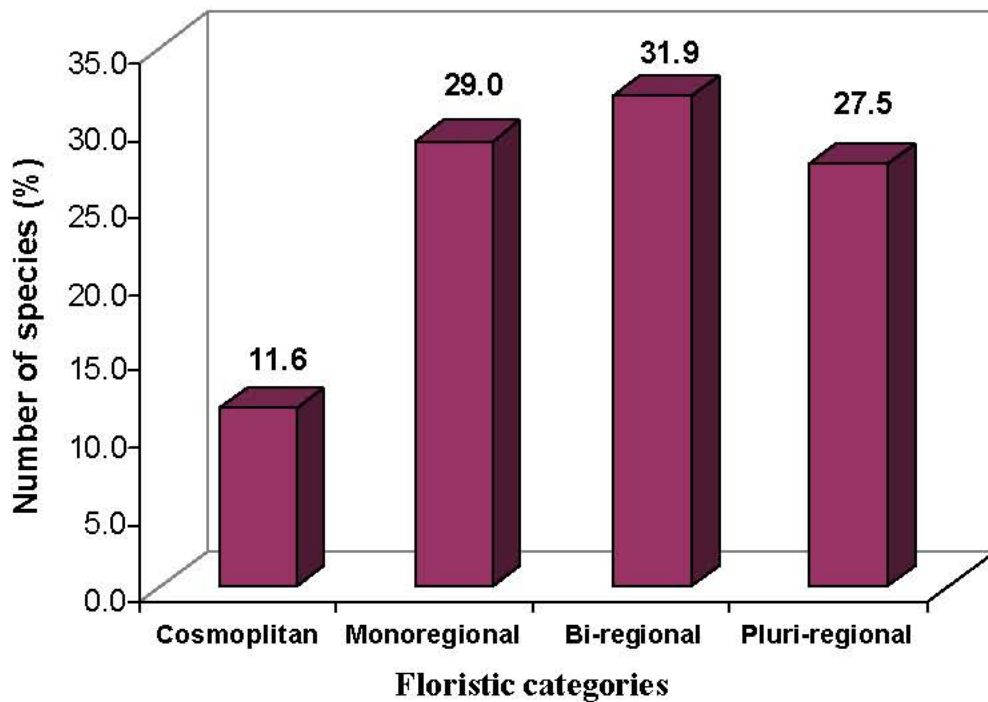


Fig. 3: Floristic categories of the species recorded in the black sand dunes of the Nile Delta coast.

