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Floristic Composition of Species Inhabiting the Threatened Oolitic Sand Dune Habitat in Egypt

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EGYPT is in the arid belt, with a semi-arid Mediterranean coast. Characteristic maritime oolitic sand dunes stretch parallel to the sea from Alexandria westward to Mersa Matruh. This habitat has a highly specialized floristic composition that never grows southward. Recently, the oolitic sand dune habitats have become threatened by urbanization expansion and global climate change, inducing a notable decline in floristic composition and species richness. The present study aimed to assess the flora land vegetation of the oolitic sand dunes along the Mediterranean coast in Egypt. The floristic composition in the surveyed area included a total of 116 psammophyte species (91 genera belonging to 27 families), with annuals comprising 47.4% and perennials comprising 40.5%. Chronological analysis revealed the dominance of the Mediterranean elements, with either mono-, bi- or pluri-regional chorotypes accounting for 64.7% of the total number of species. According to canonical correspondence analysis, the relationship between the prevailing species composition and soil variables revealed that $CaCO_3$ and organic carbon positively affected, whereas sand and clay fractions and chloride ions negatively affected, the species distribution. The deterioration of oolitic habitats due to the construction of resorts and urbanization has led to a severe decline in the vegetation and flora of the area; this expansion must be stopped.

Keywords: Chorotypes, Floristic composition, Mediterranean vegetation, Oolitic sand dune.

Introduction

Globally, the distribution of parabolic coastal sand dunes is limited, located only in restricted areas in Egypt, Brazil, New Zealand, Saudi Arabia, Australia, South Africa, and the United States (Yan & Bass, 2015). On the other hand, coastal oolitic sand dunes run parallel along the Mediterranean coast from Egypt to Morocco, from a few meters to 10 km north-south direction (publications@unido.org); these oolitic sand dunes date back to the Pleistocene (Atwia & Masoud, 2013). Coastal dunes are under biological and physical stresses, and are sensitive to environmental change (Frosini et al., 2012) and threatened by overuse, pollution, and sea-level rise (Yousif & Bubenzer, 2012), in addition to overgrazing and expanding urbanization (Atwia & Masoud, 2013). To date, no detailed study has documented the vegetation genome, including barcoding, of this vulnerable habitat type.

Arid and semi-arid land covers an area of approximately 38%; sand dunes are linked to an arid climate, with 20% of the arid zone covered by aeolian sand. Egypt is in the arid belt, with a semi-arid Mediterranean coast that stretches approximately 970 km parallel to the sea, at its utmost approximately 20 km in the north-south direction (El-Hadidi, 2000). The West Mediterranean coast, stretching from Alexandria westward to Mersa Matruh, has characteristic maritime oolitic sand dunes that stretch parallel to the sea (Zahran & Willis, 2009).

This part of the Mediterranean coast is known as the Mareotis sector, which is recognized as one of the richest phytogeographic regions

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in Egypt (Osman et al., 2015) due to its high rainfall and habitat diversity (Zahran & Willis, 2009). The Mareotis sector of the Mediterranean is characterized by successive, interrupted, undulated calcareous sand dunes formed of loose oval oolitic grains (Zahran & Willis, 2009). This special habitat is attenuated by a desert climate (Amer et al., 2020) and covered by psammophytes, a highly specialized species with the capacity to lengthen vertically when buried in sand (Zahran & Mashaly, 2000). Psammophytes have superficial roots that develop extensively to use dew and building sand mounds (Galy, 2006).

The psammophytes growing in the study area of the "Burg El-Arab- Mareotis sector" are sustained under maritime influence and never grow southward (Zahran & Mashaly, 2000). The dominant species in this area are *Ammophila arenaria, Euphorbia paralias, Lotus polyphyllos*, *Ononis vaginalis*, and *Thymalea hirsuta* (Ghaly, 2006; Elshayeb, 2020). These species are often classified as xerophytes due to the prevailing extreme edaphic and climatic conditions (Ghaly, 2006). The most proximate species to the sea shore is *Ammophila arenaria* (Poaceae), which is a fodder species for local grazing, and cultivated in Tasmania (Australia) for stabilizing sand dunes (Rudman, 2003).

The recent urbanization expansion and global climate change (the land surface has warmed 0.27°C/decade; Kelly & Gouden, 2008) has induced a decline in the floristic composition and species richness of these psammophytic habitats along the Mareotis sector over the last ten decades, with Mediterranean chorotype species being the most affected elements (Elshayeb, 2020; Amer et al., 2020). Beginning three decades ago, urbanization activities replaced the natural habitat with summer resorts **(**Elshayeb, 2020; Amer et al., 2020), leading to a severe decline in both the vegetation cover and floristic composition of maritime limestone sand dunes. Seif El-Nasr & Bidak (2005) and Bedair et al. (2020) listed the threats that directly and indirectly induced the deterioration of ecosystems and the degradation of species, namely overgrazing, over-collecting, over-cutting, clearance for agriculture, construction of summer resorts, industrial growth, automobile disruption, and quarrying It is an urgent need for implementation of management measures aiming at mitigating coastal deterioration by combining local and global actions (Bidak et al., 2021).

Due to pollution, overgrazing, and the accelerating rate of urbanization in the Mareotis sector of the Mediterranean Sea, an assessment of the current status of the area is crucial. The main goal of this study was to document the floristic composition in the threatened oolitic sand dune habitats in Egypt, and to assess the physical and chemical variables that affect the spatial distribution of the species in the area.

