On The Ecology of some Halophytes and Psammophytes in the Mediterranean Coast of Egypt

M.A. Zahran, K.J. Murphy, I.A. Mashaly, Khedr, A.A.*

Synopsis

The present investigation was carried out on some halophytes and psammophytes in the Mediterranean salt marshes and sand dunes by studying their distribution and response to the prevailing environmental factors.

Vegetation and soil were sampled in 87 stands representing the selected species. Relative frequency, Relative density and Relative cover were determined for each perennial species and were added to provide an estimate of its importance value.

Two-way indicator species analysis (TWINSPAN) was used in classification of the stands into 7 defined groups in terms of importance values of plant species.

Detrended correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were used to study species-environment relationships.

The distribution of the selected halophytic species was best correlated along the gradient of most studied soil variables. Calcium carbonate correlated strongly with the second ordination axis. It was important predictor of psammophytic species distribution.

Introduction

In Egypt the desert vegetation is by far the most important and characteristic type of the natural plant life. It covers vast areas and is formed mainly of xerophytic shrubs and undershrubs. Salt marsh vegetation is the second most important type of vegetation in Egypt and is mainly formed of halophytes. Sand dune vegetation is both coastal and inland. Along the Mediterranean Sea psammophytes are frequent on the higher and smaller dunes. Fixation of such dunes is a pressing need to reduce the erosion of the shore.

Phytosociological units within the vegetation have in the past been determined subjectively taking into account the physiognomy of the vegetation, the dominant species and their associates e.g. (KASSAS, 1953; MIGAHID & AYYAD, 1959; TADROS & EL-SHARKAWY, 1960; BATANOUNY, 1964; KASSAS & ZAHRAN, 1967, 1971; MIGAHID et al., 1971; GIRGIS, 1972; ZAHRAN et al., 1985; BRONKAMM, 1986, 1987; BRONKAMM and KHEHL, 1990).

However, objective methodology and quantitative procedures are being increasingly used to determine vegetational units using techniques involving classification and ordination. As yet there have been relatively few investigations in Egypt (ABDEL RAZIK et al., 1984; SPRINGUEL, 1990; DARGIE & EL DEMERDASH, 1991; MURPHY et al., 1993) which are based on an objective and quantitative approach to plant community analysis and there is much scope for further studies using these methods.

Comparison of variations in the composition and structure of vegetation with changes in the environment has been an informative approach in plant ecology. For example, BERGERON & BOUCHARD (1983) showed that plant communities and soils are excellent integrators of those biotic and abiotic components. They are, therefore, key elements for ecological classification especially of the complex interrelationships between those components.

In this work, on the basis of plant and soil relationships in three vegetational groups, 87 stands representing some selected halophytes and psammophytes were studied in the Mediterranean salt marshes and sand dunes of Egypt. The data were analysed using multivariate techniques which permit direct simultaneous ordination of vegetation and environmental data such as is provided by Canonical Correspondence Analysis (CCA) using the program CANOCO: (ter BRAAK, 1988).

The study area

The Mediterranean coastal land of Egypt extends from Sallum to Rafah for about 970 km. It is the narrow less-arid belt of Egypt which is divided ecologically into three sections (ZAHRAN et al., 1985): western, middle and eastern. The western section (Mariut coast) extends from Sallum to Abu Qir for about 550 km, the middle section (Deltaic coast) runs from Abu Qir to Port Said for about 180 km and the eastern section (Sinai Northern coast) stretches from Port Said to Rafah about 240 km. (Fig.1).

The remarkable features of the Mariut coast is the prevalence of ridges of soft oolitic limestone, often 20 meters or more high, extending parallel to the shore for long distances (BALL, 1939) followed by salt lagoons or salt marshes. Five main types of ecosystems may be recognised in the western Mediterranean section: sand dunes, rocky ridges, saline depressions, non-saline depressions and wadis (AYYAD & EL GHAREEB, 1984).

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* Dedicated to Prof. Dr. Reinhard Bornkamm on the occasion of his 65th birthday.

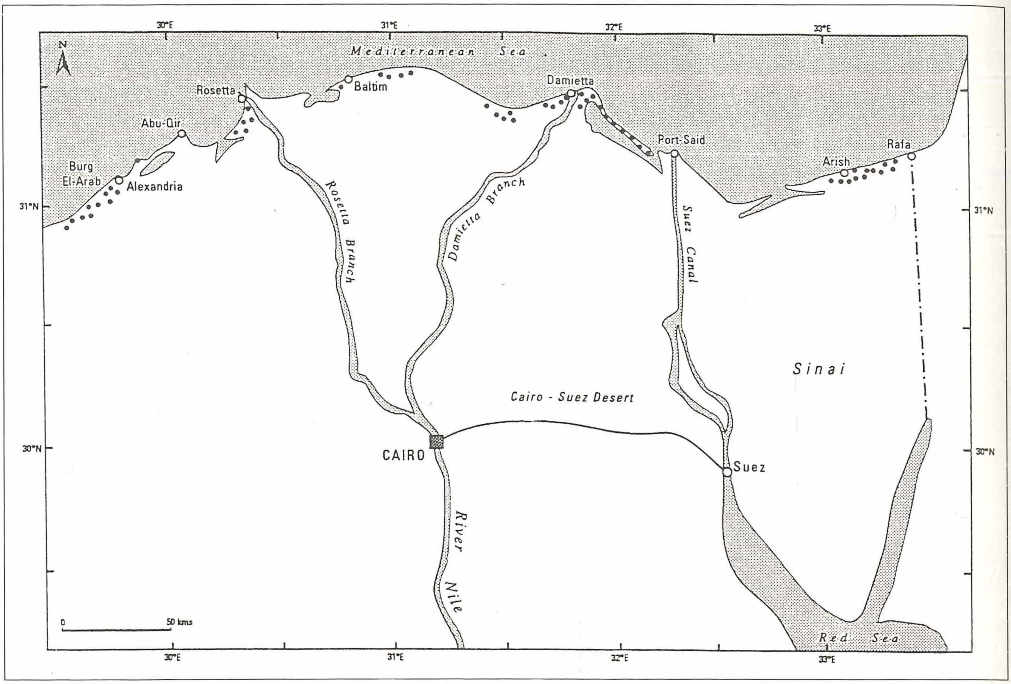

Fig. 1

A map of the Northern and Eastern part of Egypt showing the studied localities of halophytes and psammophytes (•)

The deltaic coast is built up by coarse and fine sand, silt and clay deposited by the River Nile (ABU AL-IZZ, 1971). The Main habitats are: salt marsh, sand formations, reed swamps and fertile non-cultivated land. The salt marshes extend along the whole coast and the sand formations include sand dunes and sand flats (ZAHRAN et al., 1985).