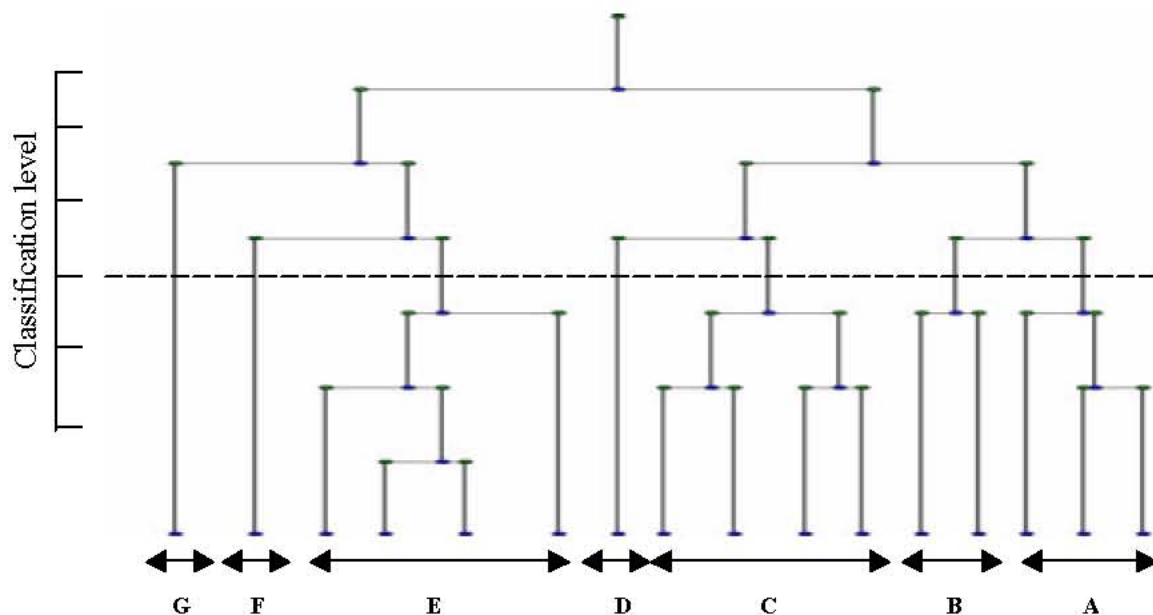


Fig. 4: The dendrogram resulting from the application of TWINSpan on the 44 sampled stands in the black sand dunes. The vegetation groups are named as follows: A) *Chenopodium murale*-*Mesembryanthemum crystallinum*, B) *Senecio glaucus* subsp. *coronopifolius*-*Cynodon dactylon*, C) *Rumex pictus*-*Cakile maritima*, D) *Nicotiana glauca*-*Cakile maritima*, E) *Rumex pictus*-*Silene succulenta*, F) *Elymus farctus*-*Silene succulenta* and G) *Asphodelus viscidulus*-*Elymus farctus*.

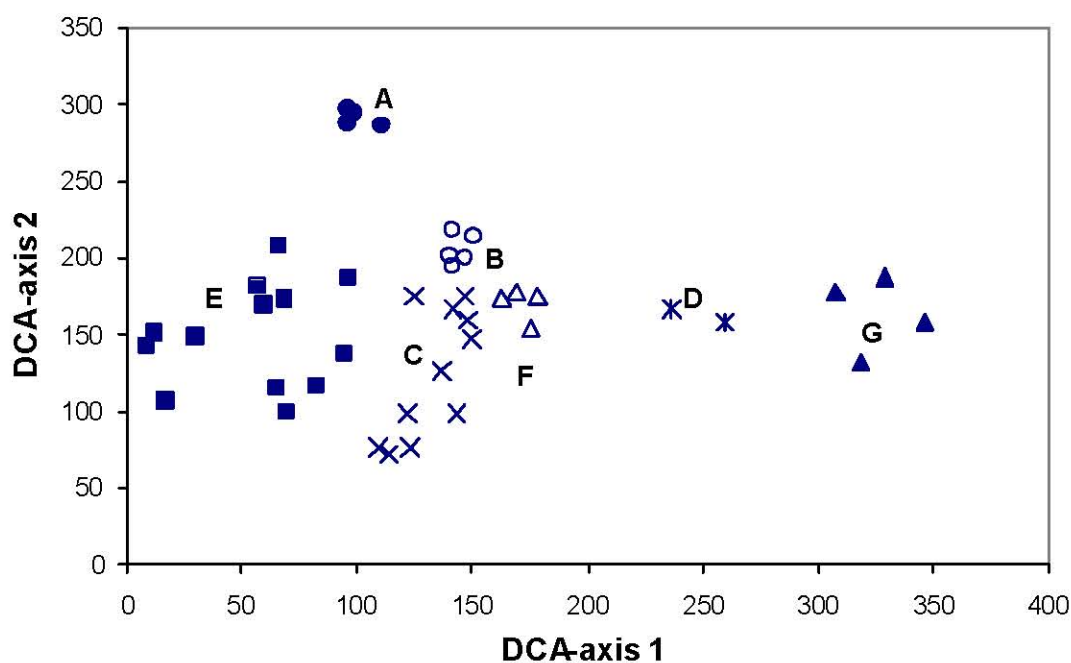


Fig. 5: DCA ordination of the 7 vegetation groups identified after the application of TWINSpan on the 44 sampled stands in the black sand dunes. The vegetation groups are named as follows: A) *Chenopodium murale*-*Mesembryanthemum crystallinum*, B) *Senecio glaucus* subsp. *coronopifolius*-*Cynodon dactylon*, C) *Rumex pictus*-*Cakile maritima*, D) *Nicotiana glauca*-*Cakile maritima*, E) *Rumex pictus*-*Silene succulenta*, F) *Elymus farctus*-*Silene succulenta* and G) *Asphodelus viscidulus*-*Elymus farctus*.