Materials and Methods

Study area

The study encompassed four sites along the Mediterranean coast: site 1 (Sidi krir, 31° 02′ 08″ N, 29° 39′ 23″ E), site 2 (Abu Sir, 30° 56′ 50″ N, 29° 30′ 34″ E), site 3 (Zomoroda village, 30° 55′ 10″ N, 29° 26′ 35″ E), and site 4 (Karawan village 30° 51′ 08″ N, 29° 26′ 35″ E); these sites are located 30, 45, 52, and 66 km west of Alexandria, respectively, and belong to the Mareotis sector, Egypt. These four areas represent the unique limestone ridges close to the sea shore at approximately 10–60 m asl (El-Hadidi, 2000). This habitat is still covered by coastal maritime oolitic sand dunes, followed by more solidified calcareous blocks with fig orchards, followed by elevated rocky ridge enclosed depression as remnants of an old waterway. At each site, two 10 x 100 m stands, perpendicular to the sea, were monitored for two successive years (2019 and 2020). These two stands were selected as follows: a stand close to the sea shore (200–400m) dominated by *Ammophila arenaria* and another stand (a fig orchard stand) distal to the sea (800–1200m) dominated by *Elymus farctus*. Presence performance (P) was calculated as the number of stands in which species were recorded, divided by the total number of stands (8) multiplied by 100.

Floristic composition

The floristic composition, in terms of the species dominated by *Ammophila arenaria* (coastal sand dune stands) and *Elymus farctus* (fig orchard stands), was evaluated through an extensive survey of the studied sites using a stratified sampling method (Ellenberg & Müller-Dombois, 1974).

Plant material and species identification

The collected species were identified, and representative samples were deposited in the Cairo University Herbarium (CAI). The sites were positioned using GPS model BHC NAVA 300.

Taxa were identified based on voucher herbarium specimens and reference books (Boulos, 1999, 2000, 2002, 2009); the species nomenclature were updated using http://www.theplantlist.org/. Species chorology was adopted according to Amer et al. (2020).

Soil analysis

Three samples of soil from each stand were collected at three depths: 0–10, 10–25, and 25–50 cm. These samples were brought to the laboratory, air dried, and thoroughly mixed to form one composite sample; gravel and debris were removed using a 2-mm sieve. Three replicates were analyzed for each soil sample. Sixteen soil variables (physical and chemical) were determined, according to Soliman et al. (2015), to examine the effect of soil variables on the spatial distribution of the species co-dominating the *Ammophila arenaria* and *Elymus farctus* stands.

Statistical analysis

We employed both classification and ordination techniques to achieve an effective vegetation analysis. The floristic data matrix (116 species and eight stands) was subjected to cluster analysis by Euclidean distance, producing a dendrogram. The vegetation groups produced from the cluster analysis were then subjected to an independent samples t-test based on the soil variables to identify any significant variations between groups using SPSS (version 20 for Windows). Indirect gradient analysis was performed using detrended correspondence analysis (DCA), and direct gradient analysis was performed using canonical correspondence analysis (CCA). The relationships between the floristic gradients and the 16 soil variables are shown in the ordination diagram produced by the CCA. Past software version 3.26 for Windows was used for both classification and ordination.

Results

Classification of the floristic composition in the studied sites

The clustering analysis of the matrix of the presence performance of the recorded 116 species against the eight stands revealed that the studied stands were distributed in two groups (Fig. 1). Group (A) included the four stands of the coastal sand dune habitat dominated by *Ammophila* sp. and Group (B) included the four stands of the subsequent habitat dominated by *Elymus* sp.

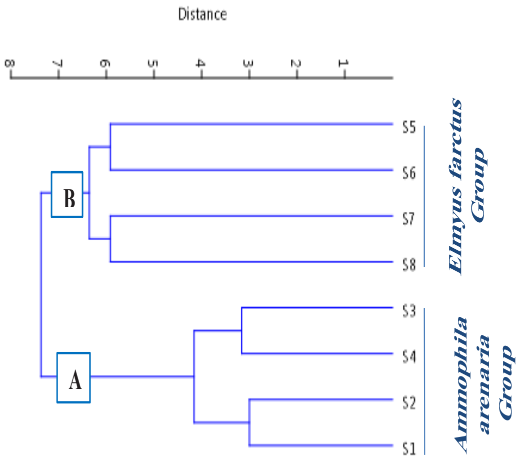

Fig. 1. Cluster analysis of the eight stands using Euclidean distance measures, based on the presence performance of the species recorded in each stand

Floristic composition

The floristic composition in the surveyed area (eight stands across two sites) revealed a total of 116 psammophyte vascular plants belonging to 91 genera in 27 families, as shown in Fig. 2. The six most species-rich families were Asteraceae (22 species), Poaceae (15 species), Fabaceae (12 species), Brassicaceae (10 species), Caryophyllaceae (7) and Chenopodiaceae (5), which accounted for 61.2% of the total number of species; the remaining 17 families accounted for 38.8% of the total number of species.