Three main habitats can be recognised in the Sinai northern coast: sabkhas (salt-affected land), sand dunes and open sand plains (ZAHRAN & WILLIS, 1992).

Although the climate of the three sections varies little, yet the vegetation is not the same. Unlike the western and eastern section, the middle one is not only affected by sea water but it is also affected by the water from the northern lakes and the Damietta and Rosetta branches of the river Nile (ZAHRAN & WILLIS, 1992).

Materials and Methods

Vegetation analysis

An extensive field sampling program was carried out during the period December 1989 to May 1991, in the salt marshes and sand dunes of the Mediterranean coast of Egypt (Fig. 1). Eighty seven stands (13 x 13 m each) were selected in salt marshes and sandy dunes to represent the investigated plant species. In each stand the vegetation was analysed quantitatively using the point-centre quarter method (COTTAM & CURTIS, 1956; AYYAD, 1970). Estimates of relative cover (RC) were obtained by applying the line intercept method using ten parallel lines distributed randomly across the stand (EL-GHAREEB & ABDEL-RAZIK, 1984) The lengths of intercept for each perennial species in the stand were then summed up and expressed as a relative value of the total length of all lines. RF, RD and RC were calculated for each perennial species and summed up to give an estimate of its importance value (IV) in each stand which is out of 300. The annual species were only recorded. Nomenclature according to TÄCKHOLM (1974).

Soil sampling and analysis

Three soil samples were taken from surface layer, (0.0–20 cm) of each stand then pooled together to form one composite sample. The soil samples were analysed physically and chemically following PIPER (1947); JACKSON (1962). Cations (Na^+, K^+, Ca^{2+} & Mg^{2+}) in soil extract were analysed using Atomic Absorption (Perkin Elmer 1100B). The method followed that of MAFF (1986). Phosphate concentration in the soil was determined by automated ascorbic acid reduction method, using a Technicon analytical system (LOBRING & BOOTH, 1973; U.S. Environmental Protection Agency 1979).

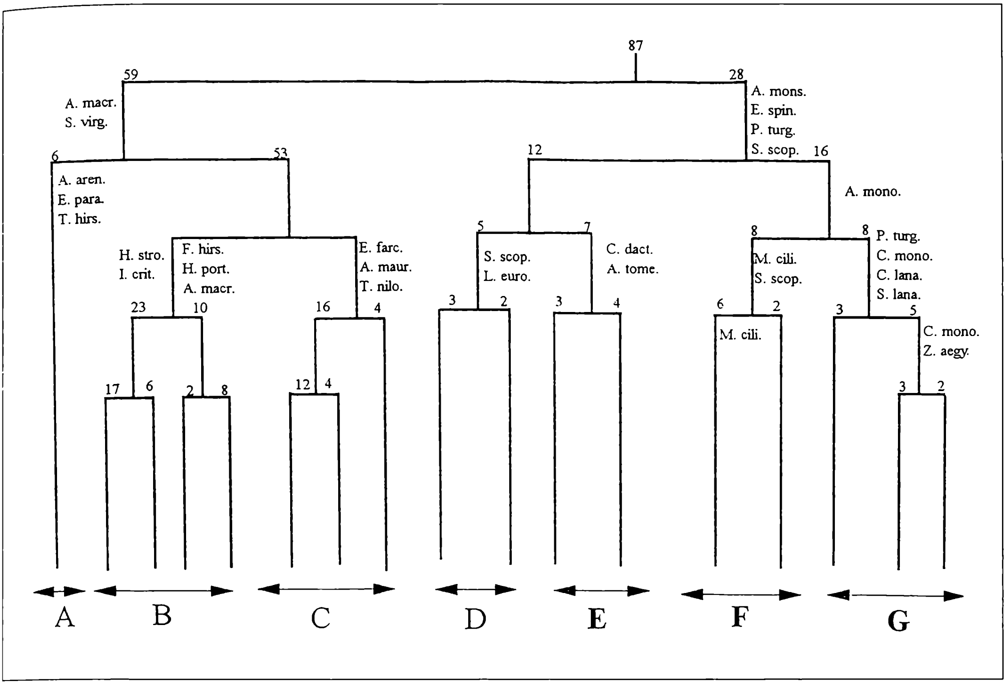

Fig. 2

TWINSPAN dendrogram of 87 stands based on importance value of some halophytes and psammophytes in the Mediterranean coast of Egypt. Indicator species names are abbreviated to the first letter of the genus and four letters of the species name.

Data analysis

Multivariate analysis

Multivariate classification of the vegetation data was carried out using the Two-Way Indicator Species Analysis (TWINSPAN), HILL, (1979a). The classification was carried out on the Glasgow University mainframe computer. IL3980 using the VME system.

TWINSPAN analysis provides an hierarchical divisive classification of the data matrix (HILL *et al.*, 1975; GAUCH, 1982). TWINSPAN classified both samples and species and constructs an ordered, two-way table which expresses succinctly the relationships of the samples and species within the data set. TWINSPAN also identifies 'indicator species'. Each species is treated as a series of 'pseudospecies', according to the abundance of that species at site.

Ordinations were carried out on IBM-compatible PC'S, using release 3.10 of CANOCO-FORTRAN programme for canonical community ordination by partial detrended correspondence analysis, principal component analysis and redundancy analysis (ter BRAAK, 1986,1987).

The option used was Canonical Correspondence Analysis (CCA). CCA produces an ordination diagram, on which points represent species and arrows represent environmental variables.