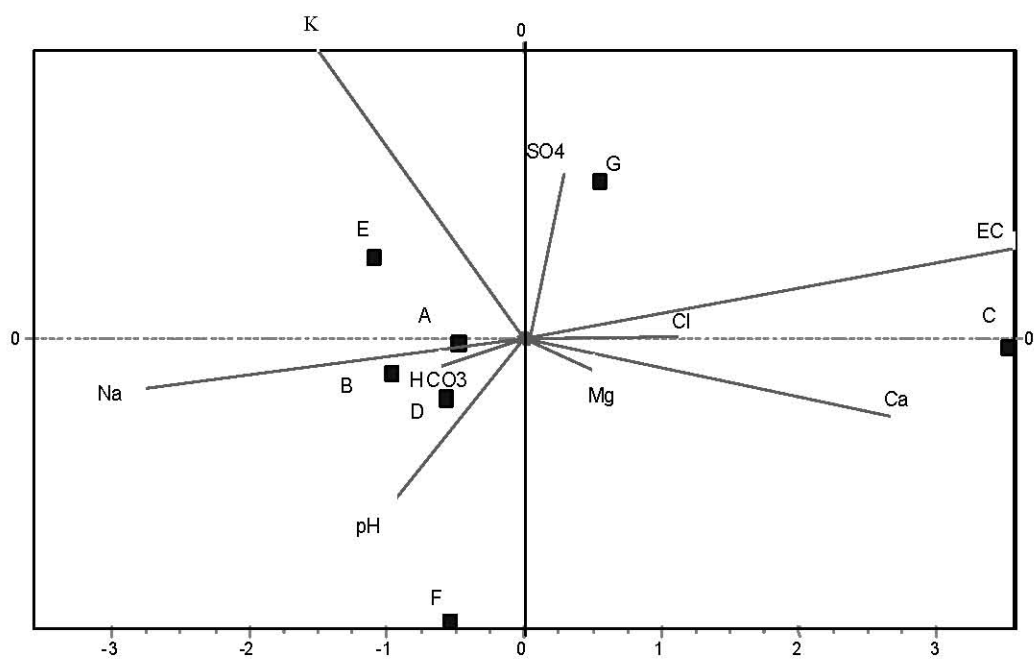


Fig. 6: PCA biplot of the vegetation groups (represented by squares) and the soil variables (represented by lines).

Mesembryanthemum crystallinum with *Chenopodium murale* ($r = 0.99$), *Cakile maritima* with *Rumex pictus* ($r = 0.87$) and *Neurada procumbens* with *Senecio glaucus* subsp. *coronopifolius* ($r = 0.81$).

DISCUSSION

Burullus sand dunes are a unique habitat, representing the only remaining natural fragment of the Nile Delta. Sixty-nine species belonging to 63 genera and 26 families were recorded in the three micro-habitats of the black sand dunes of north Nile Delta. This number represents 35% of the species recorded by Shaltout and Al-Sodany [8]. in Burullus Wetland. *Zygophyllum aegyptium*, predominates the sand formations of the deltaic Mediterranean coast was not recorded in the present study [29]. 65.2% of the recorded species in the present study was recorded by Shaltout & Khalil [30] in the sand formations of Burullus Wetland, 52.2% by Ayyad [6] and Scholten *et al.* [31] and 39.1% by Ayyad and El-Bayyoumy [32] on the sand dunes of the western Mediterranean coast. Some species recorded in this study were not recorded by Shaltout & Khalil [30]: *Calligonum polygonoides*, *Nicotiana glauca* and *Astragalus fruticosus* (perennials) and *Anchusa humilis*, *Calendula arvensis* and *Mellilotus messanensis* (annuals). On the other hand, some species recorded by Shaltout and Khalil [30] were not recorded in this study: *Arthrocnemum macrostachyum*, *Sarcocornia fruticosa* and *Cistanche phelypaea* (perennials) and *Trigonella stellata*, *Lotus halophilus* and *Orobancha crenata* (annuals). *Retama raetum*, *Sarcocornia fruticosa* and *Thymelaea hirsute* were recorded [33], along the part of the International Highway that crosses through Burullus Wetland, are absent in this investigation. Some species recorded on the sand dunes of the western Mediterranean coast [32] were not recorded in the present study: *Ammophila arenaria*, *Euphorbia paralias* and *Pancatium maritimum*, while some of the species recorded in the present study were not recorded in the western Mediterranean coast: *Neurada procumbens*, *Nicotiana glauca* and *Rumex pectus*. It worth noting, that the species composition of the studied dunes varied considerably from those of the western Mediterranean coast. This may be attributed mainly to the difference in climatic conditions and the soil elemental composition. The floristic elements of the Western Mediterranean coastal belt enjoy better climatic conditions than those of the other parts of Egypt [29]. According to Moustafa [3], black sand dunes, exhibits anomalous contents for the total heavy minerals.