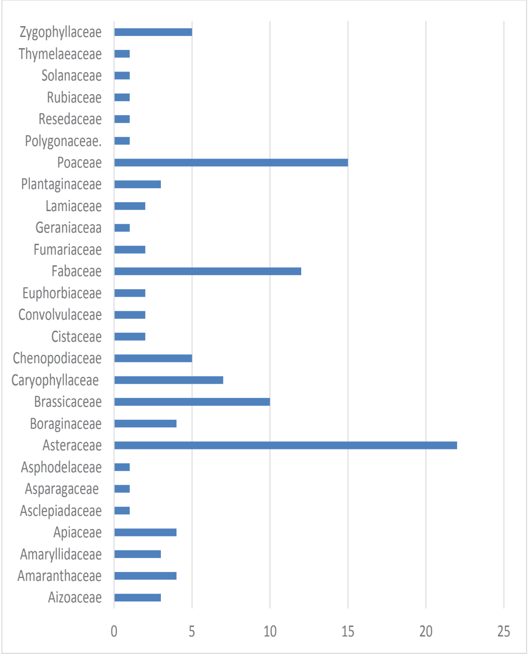

Fig. 2. Representation of the number of species in each family

The most species-rich genera was *Centaurea*, with 4 species. *Fagonia, Launaea*, and *Plantago* were represented by 3 species each, and 16 genera were represented by 2 species each; the remaining 71 genera were represented by one species each. The total number of species varied across the studied sites. The number of species recorded in the *Elymus* habitat was 91, accounting for about 78.4% of the total number of recorded species, whereas only 47 species, or 40.5% of all recorded species, were found in the stands of the *Ammophila* habitat. Moreover, annuals slightly dominated perennials; they were represented by 47.4 and 37.9% of the species, respectively (Table 1).

Twenty-two ubiquitous species with the broadest ecological amplitude were recorded in at least one stand of the two different habitats, with four recording the highest performance values of 62.5%; namely *Echinops spinosissimus, Hordeum marinum* subsp. *Marinum, Emex spinosus*, and *Tetraena alba*. Three species (*Ammi majus, Asparagus stipularis* v. *tenuispinus*, and *Lycium europaeum*) had a presence performance of 50%, whereas another 12 species (*Anabasis articulata*, *Noaea mucronate, Eryngium creticum, Ifloga spicata, Limbarda crithmoides, Echium angustifolium, Herniaria hemistemon, Atriplex halimus, Astragalus peregrinus, Plantago notata, Lygeum spartum*, and *Fagonia arabica*) recorded performances of 37.5%. The lowest performance (25%) was recorded by *Deverra tortuosa, Teucrium polium*, and *Phragmites australis.*

Among the 47 species that were present in the *Ammophila*-dominated stands, twenty-eight species were confined to the stands (1, 2, 3, and 4) of the coastal sand dune characterized by the *Ammophila* habitat (Group A). In addition to the dominant *Ammophila arenaria*, four species were recorded in all stands, but at different densities: *Euphorbia paralias, Lotus polyphyllos, Ononis vaginalis*, and *Reseda decursiva*. On the contrary, *Centaurea glomerata, Echiochilon fruticosum Silene succulenta*, and *Helianthemum stipulatum* were occasionally recorded in only one stand.

In stands dominated by *Elymus* (Group B), 91 species were recorded. Ten species were recorded in all stands (5, 6, 7, and 8), but with different densities. These include, besides the *Elymus species, Achillea santolina, Centaurea alexandrina, Lobularia libyca, Stellaria pallida, Atriplex inflata, Convolvulus althaeoides, Aegilops kotschyi, Hordeum murinum* subsp. *Leporinum* and *Hordeum marinum subsp. Marinum*, the former 9 species were confined to this habitat. Sixty-eight species were confined to the stands demoninated by *Elymus*, with 10 recorded in all stands, 11 in 3 stands, 43 in 2 stands, and 5 in 1 stand.

Chorological affinities

Table 2 summarizes the chronological analysis of the 116 recorded species. The mono-regional chorotype was represented by 43 species (37.1%), of which 25 species were Mediterranean (21.6%) and 16 species were Saharo-Arabian (13.8%). On the other hand, the bi-regional chorotype comprised 51 species (44%), dominated by Mediterranean Saharo-Arabian species (19 species) followed by Mediterranean Irano-Turanian species (16 species; 3.8%). Additionally, the pluri-regional chorotype was represented by 22 species (19%).

Table 3 outlines the mean values, standard deviation and t-test values (*t*-statistic and *P value*) of the studied variables for the two sites (8 stands). The pH of the two sites was slightly alkaline. All physical properties of the examined soil variables exhibited highly significant values ($P \leq 0.05$). In addition, electric conductivity (EC), Na^+, SO_4^{-2}, organic carbon, and $CaCO_3$ were from chemical variables that exhibited highly significant values ($P \leq 0.05$).

Data retrieved from the t-tests (Table 3) indicated that the four stands dominated by *Ammophila arenaria* (Group A) were distinguished by having a higher sandy fraction (SF), electric conductivity (EC), Na^+, SO_4^{-2}, and $CaCO_3$ than the stands in Group B (the four stands dominated by *Elymus farctus)*; Group B was distinguished by having a higher percentage of sand and clay, and organic carbon.

The relationship between the floristic composition results and the soil analysis of the eight stands was studied using CCA, with arrows representing the examined soil variables (Fig. 3). Stands 3 and 4 of Group A affected the percentage of SF, moisture content (MC), EC, Na^+, K^+, Cl^-, SO_4^{-2}, and $CaCO_3$, whereas stands 1 and 2 were clearly affected by pH. On the other hand, stands 5, 6, and 7 of Group B correlated with Mg^{+2}, whereas stand 8 was affected by Ca^{+2}, organic carbon, and the percentage of sand and clay.