Analysis of variance

One-way analysis of variance (ANOVA) is used to test whether there are any significant differences between a set of means of soil variables representing TWINSPAN vegetational groups using Minitab computer based statistical package.

Results

Halophytes and psammophytes in the Mediterranean coast of Egypt

The main habitats of the Mediterranean coast of Egypt include salt marshes and sand dunes. Parts of the salt marshes in this area are at the sea level or slightly higher are water logged specially in winter when water table is near to the soil surface. Lower parts of this habitat support only salt tolerant halophytes ZAHRAN (1982). The sand dune communities are characterised by limited number of species as only specialised plants can grow in this habitat (psammophytes). In these two habitats some halophytes and psammophytes are restricted to salt marsh or sand dunes only; others however, are present in both habitats.

A data set of 87 stands of vegetation growing in Mediterranean salt marsh and sand dune habitats was analysed using Two Way Indicator Species Analysis (TWINSPAN: HILL, 1979a) to classify the stands into seven vegetational groups (labelled A–G in Fig. 2).

Each sample group comprises a set of stands with greater with-set homogeneity of vegetation, than when compared with other sample-groups. Each group is characterised by indicator species, identified by TWINSPAN for each group at each level of hierarchical classification. Preferential species, less clearly associated with an individual sample- group, but still useful in indicating its existence, are also identified. Table 1 lists the indicator and preferential species identified for each sample-group in terms of IV rating (maximum score: 300).

The seven sample-groups may be taken as representing seven separate vegetation types from quite distinct habitat types.

Group A: stands (n=6, from calcareous sand dunes at Burg El Arab) formed a group distinct from all other vegetation types, Fig. 2 (splitting off from the rest at level 2 to form a single homogenous sample-group). This vegetation type is characterised by abundant *Ammophila arenaria* together with *Euphorbia paralias* unlike any other group.

Group B: (33 stands) included all salt-marsh stands. This group had a diverse set of indicator and preferential species (Table 2), the most important of

Tab. 1

Means of Importance Value (IV) of indicator and preferential halophytic and psammophytic species in the different vegetational groups in the Mediterranean coast of Egypt.

Group number	**A**	**B**	**C**	**D**	**E**	**F**	**G**
No.of stands	**6**	**33**	**20**	**5**	**7**	**8**	8
Ammophila arenaria	**123.6**	–	–	–	–	–	–
Euphorbia paralias	**46.5**	–	–	–	–	–	–
Thymalaea hirsuta	**19.0**	4.0	–	35.0	–	31.0	28.0
Arthrocnemum macrostachyum	–	**137.6**	**27.2**	–	–	–	–
Sporobolus vrginicus	–	83.5	68.6	–	–	–	–
Halimione portulacoides	–	**33.9**	–	–	–	–	–
Frankenia hirsuta	–	**37.5**	–	–	–	–	–
Halocnemum strobilaceum	–	**43.4**	–	–	–	–	–
Inula crithmoides	–	**100.4**	79.7	–	–	–	–
Cressa cretica	–	31.5	36.0	–	–	–	–
Limoniastrum monopetalum	–	34.0	7.0	–	–	–	–
Juncus rigidus	–	39.0	–	–	–	–	–
Elymus farctus	6.0	–	**151.6**	102.0	–	–	–
Alhagi maurorum	–	1.0	**28.9**	98.3	48.7	–	–
Tamarix nilotica	–	27.0	21.7	–	–	–	–
Cynodon dactylon	–	25.0	8.0	–	**77.2**	–	–
Lycium europaeum	1.0	–	–	**48.7**	–	–	–
Echinops spinosissimus	–	–	6.5	44.5	149.5	6.6	1.0
Moltikiopsis ciliata	–	–	–	44.0	–	**65.8**	–
Stipagrostis lanata	–	–	74.0	8.0	–	24.7	9.0
Silene succulenta	3.5	–	–	75.5	–	–	–
Astragalus tomentosus	–	–	–	–	**43.0**	–	–
Stipagrostis scoparia	–	–	–	**30.0**	–	**38.0**	42.2
Panicum turgidum	–	–	–	–	–	13.0	**46.0**
Artemisia monosperma	–	–	–	–	–	179.4	**129.8**
Convolvulus lanatus	–	–	–	–	–	–	**11.2**
Cornulaca monocantha	–	–	–	–	–	–	**77.0**

Importance values of indicator species for each group are shown in bold.

Tab. 2
Means, standard deviation (±) and significance of variation between groups (analysis of variance between sample-groups A–G; F.ratio) for 14 edaphic variables in 7 groups of stands, distinguished by TWINSPAN from halophyte and psammophyte habitat in the Mediterranean coast of Egypt.

Group number	A	B	C	D	E	F	G	$F_{(ratio)}$
Number of stands	6	33	20	5	7	8	8	
Locality	A	D+R+A	R+A	D+B	D+R	S	S	
Fine fractions (%)	2.98	4.84	4.99	1.01	1.49	1.74	1.84	7.19*
	±1.61	±2.53	±2.91	±0.86	±0.66	±0.38	±0.50	
Moisture content (%)	1.46	10.88	1.57	1.33	0.15	0.66	0.29	8.28*
	±0.35	±9.62	±0.98	±0.63	±0.11	±0.42	±0.09	
Calcium carbonates (%)	50.5	10.92	2.57	5.40	0.97	1.38	0.50	41.64**
	±3.39	±10.55	±3.98	±6.26	±1.58	±1.53	±0.46	
Organic carbon (%)	0.28	1.04	0.51	0.89	0.45	0.25	0.26	6.27*
	±0.13	±0.68	±0.42	±0.47	±0.22	±0.06	±0.12	
Total phosphorus (ppm)	4.67	31.88	20.15	10.6	20.29	19.25	13.0	13.07**
	±1.63	±12.90	±5.90	±2.7	±5.2	±5.2	±4.6	
pH	8.30	8.04	7.52	7.70	7.24	7.55	7.36	3.95
	±7.40	±0.88	±0.36	±0.23	±0.32	±0.37	±0.17	
EC (mS cm^{-1})	0.23	4.30	1.05	0.50	0.38	0.23	0.26	13.23**
	±0.13	±2.58	±2.08	±0.19	±0.68	±0.18	±0.20	
Cl^- (%)	0.11	8.67	0.41	0.22	0.13	0.03	0.04	12.38**
	±0.12	±9.39	±0.80	±0.28	±0.25	±0.02	±0.05	
SO_4^{2-}(%)	0.05	1.08	0.19	0.11	0.05	0.02	0.06	5.62*
	±0.05	±1.15	±0.39	±0.04	±0.06	±0.01	±0.10	
HCO_3- (%)	0.04	0.05	0.03	0.04	0.01	0.001	0.02	6.24*
	±0.02	±0.03	±0.02	±0.03	±0.01	±0.001	±0.05	
Na^+ (ppm)	147.5	1366	491.9	142.8	137.6	17.1	15.9	18.61**
	±79.0	±608	±666	±104	±60	±7	±3	
K^+ (ppm)	404	429	249	48	138	14	14	8.69*
	±276	±273	±212	±33	±41	±7.2	±1.9	
Ca^{++} (ppm)	2612	2492	1027	381	285	427	251	12.76**
	±1049	1392	±981	±237	±75	±126	±144	
Mg^{++} (ppm)	100	95	71	27	35	8	11	3.7
	±67	±93	±57	±14	±7	±3	±4	