Thirty-four species were recorded on the dune tops, 44 along the dune slopes and 58 were recorded in the interdunes. The vegetation cover of the south-facing slopes to the sea is considerably greater than that of the north-facing one. These differences in cover may be because the south-facing slopes are not subjected to the direct effect of cold, strong north winds which lower the temperature and may uproot many seedlings on the north-facing slopes [29]. *Calligonum polygonoides* and *Moltkiopsis ciliata* recorded in the present study were also recorded in the interdunes of Bardawil Wetland [9]. *Calligonum polygonoides* has been classified as resistant to deep sand cover or removal [34]. *Moltkiopsis ciliata* is dominant on the sandy dunes of Egypt [35]. Compared to other Egyptian ecoregions and habitat types, the dunes are characterized by a relatively high vegetation cover which reaches 80% in interdunal areas.

The life form spectra provide information which may help in assessing the response of vegetation to variations in environmental factors [36]. The Mediterranean climate was designated as a "therophyte climate" [15] because of the high percentage (> 50% of the total species) of this life form in several Mediterranean floras [37]. The present study demonstrated that therophytes were represented by 59.5% of the total recorded species, 13.0% geophytes-helophytes, 10.1% hemicryptophytes and 8.7% chamaephytes and phanerophytes. The dominance of therophytes over the other life forms seems to be a response to the hot-dry climate, topographic variation and biotic influence [38]. The highest values of hemicryptophytes and chamaephytes may be attributed to the ability of species belonging to these life forms to resist drought, salinity, sand accumulation and grazing [34]. The floristic categories of the recorded species showed that the bi-regional taxa had the highest contribution, followed by the monoregional, pluriregional and cosmopolitan (11.6%). The dominance of inter-regional species (bi-, tri- and pluri-regionals) over mono regional ones is referred to the presence of interzonal habitats, such as anthropogenic or hydro-, halo- and psammophilous sites [39]. Fourty-two species were Mediterranean and 30 were Saharo-Arabian taxa. According to Zohary [39], the Mediterranean territory of the Middle East occupies a comparatively narrow belt along the Mediterranean Sea and there is a gap in this belt between southern Palestine and Libya in which the Saharo-Arabian belt closely approaches the Mediterranean coast. The presence of the phytogeographical elements other than the Mediterranean, in the study area is believed to be a

reflection of intense climatic changes and/or the degradation of the Mediterranean ecosystem which facilitated the invasion of some elements from the adjacent regions [40].

The classification of the vegetation of the black sand dunes using TWINSpan analysis led to identify 7 vegetation groups. These groups were separated along the DCA ordination axes reflecting moisture gradient. The moisture gradient starts with communities representing the interdunes (*Chenopodium murale-Mesembryanthemum crystallinum*), dune slopes (*Nicotiana glauca-Cakile maritima* and *Asphodelus viscidulus-Elymus farctus*) and dune tops (*Rumex pictus-Silene succulenta*). The dune vegetation communities are more or less related to the communities described by Zahran *et al.* [35] on the Mediterranean deltaic coast. Environmental factors affecting the vegetation in the present study are typical of those known to control halophytes and psammophytes [36].

The diversity of plant communities generated from multivariate analysis indicated that the communities that represent the interdunes are more diverse than the others. This may be due to the high number of weedy and urban species which could be introduced to the area through cultivation or urbanization. Moreover, the high diversity of such habitats is associated with the increase in annuals during spring [41]. No doubt that, the increasing number of the weeds of urban habitats in a certain area reflects the degree of human impacts or, the so-called, degree of artificialization or hermeroby [42]. This indicates that the natural status of the black sand dunes of north Nile Delta is highly altered and suffers from the growing rate of human population with no opportunity for immigration and/or expansion. As such, there has been both time and opportunity for man to exert considerable changes upon this natural habitat and its flora. Therefore, the conservation of natural habitats of northern Nile Delta especially the black sand dunes, which will be threatened by agricultural and urban expansions as well as the proposed mining activities, is of vital importance.

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