TABLE 1. The presence performance (P, %) of the associated species within the studied *Ammophila* and *Elymus* sites, including their life span and chorotypes; A= Annual, P= Perennial, TS= Tree or shrub, n= Number of stands where species recorded. For chorotype abbreviations, see Table 2

Species	Life span	Chorotype	*Ammophila* sites (n)	*Elymus* sites (n)	P
Aizoaceae					
Aizoon canariense L.	A	SA-SI + S-Z	0	2	25
Mesembryanthemum crystallinum L.	A	MED + ER-SR	0	3	37.5
Mesembryanthemum forsskalii Hochst. ex Boiss	A	SA-SI + S-Z	0	2	25
Amaranthaceae					
Anabasis articulata (Forssk.) Moq.	P	SA-SI	1	2	37.5
Salsola tetrandra Forssk.	P	SA-SI	0	1	12.5
Suaeda pruinosa Lange	P	ME + SA-SI	0	2	25
Noaea mucronata (Forssk.) Asch. & Schweinf.	TS	IR-TR	1	2	37.5
Amaryllidaceae					
Allium aschersonianum Barbey	P	IR-TR	2	0	25
Allium roseum L.	P	MED + SA-SI	2	0	25
Pancratium maritimum L.	P	MED	2	0	25
Apiaceae					
Ammi majus L.	A	MED + IR-TR	1	3	50
Devera tortuosa (Desf.) DC.	TS	SA-SI	2	1	25
Eryngium creticum Lam.	P	MED	3	2	37.5
Pseudorlaya pumila (L.) Grande	A	MED + SA-SI	0	2	25
Asclepiadaceae					
Cynanchum acutum L.	P	MED + IR-TR + ER-SR	0	3	37.5
Asparagaceae					
Asparagus stipularis Forssk v. *tenuispinus* Holmboe	TS	MED	2	2	50
Asphodelaceae					
Asphodelus tenuifolius Cav.	A	MED + SA-SI	0	2	25
Asteraceae					
Achillea fragrantissma (Forssk.) Sch.Bip	TS	MED	0	2	25
Achillea santolina L.	A	MED + IR-TR	0	**4**	50
Anthemis microsperma Boiss & Kotschy	A	MED	0	2	25
Artemisia monosperma Delile	TS	MED	0	2	25
Carduncellus mareoticus (Delile) Hanelt		MED + IR-TR	0	3	37.5
Centaurea alexandrina Delile	P	MED	0	**4**	50
Centaurea calcitrapa L.	P	MED + ER-SR	0	3	37.5
Centaurea glomerata Vahl	A	MED	1	0	12.5
Centaurea pallescens Delile v. *brevicaulis*	P	MED	0	2	25
Echinops spinosissimus Turra	P	MED	3	2	62.5
Hyoseris radiata L.	P	MED	2	0	25
Ifloga spicata (Forssk.) Sch.Bip.	A	ME + SA-SI	1	2	37.5
Launaea capitata (Spreng.) Dandy	A	SA-SI	0	2	25
Launaea mucronata subsp. cassiniana (Jaub. & Spach) N.Kilian	P	ME + SA-SI	2	0	25
Launaea nudicaulis (L.) Hook.f.	P	IR-TR + SA-SI + S-Z	0	2	25
Limbarda crithmoides (L.) Dumort.	A	ME + SA-SI	1	2	37.5
Matricaria aurea (Loefl.) Sch.Bip.	A	MED + IR-TR	0	2	25

TABLE 1. Cont.

Species	**Life span**	**Chorotype**	***Ammophila* sites (n)**	***Elymus* sites (n)**	**P**
Onopordum alexandrinum Boiss.	P	MED + IR-TR + SA-SI	0	2	25
Otanthus maritimus (L.) Hoffmanns. & Link	P	MED + ER-SR	2	0	25
Phagnalon rupestre (L.) DC.	TS	MED + IR-TR	2	0	25
Picris asplenioides L.	A	MED + IR-TR	0	2	25
Senecio glaucus subsp. *coronopifolius* (Maire) C. Alexander	A	IR-TR + SA-SI	0	2	25
Boraginaceae					
Anchusa aegyptiaca (L.) A. DC.	A	MED + IR-TR	0	3	37.5
Echium angustifolium Mill	P	SA-SI	2	1	37.5
Echiochilon fruticosum Desf.	P	SA + IR-TR	1	0	12.5
Heliotropium digynum (Frossk.) Asch.	P	SA-SI	0	2	25
Brassicaceae					
Brassica tournefortii Gouan	A	MED + SA-SI	0	2	12.5
Cakile maritima Scop.	A	MED + ER-SR	0	2	25
Carrichtera annua (L.) DC.	A	MED	0	2	25
Coronopus squamatus (Forssk.) Asch.	P	MED + IR-TR + ER-SR	0	3	37.5
Enarthrocarpus lyratus (Forssk.) DC.	A	MED	0	2	25
Lobularia libyca (Viv.) C. F. W. Meissn	A	SA-SI	0	**4**	50
Lobularia maritima (L.) Desv.	P	MED	0	3	37.5
Matthiola longipetala (Vent.) DC.	A	MED + IR-TR	0	2	25
Sisymbrium irio L.	A	MED + IR-TR	0	2	25
Zilla spinosa (L.) Prantl	TS	SA-SI	0	2	25
Caryophyllaceae					
Gymnocarpos decandrus Frossk.	TS	MED + SA-SI	2	0	25
Herniaria hemistemon J.Gay	P	MED	2	1	37.5
Silene succulenta Forssk.	P	MED	1	0	12.5
Silene villosa Forssk.	A	SA-SI	0	2	25
Spergularia marina (L.) Griseb.	P	MED + IR-TR	0	1	12.5
Spergularia media (L.) C. Presl	P	MED + IR-TR + ER-SR	0	1	12.5
Stellaria pallida (Dumort.) Murb.	A	MED + ER-SR	0	**4**	50
Chenopodiaceae					
Atriplex halimus L.	TS	MED + SA-SI	1	2	37.5
Atriplex inflata F. Muell.	P	MED + SA-SI	0	**4**	50
Bassia indica (Wight) A. J. Scott	A	IR-TR + S-Z	0	2	25
Chenopodium album L.	A	COSM.	0	2	25
Salsola kali L.	A	PAL	0	2	25
Cistaceae					
Helianthemum lippii (L.) Dum.Cours.	TS	MED + IR-TR	2	0	25
Helianthemum stipulatum (Forssk.) C.Chr.	TS	SA-SI	1	0	12.5
Convolvulaceae					
Convolvulus althaeoides L.	P	MED	0	**4**	50
Convolvulus arvensis L.	P	Cosm	0	2	12.5
Euphorbiaceae					
Euphorbia paralias L.	P	MED	**4**	0	50