* significant at P=0.05 , ** significant at P= 0.01

A=Alexandria, D=Damietta, B=Baltim, R=Rosetta and S=Sinai.

which (measured by IV) were *Arthrocnemum macrostachyum* and *Inula crithmoides*. This vegetation type showed a close affinity to Group C: (20 stands, from foredunes and salt affected dunes), in which both halophyte and psammophyte species showed up as indicators and preferentials, some being shared with Group B (e.g. *Arthrocnemum macrostachyum)*. However, a notable distinguishing feature was the presence of *Elymus farctus*: an indicator and dominant in Group C but entirely absent from Group B stands.

All the remaining sample-groups were from psammophyte habitats. Table (2) shows that there were clear differences in plant community structure and composition, as revealed by indicator and preferential species between these 5 groups. However there were certain features in common.

Group D: (5 stands, from stabilised sand dunes) and Group F: (8 stands, from North Sinai sand dunes) showed *Stipagrostis scoparia* as an indicator species and had a number of other species in common.

Group E: (7 stands) was also from high stabilised dunes, at Rosetta, and was shown (see Fig. 2) to be subdivided from Group D only at level 3 of the hierarchical classification, dividing off on the presence of *Cynodon dactylon* and *Astragalus tomentosus* as indicators (neither being present in Group D stands).

Stands of Group D, E and F (totally 22 stands) may represent variants of a single vegetation type, typical of stabilised sand dunes.

This leaves 2 sample groups as rather different from the rest. Group G: (8 stands)was from the high sand plains of north Sinai. The indicators are xerophytic psammophyte species, two of which (*Convolvulus lanatus, Cornulaca monocantha*) are entirely absent from any other vegetation type identified in this exercise. However, Figure 2 suggests that Group G: has a certain affinity to Group F: The two groups have in common 6 species out of 9 recorded at one or the other. (see Table 2), including three which are preferential or indicator species for both groups. Geographical location (both sets of stands are from north

Tab. 3a

Results of ordination by CCA of some selected halophytes and psammophytes in the Mediterranean coast of Egypt: Eigenvalues and the species-environment correlation coefficient for the first four axes.

Parameter	Axes			
	1	2	3	4
Eigenvalues	0.793	0.732	0.408	0.303
Species environment correlation	0.932	0.919	0.776	0.694

Tab. 3b

Interset correlations of environmental variables with first four axes of CCA.

N	Soil variable	Axis 1	Axis 2	Axis 3	Axis 4
1	Fine fraction (%)	–0.131	0.570	-0.125	–0.264
2	Moisture content (%)	–0.218	0.593	0.250	0.032
3	$CaCO_3$ (%)	0.761	0.436	0.163	0.088
4	Org. carbon (%)	–0.217	0.376	0.242	–0.336
5	T. phosphate (ppm)	–0.481	0.419	0.006	0.188
6	pH	0.195	0.368	0.369	–0.297
7	EC (mS cm^{-1})	–0.301	0.688	0.259	0.016
8	Cl^- (%)	–0.289	0.705	0.273	0.037
9	SO_4^{2-}(%)	–0.278	0.660	0.255	–0.034
10	HCO_3^- (%)	–0.052	0.414	0.259	–0.141
11	Na^+ (ppm)	–0.319	0.767	0.108	0.109
12	K^+ (ppm)	0.053	0.675	0.107	0.047
13	Ca^{2+} (ppm)	0.020	0.677	0.310	0.045
14	Mg^{2+} (pm)	–0.017	0.565	0.018	0.063

Sinai), or common habitat features, or both, may explain this affinity.

In summary, the results of the TWINSPAN vegetation classification suggests that seven distinct types of vegetation may be identified. One of these (Group B) is the salt marsh type, this has some affinity with type Group C (foredunes and salt-affected dunes), but little in common with the remaining groups all of which comprised sand dune vegetation. Of these, Group A was highly distinctive, being dominated by *Ammophila arenaria*, on calcareous sand dunes.

The remainder (D–G) formed a rather noisy set of vegetation samples, but still more similar to each other than A, B, or C. Within this set, it might be argued that Group G, from north Sinai sand plains, was sufficiently different to be placed on its own. However, D, E and F, all from stabilised dunes, probably represent variants of a stabilised – dune psammophyte vegetation type.

The environmental characteristics of the habitats represented by vegetation types A–G will now be described.

Environment Interpretation of the Vegetational Groups

Soil characteristics of each of the seven sample groups identified by TWINSPAN are summarised in Table (3). Mean values of $CaCO_3$, total phosphorus, EC, Cl^-, Na^+ and Ca^{2+} content in the soil showed significant variation between groups. Moisture content, fine fractions (silt and clay), organic carbon, sulphate, bicarbonates, and potassium ion concentration were higher in the salt marsh and salt-affected dunes represented by Groups B and C than in the dune groups, (significant at $p = 0.01$). Mg^{2+} and soil reaction (pH) showed no significant variation within Groups A-G.

Group A: The calcareous sand dunes at Burg El Arab, had soils characterised by high values of $CaCO_3$, Ca^{2+} and pH, but low concentrations of organic carbon and total phosphorus.

Group B: The Mediterranean salt marsh soils were characterised by high percentage of fine fractions, moisture content and organic carbon. They had a high content of total phosphorus, high EC, and high Cl^- and high Na^+ ion concentration.

Group C: Most stands of this group occurred on foredunes which are more mobile and more or less affected by salt spray from the sea. They were characterised by relatively high percentage of fine fractions and relatively high values for total phosphorus, EC, Cl^- and Na^+.

Group D: Stands of this group were all on stabilised dunes in the middle section of the Nile Delta, and were characterised by relatively low content of $CaCO_3$ and low values for all other chemical characteristics (Table 2).

Group E: These soils, from stands located on the stabilised dunes in the western section of the Nile Delta at Rosetta, were characterised by relatively high content of phosphorus. Although the soil had low salinity, the concentrations of Na^+ and K^+ were relatively high.

Group F: located on mobile sand dunes in north Sinai, running parallel to the sea, the soils of this group had relatively high phosphorus concentrations, but exceptionally low bicarbonate content.

Group G: All stands of this group were from sand plains in north Sinai. The soils were uniformly poor in chemical characteristics.

DCA ordination

The odination diagram given by DCA is shown in Fig. 3 (a&b) for the stands and the species respectively. The major groups obtained by TWINSPAN classification are show overlaid on DCA axes 1 & 2. It is clear that group A dominated by psammophytes *Ammophila arenaria* and *Euphorbia paralias* is separated from other groups at the middle right side. On the other hand, group B which is dominated by halophytic species is separated at the upper left side of the diagram. Group C is overlapped with group B. The other groups D, E, F and G are separated on the both axes as shown in the diagram.

Canonical Correspondence Analysis (CCA) ordination

The ordination diagram produced by CCA is shown in Figure 4, The The length of the arrow represents the importance of that variable. The length is derived from the eigen value of the axes (i.e. how much the variation in the data is explained by the axis) and the interset correlation of that variable with the axis (Table 3a & b). The length and the direction of an arrow representing a given environmental variable provides an indication, respectively of the importance and direction of the gradient of environmental change, for that variable, within the set of samples measured. By dropping a perpendicular to the arrow from each „species-point" an indication is provided of the relative position of species along the environmental gradient which the arrow represents. For example, on the PO_4 arrow in Fig. 4, *Juncus rigidus* scores most highly suggesting a strong affinity for high-PO_4 soils followed by Inula crithmoides then with a group of species (*Halimione portulacoides, Limoniastrum monopetalum, Arthrocnemum macrostachyum, Cressa cretica* and *Frankenia hirsuta*) all associated with edaphic phosphate content in the mid range of the values recorded. Because it is the relative positions of species in regard to PO_4 which is of interest, it is possible to extrapolate the arrow back through the origin providing an indication of a second large group of species (*Elymus farctus, Pani-*

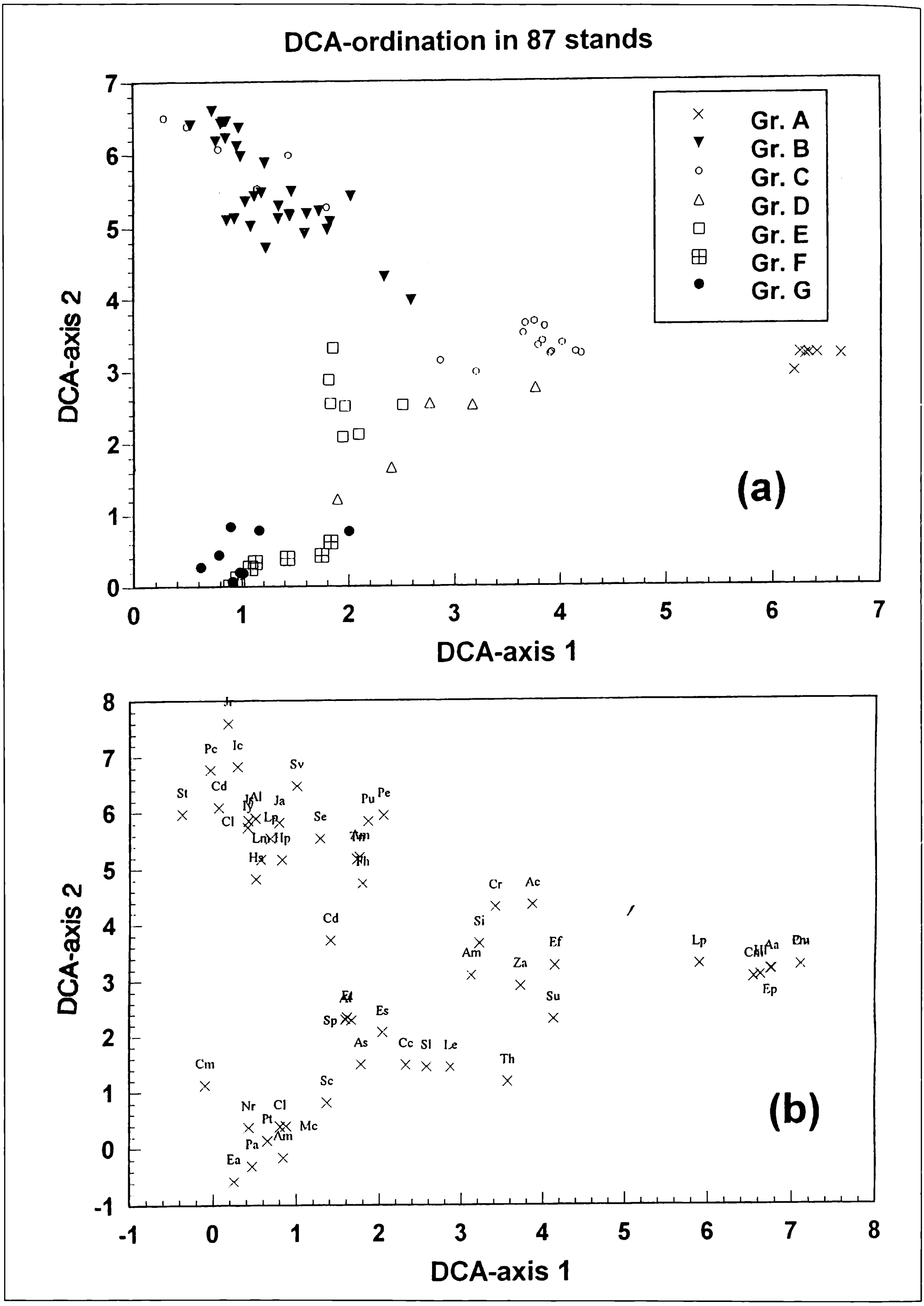

Fig. 3

(a) DCA ordination of 87 stands, with TWINSPAN groups.