TABLE 1. Cont.

Species	Life span	Chorotype	*Ammophila* sites (n)	*Elymus* sites (n)	P
Euphorbia prostrata Aiton	A	NEO	0	3	37.5
Fabaceae					
Astragalus peregrinus Vahl	A	SA-SI	1	2	37.5
Astragalus spinosus (Forssk.) Muschl.	P	MED + IR-TR	2	0	25
Hippocrepis areolata Desv.	A	MED + SA-SI	0	1	12.5
Lotus polyphyllos E. D. Clarke	TS	MED	**4**	0	50
Medicago polymorpha L.	A	COSM.	0	2	25
Onobrychis crista-galli (L.) Lam.	A	MED + IR-TR + SA-SI	0	2	25
Ononis serrata Forssk.	A	MED + SA-SI	2	0	25
Ononis vaginalis Vahl	A	MED + SA-SI	4	0	50
Retama raetam (Forssk.) Webb & Berthel.	TS	MED + IR-TR + SA-SI	2	0	25
Trifolium tomentosum L.	A	MED + IR-TR + ER-SR	0	2	25
Vicia hirsuta (L.) Gray	A	PAL	0	2	25
Vicia monantha RetZ.	A	MED + IR-TR	0	2	25
Fumariaceae					
Fumaria densiflora DC.	A	MED + IR-TR + ER-SR	0	2	25
Fumaria parviflora Lam.	A	MED + IR-TR + ER-SR	0	3	37.5
Geraniaceae					
Erodium crassifolium (L.) L'Hér.	P	SA-SI	0	2	25
Lamiaceae					
Salvia lanigera Poir.	P	MED + SA-SI	2	0	25
Teucrium polium L.	P	MED + IR-TR	1	1	25
Plantaginaceae					
Plantago crypsoides Boiss.	A	MED	2	0	25
Plantago notata Lag.	A	IR-TR + SA-SI	1	2	37.5
Plantago ovata Forssk.	A	IR-TR + SA-SI	0	2	25
Poaceae					
Aegilops bicornis (Forssk.) Jaub. & Spach	A	MED	0	3	37.5
Aegilops kotschyi Boiss.	A	IR-TR + SA-SI	0	4	50
Ammophila arenaria (L.) Link	P	MED	4	0	50
Avena sterilis L.	A	MED + IR-TR	0	2	25
Bromus catharticus Vahl	A	COSM.	0	2	25
Cenchrus ciliaris L.	P	PAL	0	1	12.5
Cutandia dichotoma (Forssk.) Trab.	A	IR-TR + SA-SI	0	2	25
Elymus farctus (Viv.) Runem. ex Melderis	P	MED	0	**4**	50
Hordeum marinum Huds. *subsp. marinum*	A	MED + IR-TR + ER-SR	1	**4**	62.5
Hordeum murinum L. subsp. *leporinum* (Link) Arcang.	A	MED + IR-TR	0	**4**	50
Imperata cylindrica (L.) Raeusch.	P	PAL	0	2	25
Lolium multiflorum Lam.	P	MED + IR-TR + ER-SR	0	3	37.5
Lygeum spartum Loefl. ex L.	A	MED + ER-SR	1	2	37.5
Phragmites australis (Cav.) Trin. ex Steud.	P	COSM.	1	1	25
Setaria pumila (Poir.) Roem. & Schult.	A	MED + ER-SR	0	2	25
Polygonaceae.					

TABLE 1. Cont.

Species	Life span	Chorotype	*Ammophila* sites (n)	*Elymus* sites (n)	P
Emex spinosa (L.) Campd.	A	MED + SA-SI	3	2	62.5
Resedaceae					
Reseda decursiva Forssk.	A	SA-SI	**4**	0	50
Rubiaceae					
Crucianella maritima L.	P	MED	3	0	37.5
Solanaceae					
Lycium europaeum L.	TS	MED	1	3	50
Thymelaeaceae					
Thymelaea hirsuta (L.) Endl.	TS	MED + SA-SI	3	0	37.5
Zygophyllaceae					
Fagonia arabica L.	TS	MED + SA-SI	1	2	37.5
Fagonia cretica L.	P	SA-SI	0	2	25
Fagonia indica Burm.f.	P	SA-SI	0	1	12.5
Tetraena alba (L.f.) Beier & Thulin	TS	MED + SA-SI	3	2	62.5
Tetraena simplex (L.) Beier & Thulin	A	SA-SI	0	2	25

Total number of species 4791

TABLE 2. Chorological analysis of the recorded species; COSM= Cosmopolitan, ER-SR= Euro-Siberian, IR-TR-= Irano-Turanian, MED= Mediterranean, NEO= Neotropics, PAL= Palaeotropical, PAN= Pantropical, SA-AR= Saharo-Arabian, S-Z= Sudano-Zambezian

Chorology	Number of species	Percentage %
Mono-regional		
MED	25	21.6
SA-AR	16	13.8
IR-TR	2	1.7
Sub-total	43	37.1
Bi-regional		
MED + SA-SI	19	16.4
MED + IR-TR	16	13.8
MED + ER-SR	7	6
IR-TR + SA-SI	6	5.2
IR-TR + S-Z	1	0.9
SA-SI + S-Z	2	1.7
Sub-total	51	44
Pluri-regional		
MED + IR-TR + ER-SR	8	6.9
COSM	5	4.3
MED + IR-TR + SA-SI	3	2.6
IR-TR + SA-SI + S-Z	1	0.9
NEO	1	0.9
PAL	4	3.4
Sub-total	22	19
Total	116	100%

The successive decrease of eigenvalues (Table 4) of the four CCA axes (0.8003, 0.2900, 0.2379 and 0.25664 for axes 1, 2, 3, and 4, respectively) suggest that the data set was well structured. The species-soil correlations were high for the four axes, explaining 46.35% of the cumulative variance for Axis 1 and 63.14% for Axis 2. These results suggest an association between vegetation and the measured soil variables presented in the biplot.

The inter-set correlations resulting from the CCA of the examined soil variables are shown in Table 4. Axis 1 positively correlated with $CaCO_3$ (0.9709) and negatively correlated with the percentage of silt and clay (−0.9623). As such, the CCA of Axis 1 can be interpreted as $CaCO_3$ – the silt and clay gradient. Axis 2 positively correlated with organic carbon (0.2006) and negatively correlated with Cl^- (−0.4718). As such, the CCA of Axis 2 can be interpreted as the organic carbon-Cl^- gradient. The CCA ordination biplot diagram (Fig. 3) was similar to the ordination pattern obtained from the floristic DCA (Fig. 4), with most of the stands remaining in their respective cluster group.

Discussion

The floristic diversity of the studied area is important due to its position among the Mediterranean oolitic habitats in Egypt, which have been recently subjected to urbanization expansion (Ahmed et al., 2014), in addition to the notable decline in rainfall inducing a decline in species diversity. Galal & Fawzy (2007) reported that the vegetation diversity along this coast has declined by 35%. The Mediterranean species demonstrated pole ward expansion and were replaced by xeric species (Amer et al., 2020).

TABLE 3. Independent sample t-test comparing soil variables across stands representing the groups obtained by cluster analysis, with means, standard deviations and P values; P≤ 0.05. MS= Medium sand (%), FS= Sandy fraction (%), VS= Very fine sand (%), S&C = Sand and clay (%), MC= Moisture content (%), EC= Electric conductivity (mmhos/cm) OC = Organic carbon (%). Other variables were measured in Meq/L, except for CaCO3 (%)

Soil variables	Group A	Group B	t-value	Sig P (2-tailed)
MS	9.18±0.17	16.35±0.85	16.410	**0.000**
FS	69.58±0.33	59.88±1.55	12.225	**0.000**
VS	20.15±0.12	19.25±0.59	2.952	**0.026**
S&C	1.05±0.04	**4.75±1.02**	7.249	**0.000**
SF	**98.95±0.04**	92.75±3.06	4.046	**0.007**
MC%	3.03±0.35	2.72±0.34	1.263	0.253
PH	7.79±0.10	7.68±0.04	1.931	0.102
EC	**0.43±0.03**	0.33±0.01	5.523	**0.001**
Ca^{+2}	1.76±0.29	1.88±0.28	0.610	0.564
Mg^{+2}	1.05±0.04	1.38±0.34	1.860	0.112
Na^{+}	**2.11±0.18**	1.52±0.17	4.611	**0.004**
K^{+}	0.34±0.02	0.30±0.06	1.149	0.294
Cl^{-}	3.65±0.53	3.18±0.17	1.713	0.138
SO_4^{-2}	**0.60±0.06**	0.44±0.08	3.103	**0.021**
OC	0.02±0.01	**0.16±0.02**	9.511	**0.000**
$CaCO_3$	**93.78±0.68**	81.34±1.64	13.924	**0.000**

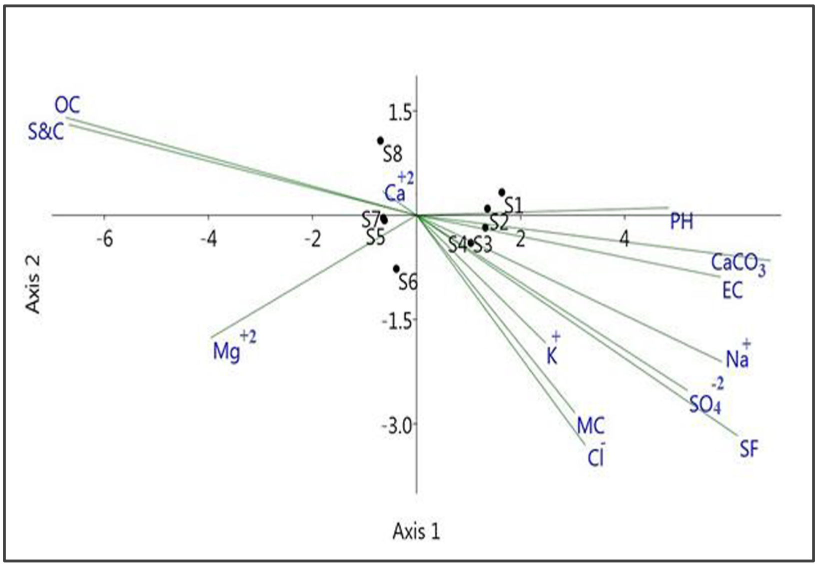

Fig. 3. The CCA ordination biplot of the first two axes showing the distribution of the stands with the examined soil variables (for abbreviations, see Table 3).