(b) DCA ordination of species with the names abbreviated into the first letters of the genus and species. For complete names of the species, see the appendix.

cum turgidum and *Silene succulenta*) associated with low PO_4 and, finally, 2 species (*Ammophila arenaria* and *Euphorbia paralias*) which are associated with soils of very low phosphate content. Cross referencing to Table (2) shows that soils of Group A (of which these species are indicators) had the lowest mean PO_4 content of 4.67 ppm ± 1.63.

Similar comparisons make it clear that the halophytic species *Juncus rigidus, Limoniastrum monopetalum, Arthrocnemum macrostachyum, Halimione portulacoides, Inula crithmoides, Cressa cretica*, and *Frankenia hirsuta* are all found in the habitats with the highest concentration of Na^+, Cl^-, SO_4-, EC, Mg^{2+}, K^+, Ca^{2+} and moisture content in the soil.

The psammophytes *Ammophila arenaria, Euphorbia paralias, Elymus farctus, Silene succulenta* and *Alhagi maurorum* occur in habitats with intermediate concentrations of the above elements in the soil. This may be attributed to the effect of the nearby Mediterranean sea.

Other species *Echinops spinosissimus, Artemisia monosperma, Panicum turgidum*, and *Thymelaea hirsuta* which showed distribution both on sand dunes and desert are found at the lowest levels of Cl^-, Na^+, SO_4^{2-}, moisture content, EC, and major cations in soil.

For calcium carbonate arrow *Ammophila arenaria* and *Euphorbia paralias* occurred in soil with the highest levels and may be considered as indicators of $CaCO_3$ in the soil. *Silene succulenta, Elymus farctus, Alhagi maurorum,* and *Thymelaea hirsuta* were found in the mid range of $CaCO_3$ in the soil followed by psammophytic species *Artemisia, Panicum* and *Echinops.*

The selected halophytes are mainly found at low level of $CaCO_3$ in the soil.

Discussion

The present study is aimed at investigating the ecological characteristics and adaptation of some plants growing under different environmental conditions. For this purpose some selected plant species belonging to different ecological groups were chosen: halophytes and psammophytes.

Although the number of halophytes in Egypt is low, with 80 terrestrial plant species from 17 families (BATANOUNY & ABO-SITTA, 1977; ZAHRAN, 1982), they constitute the vegetation of extensive areas in the country.

Psammophytes are sometimes classified under xerophytes due to the extreme edaphic and climatic conditions prevailing in their habitats but hydroecological studies on sand dune vegetation reveal that the sand dune plants differ in their water ecological behaviour from both halophytes and xerophytes (ZOHARY & FAHN, 1952). Psammophytes have highly specialised growth forms and many have the ability to elongate vertically on burial with sand (GIRGIS, 1973)

Appendix 1:
List of perennial plant species present at sites sampled.

1-*Artemisia monosperma* Del.
2-*Atractylis carduus* Forssk.
3-*Cornulaca moncantha* Del.
4-*Cyperus capitatus* Vand.
5-*Echinops spinosissimus* Turr.
6-*Eremobium aegyptiacum* (Spreng.) Asch.
7-*Moltkiopsis ciliata* (Forrsk.) Johnst.
8-*Nitraria retusa* (Forssk.) Asch.
9-*Stipagrostis lanata* Forssk.
10-*Stipagrostis scoparia* (Trin. et Rupr.) deWinter
11-*Panicum turgidum* Forssk.
12-*Plantago albicans* L.
13-*Thymelaea hirsuta* (L.) Endl.
14-*Zygophyllum aegyptium* L.
15-*Convolvulus lanatus* Vahl.
16-*Cynodon dactylon* L.
17-*Elymus farctus* (Viv.) Runem. ssp. junceum.
18-*Polygonum equisetiforme* Sibth. & Sm.
19-*Alhagi maurorum* Medic.
20-*Asparagus stipularis* Forssk.
21-*Ammophila arenaria* (L.) Link.
22-*Crucianella maritima* L.
23-*Asphodelus microcarpus* Salzm. & Viv.
24-*Echinops tackholmiana* Amin.
25-*Euphorbia paralias* L.
26-*Hyoseris lucida* L.
27-*Lycium europium* L.
28-*Lotus polyphyllos* Clarke
29-*Ononis vaginalis* Vahl.
30-*Pancratium maritimum* L.
31-*Saccharum spontaneum* L. *v. aegyptiacum* (Willd.)
32-*Silene succulenta* Forssk.
33-*Arthrocnemum macrostachyum* (Del.) Ung.-Sternb.
34-*Halimione portulacoides* (L.) Allen.
35-*Conyza dioscoroides* (L.) Desf.
36-*Cressa cretica* L.
37-*Cyperus laevigatus* L.
38-*Frankenia hirsuta* L.
39-*Halocnemum strobilaceum* (Pallas) M. Bieb.
40-*Inula crithmoides* L.
41-*Imperata cylindrica* (L.) Beauv.
42-*Juncus acutus* L.
43-*Juncus rigidus* C.A. Mey.
44-*Juncus subulatus* Forssk.
45-*Limoniastrum monopetalum* (L.) Bioss.
46-*Limonium pruinosum* (L.) Ktze.
47-*Phragmites australis* (Cav.) Trin. ex Steud.
48-*Plantago crassifolia* Forssk.
49-*Sporobolus virginicus* (L.) Kunth.
50-*Sporobolus spicatus* (Vahl.) Kunth.
51-*Salsola tetrandra* Forssk.
52-*Suaeda vera* Forssk.
53-*Tamarix nilotica* (Ehrenb.) Bge
54-*Echium sericeum* Vahl.
55-*Astragalus tomentosus* Lam.