TABLE 4. CCA analysis results showing the inter-set correlations of the soil variables, together with eigenvalues and the species-soil correlation in the studied habitats. For abbreviations and units, see Table 3

Axes	Ax1	Ax2	Ax3	Ax4
Eigenvalues	0.8003	0.2900	0.2379	0.1664
Species-soil correlations	46.35	16.79	13.78	9.634
MC	0.4342	-0.4056	0.0743	-0.3547
S&C	**-0.9623**	0.1859	0.0431	0.2705
Sf	0.8807	-0.4528	0.1802	-0.2303
PH	0.6909	0.0152	-0.0392	0.0938
EC	0.8335	-0.1266	-0.1835	-0.6343
Ca^{+2}	-0.0928	0.0484	0.2977	0.7025
Mg^{+2}	-0.5640	-0.2515	0.1823	0.0982
Na^{+}	0.8368	-0.3006	-0.1095	-0.5685
K^{+}	0.3532	-0.2615	-0.3598	-0.3315
Cl^{-}	0.4624	**-0.4718**	-0.2194	-0.8651
SO_4^{-2}	0.7435	-0.3598	-0.0621	-0.5733
OC	-0.9534	**0.2006**	0.0966	0.3198
$CaCO_3$	**0.9709**	-0.0930	-0.1404	-0.2461

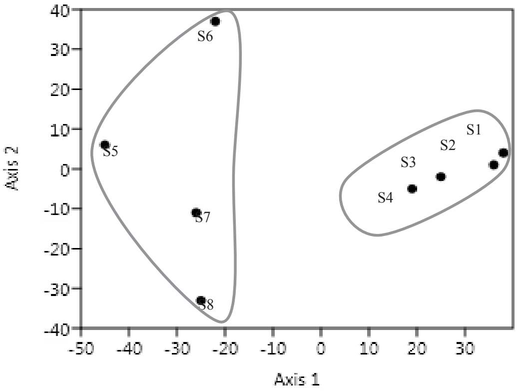

Fig. 4. Detrended correspondence analysis (DCA) of the studied stands, based on the plant species recorded in each stand

Over more than 30 years of teaching flora to bachelor students, one could collect more than 100 species in one of these stands. In 2015, Shaltout et al. (2015) recorded 233 species in the sand dune habitat of the area; meanwhile, Shaltout & Ahmed (2012) recorded 208 species in the coastal dunes. The total recorded species in the present study was 116 species. Reduction of plant cover due to cutting wood, over-picking, or plowing causes the soil surface layer to regress under the influence of water erosion or wind pressure (Ahmed et al., 2014). In recent decades, the human strain on the environment has been increasing, using new technology in the agriculture and development of quarries and settlements (Shaltout & Ahmed, 2012). Due to the ongoing construction of summer resort communities, this region has been destroyed; these anthropogenic impacts have various repercussions, including effects on soil, natural resources, wildlife and plants, migratory birds, local attitudes, and cultural surroundings (Batanouny, 1999).

Ayyad (1973) noted that coastal dunes are subjected to the effect of mostly north-westerly winds. In many transversal dunes, sand travels inland; farther inland, these dunes become broader and are somewhat stabilized. This effect explains the varied number of registered species in the two distinct habitats, with 91 species in the *Elymus* habitats and only 47 in the *Ammophila* habitats. The studied oolitic sand dune was dominated by annuals (47.4%) over perennials (37.9%), highlighting the detrimental weather conditions, lack of moisture, unstable substrate, and reproductive capacity of these annuals in disturbed habitats (Amer & Elshayeb, 2020).

Although *Ammophila arenaria* and *Elymus farctus* were the dominant species in the stands of sites 1 and 2, respectively, they did not have the highest presence performance (50% each), indicating that each of these two species are confined to their stands; four other species had higher performance (62.5%). Similarly, the *Elymus* stands were co-dominated by annual species, including *Achillea santolina, Achillea fragrantissma*, *Launaea capitata*, and *Cakile maritima*. The co-dominance of annuals in the Mediterranean psammophytes has been previously explained by Galy (2006**.** On the other hand, the *Ammophila* stands were co-dominated by perennials, including *Gymnocarpos decandrus***,** *Euphorbia paralias*, *Thymelaea hirsute*, and *Tetraena alba*; congruent results have been reported by Zahran & Willis (2009). This habitat is characterized by highly drought-adapted species, such as *Ononis vaginalis, Euphorbia paralias*, and *Crucianella maritima*; an analogous feature was observed by Salama et al. (2005) and Amer et al. (2020).

The observed dominance of species related to Asteraceae, Poaceae, Fabaceae, and Brassicaceae is a feature that distinguishes the Mediterranean sector in North Africa (Shaltout & El-Kady, 1999; Amer & Elshayeb, 2020; Shaltout et al., 2015). Additionally, Poaceae species are sand binder plants that produce adventitious roots to fix sand dunes (Zahran & Willis, 2009).

Clustering analysis revealed that the studied stands clearly split into two groups: Group (A) represented the coastal sand dune stands dominated by *Ammophila* sp. and Group (B) represented the stands dominated by *Elymus* sp. Overall, the species diversity in the *Elymus* stands (78.4%) was greater than that in the *Ammophila* stands (40.5%). In addition, the *Ammophila*-dominated stands had low species diversity compared to the *Elymus*-dominated stands, with 28 and 69 confined species, respectively. The low species diversity in the *Ammophila*-dominated stands is incongruent with the results achieved by Zaharan & Willis (1992) and Amer et al. (2020) in unstable maritime oolitic sand dunes receiving sea spray and characterized by poor nutrient content.

The chorotype analysis (Table 2) showed the co-dominance of bi-regionals (44%) with mono-regionals (37.1%). Contradictory results were reported by Amer et al. (2020) in a more western site (Sallum sector), where mono-regionals were the dominant chorotype. Despite this, these oolitic sand dunes still harbor higher percentages of mono- and bi-regional Mediterranean elements (57.7%, Table 2); this unique composition increases these sites' importance as model areas for future studies of climate change and highlight an urgent need for protection. Amer et al. (2020) and Amer & Elshayeb (2020) reported that the percentages of these chorotypes decreased westward in the Sallum sector, which had 21.2 and 5% of the same chorotypes, respectively. In addition to the decline of Mediterranean elements and the northward expansion of xeric species, temperature rises and rainfall demises have also had an effect over the last 10 decades.

Soil traits were the main factor controlling the species' spatial distribution in the studied habitats; oolitic psammophytes (*Ammophila arenaria* & *Elymus farctus* stands) grow in habitats with poor nutrients and organic carbon (Zahran et al., 1996; Galy, 2006). There was a minor difference between stands: the *Elymus* stands were characterized by higher organic carbon compared to the *Ammophila* stands. This result is incongruent with those reported by Abdelaal (2019) and Amer et al. (2020).

The CCA biplot illustrated that *Elymus*-associated species were linked with silt and clay, and higher organic carbon, which were co-dominant with annuals such as *Senecio glaucus* subsp. *coronopifolius*, *Picris asplenioides*, *Anchusa aegyptiaca*, *Lobularia libyca*, and *Launaea capitata*. Congruent results were previously reported by Galy (2006). The soil supporting the prevalent species in the *Elymus* stands was characterized by lower $CaCO_3$, cations, anions, and soil moisture content compared to that in the *Ammophila* stands (Table 3). This association between vegetation and soil variables is in agreement with the findings of Barbour et al. (1985) and Zahran et al. (1996), the latter of which claimed that $CaCO_3$ is an important indicator for the distribution of psammophytes in the western Mediterranean coastal sand dunes, which reached up to 96%. The nutrients in the habitats of coastal sand dunes are poor, and plant productivity is limited by both nitrogen and phosphorus (Frosini et al., 2012).

The results of the current study suggest that the harm to the coastal dunes caused by the construction of summer resorts and any other land utilization in the Mediterranean must be reduced or stopped to conserve the biota of the ecosystem, especially plants and vegetation, including many unique, endemic, and nearly endemic species.

Conflict of interests: The authors declare no conflict of interest.

Authors contribution: A.T. Soliman, Wafaa Amer and Azza Hamed conceived the original ideas and designed the field trips; collecting the data. The manuscript was written by A.S., W.A. and A.H.; A.T. and A.H. did the data acquisition; A.S. and A.H. analyzed the data; A.S. revised the manuscript and corrected the reviewers' requisites. A.S., W.A. and A.H. participated in the final form.

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التركيب الفلوري للأنواع النباتية المهددة بالانقراض في مناطق الكثبان الرملية الساحلية بمصر

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تقع مصر في الحزام الجاف مع ساحل البحر الأبيض المتوسط شبه القاحل. وتمتد الكثبان الرملية الساحلية المميزة للمنطقة بموازاة البحر من الإسكندرية غربًا إلى مرسى مطروح. هذا الموئل يتميز بتكوين فلوري فريد يختلف كلية عما ينمو في المناطق التي تحدوه جنوبًا. في الآونة الأخيرة، تتعرض موائل الكثبان الرملية الأوليتية لتهديد شديد بسبب التوسع العمراني والحضري وتغير المناخ العالمي، وقد أدى ذلك إلى انخفاض ملحوظ في التكوين الفلوري وندرة الأنواع النباتية. تهدف الدراسة الحالية إلى تقييم الغطاء النباتي لنباتات الكثبان الرملية الأوليتية. وقد أسفرت الدراسة أن فلورة المنطقة التي تم مسحها تتكون من 116 نوعًا من النباتات الزهرية (تنتمي إلى 91 جنسًا في 27 عائلة نباتية)، وتشكل النباتات الحولية حوالي 47.4%، وقد سجلت النباتات المعمرة 40.5%. ومما هو جدير بالذكر أن التحليل الوقتي chorotypes أظهر هيمنة عناصر البحر الأبيض المتوسط (سواء كانت أنماط أحادية أو ثنائية أو متعددة الإقليمية والتي سجلت حوالي 64.7% من العدد الإجمالي للأنواع). وقد أظهرت الدراسات التحليلية للتربة العلاقة بين التركيب السائد للأنواع ومتغيرات التربة وأنها تأثرت إيجابيا بمحتوى كربونات الكالسيوم والكربون العضوي، وتأثرت سلبيا بمحتوى الرمل والطين وأيونات الكلوريد وأن هذا يتحكم في توزيع الأنواع النباتية في منطقة الدراسة. وقد أظهرت الدراسة تدهور الموائل الأوليتية نتيجة لبناء المنتجعات والتوسع الحضري عن انخفاض حاد في الغطاء النباتي والنباتات في المنطقة، ويجب إيقاف هذا التوسع.