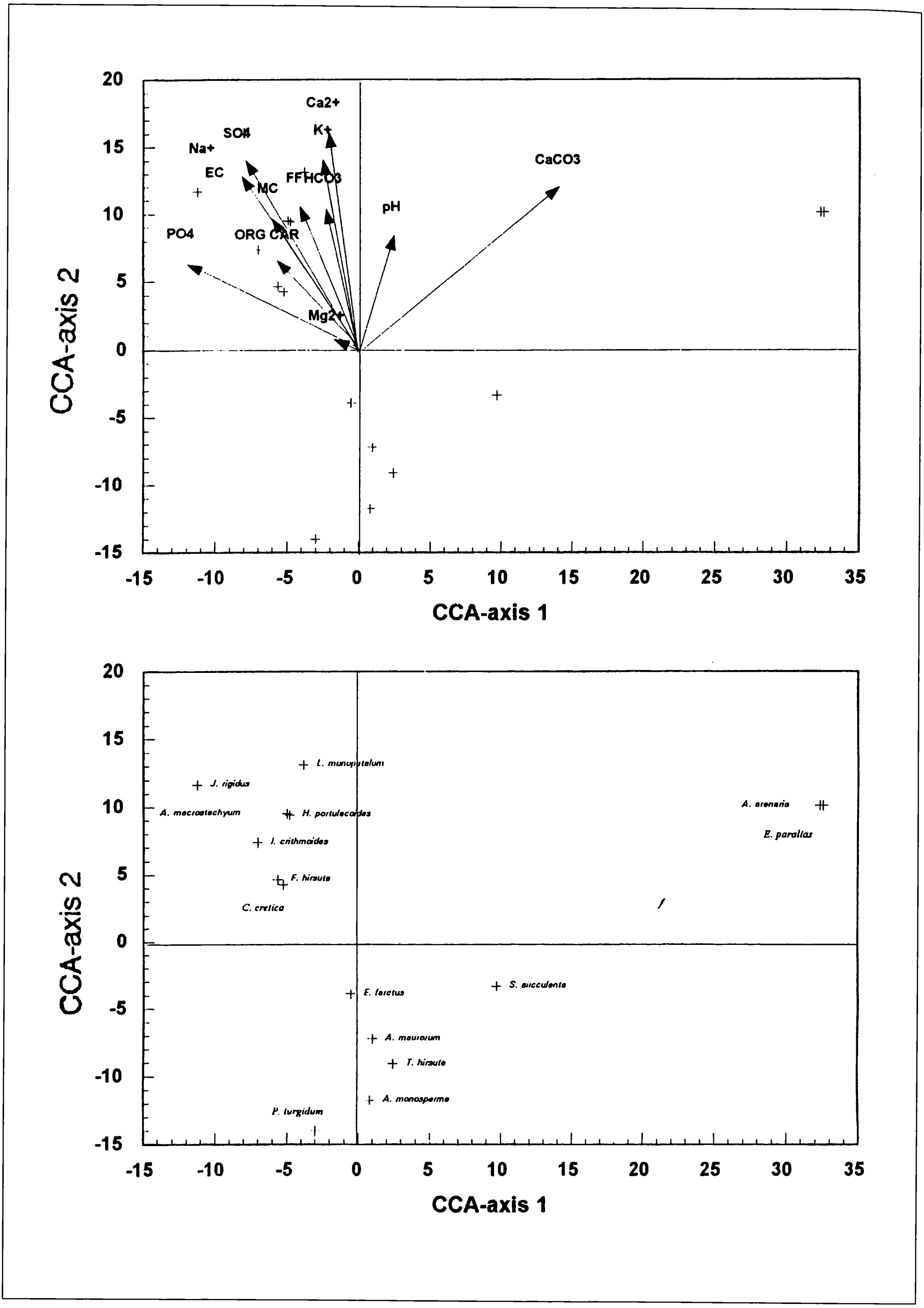

Fig. 3

(a) DCA ordination of 87 stands, with TWINSPAN groups.

(b) DCA ordination of species with the name abbreviated into the first letters of the genus and species. For complete names of the species, see the appendix.

They are also adapted to survive partial exposure of their underground organs without serious effect.

TWINSPAN classification of halophytes and psammophytes

The use of TWINSPAN program has proved useful in classifying halophytic and psammophytic species coinciding with topographic variations. It resulted in identification of 7 vegetational groups at level 3 of the TWINSPAN classification (Fig.2). Each group comprises a number of stands which are similar in terms of vegetation and characterised by a number of indicator and/or preferential species.

Six stands forming Group A of TWINSPAN-analysis are separated and are different in terms of vegetation. This represents the calcareous sand dunes, the soils of which are rich in $CaCO_3$ and Ca^{2+}, and have high pH. The indicator species of this group are *Ammophila arenaria, Euphorbia paralias* and *Thymelaea hirsuta.*

A. arenaria and *E. paralias* are characteristic of „young" calcareous sand dunes (EL GHONEMY, 1973; AYYAD & EL GHAREEB, 1984). However, in the more advanced stages of dune stabilisation T. hirsuta is more common (AYYAD, 1973).

The halophytes: *Arthrocnemum macrostachyum, Halimione portulacoides, Frankenia hirsuta, Cressa cretica, Inula crithmoides* and *Halocnemon strobilaceum* are indicator species of TWINSPAN Group B. This was associated with high values of Cl^-, SO_4^{2-}, EC, organic carbon and cations in the soil. Generally, halophyte communities world-wide were observed to exhibit large vegetational zones mainly interpreted as a results of salinity and water gradient (CHAPMAN, 1974).

The early stages of dune formations are unstable and their soils are loose, poor in nutrients and probably saline. These were represented by TWINSPAN Group C, and characterised by *Elymus farctus* as indicator species growing with some halophytes (preferential species) e.g. *Arthrocnemum macrostachyum* and *Inula crithmoides.*

Elymus farctus was recorded as dominating foredunes in the Nile Delta (EL-GHAREEB & REZK, 1989) and other countries CHAPMAN (1976) in Europe; GIMINGHAM (1964) in Britain and SYKES & WILSON (1989) in New Zealand.

The psammophytes of Group E form a number of stands on fixed dunes at the end of the Rosetta branch of the River Nile. The indicator species are *Astragalus fruticosum* and *Cynodon dactylon.* The soil was sandy and poor in nutrients.

The other two TWINSPAN groups (F and G) are separated in the eastern part of Egypt at Sinai sand dunes. Both are nearly similar in terms of vegetation, however, the separation into two groups may be due to variation in soil, slope, exposure and elevation above sea level. The indicator species of group F are *Moltkiopsis ciliata* and *Stipagrostis scoparia* which dominate the more advanced stages of dunes. In group G, the indicator species are psammoxerophytes (*Panicum turgidum, Cornulaca monocantha, Stipagrostis lanata* and *Convolvulus lanatus*) which dominate the leeward of the dunes. Their separation is in accordance with KASSAS (1955b), who mentioned that the inland sand dunes of the Mediterranean coastal area of Sinai may be formed by the accumulation of sand on desert mountains. Preferential species in the two groups are *Artemisia monosperma* and *Thymelaea hirsuta.*

CCA ordination of the selected halophytes and psammophytes along the gradient of environmental variables

The most evident correlations appear from the diagram of the first and second ordination axes (Fig.4). The expected correlations among the environmental variables (the arrows of $CaCO_3$, pH, Ca^{2+} and K^+) is quite obvious. The rest of environmental variables EC, Cl^- and SO_{4^-} are correlated on the other side of the diagram.

Well marked correlation between species along the gradient of environmental variables are clear. Psammophytic species *Ammophila arenaria* and *Euphorbia paralias* are at high concentration of $CaCO_3$, in the soil and low concentration of cations, EC, Cl^-, SO_{4^-} and PO_4^{3-}. The behaviour of these species was the same on sand dunes in New Zealand (SYKES & WILSON, 1989) and grow under low nutrient conditions (WILLIS et al., 1959a, 1959b; WILLIS & YAMM, 1961; RANWELL, 1972). The nutrient input to dunes is mostly via salt spray (ART et al., 1974). It was suggested by REZK (1970) that *Ammophila arenaria* requires a high percentage of $CaCO_3$ in the soil and low salinity. *A. arenaria* on dunes exhibits high levels of phenotypic flexibility, growth in a range of environments indicating that plants from foredune populations are higher 'responders' than those from mature dunes (GRAY, 1985). It showed distinctly lower abundance on the stable dunes than active dunes . The reverse was true for *E. paralias*, this is in accordance with KAMAL (1982). *Silene succulenta* is found at intermediate levels of $CaCO_3$ in the soil and low levels of all environmental variables.

Elymus farctus is recorded to dominate on foredunes and early stages of dune formation which are less stable and their soil loose, poor in nutrients and probably affected by salt marsh. It is correlated with intermediate concentrations of $CaCO_3$, cations, anions and moisture content in the soil.

E. farctus has considerable resistance to salinity and considered as a facultative halophyte (BARBOUR, 1970; ROZEMA et al., 1983; BARBOUR et al., 1985). *E. farctus* has the ability of dune fixation and of furnishing a less hostile habitat for other species e.g. *Echinops spinosissimus, Artemisia monosperma, Alhagi maurorum, Thymelaea hirsuta* and *Silene succulenta* which become more and more common until they dominate the stable dunes. *E. farctus* is considered as the pioneer of psammophere (EL-GHAREEB & REZK, 1989).

Alhagi maurorum showed a wide distribution nearly in all phytogeographical regions in Egypt (KASSAS, 1955a; ZAHRAN, 1982). It is recorded to dominate some parts of sand dunes in the present study with low nutrients in the soil. *Thymelaea hirsuta* is recorded as halophyte, psammophyte and xerophyte in the present study, the wide ecological amplitude of this species was correlated nicely along the gradient of environmental variables in all habitats (Fig.4).

Echinops spinosissimus is recorded to dominate the stabilised sand dunes with low nutrients and low moisture content in the soil.

Artemisia monosperma and *Panicum turgidum* are xerophytic psammophytes with wide ecological distribution on sand dunes in north Sinai and sandy desert in Egypt. The distribution of the two species along the gradient of environmental variables showed their soils are poor in nutrients; physical characteristics of sand and/or climatic factors may be the main factors affect their growth and distribution.

It is clear that all halophytes have relatively high ability to grow and dominate in habitats with relatively high concentrations of cations, anions, EC and moisture content. However, the response of halophytes to edaphic factors are different as shown in Fig (4). Juncus rigidus, *Arthrocnemum macrostachyum, Halimione portulacoides* and *Inula crithmoides* are recorded at high concentrations of EC, Cl^-, SO_{4^-}, Na^+, organic carbon, fine fractions and high moisture content in the soil. On the other hand Frankenia hirsuta and *Cressa cretica* grow in soil with low moisture content. Both are considered among dry salt marsh habitats in the Mediterranean coast of Egypt (MASHALY, 1987; ZAHRAN et al., 1989).

The halophytes are largely determined by moisture gradient (CHANG & GAUCH, 1986; DAY et al., 1988), salinity and moisture content (WINTER, 1990), salinity, ground water table and moisture content (CORRIE, 1985).

The nature of the work reported here was such that rather than describing precisely how environmental factors have affected the distribution of plant species in different ecological groups, it showed how environmental factors are related to plant species distribution.

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Addresses

Zahran, M.A.
Mashaly, I.A.
Department of Botany, Faculty of Science, Mansoura University, Mansoura, Egypt

Murphy, K.J.
Department of Botany, School of biological Science, Glasgow University, Glasgow, UK.

Khedr, A.A.
Department of Botany, Faculty of Science at Damietta, Mansoura University, Damietta, Egypt

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