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Vegetation composition of Egyptian inland saltmarshes

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Abstract. The vegetation-environment relationships in the inland saltmarshes of two geographically distant oases of the Western Desert of Egypt, Siwa, and Dakhla Oases, are described. Two data sets (25 species × 68 stands for Siwa Oasis and 29 species × 89 stands for Dakhla Oasis) were analysed, using multivariate procedures, i.e., two-way indicator species analysis (TWINSPAN), detrended correspondence analysis (DCA), and detrended canonical correspondence analysis (DCCA), to produce a classification of plant communities in the studied areas, and to examine the relationships of these plant communities to certain edaphic factors, namely soil reaction, total soluble salts, calcium carbonate, organic matter, moisture content, and fine fractions. Twelve halophytic plant communities linked to two main habitats (wet-moist and dry-mesic) were identified. *Alhagi graecorum, Tamarix nilotica, Cressa cretica, Juncus rigidus* and *Phragmites australis* were the most common in the two oases. Whereas communities of *Cyperus laevigatus, Suaeda aegyptiaca, Suaeda vermiculata, Typha domingensis,* and *Aeluropus lagopoides* are recorded from the Dakhla Oasis, *Cladium mariscus* and *Arthrocnemum macrostachyum* communities are recorded from the Siwa Oasis. The most important edaphic variables affecting the distribution and structure of the plant communities are salinity, moisture content and fine fractions, nevertheless $CaCO_3$ content seems to be more effective in the Dakhla Oasis. A new agricultural strategy that minimizes the increase of salinized lands is called for.

Keywords: Egypt; Halophytes; Multivariate analysis; Oases; Phytosociology; Saltmarsh vegetation; Secondary salines.

Introduction

Saline lands are widely distributed globally and make up about 10% of the Earth's terrestrial surface (O'Leary and Glenn, 1994). Compared to studies of coastal marshes, little attention has been paid to inland saline landscapes (Adam, 1990; Krüger and Peinemann, 1996). The inland saltmarshes of the Egypt's Western Desert are found in the form of Sabkhas (Zahran, 1982) around the lakes, springs and wells of the oases, e.g., Siwa, Dakhla, Kharga, Bahariya and Farafra, and depressions, e.g., Qattara, Wadi El-Natrun, and El-Faiyum (Figure 1). Being lower in altitude than the surrounding territories, the inland saltmarshes are characterized by a shallow underground water table. In certain instances, the underground water is exposed, forming lakes of brackish or saline water (Zahran and Girgis, 1970; Zahran, 1972). The formation of these salines is due to the uncontrolled spilling of water and flooding of the plains or to the water table, which is near to the ground (Migahid et al., 1960). Under the severe arid conditions of the oases and the lack of a drainage system, flooding of the soil with slightly saline artesian water rapidly increases its salinity. In contrast to the littoral saltmarshes, these salines can be considered as secondary. The vegetation has a patchy structure, with different patches containing different species (or sometimes one species) and even different growth forms (Abu-Ziada, 1980; El-Hadidi, 1993). Despite the low number of halophytes in Egypt, with 80 terrestrial plant species from 17 families (Batanouny and Abo Sitta, 1977), they constitute the principal vegetation of extensive areas in the country. The halophytic flora is poor, being composed mainly of perennial grasses, rushes, (dwarf-) shrubs, and some annuals which are associated with saline environments, e.g., *Frankenia pulverulenta* L., *Lotus corniculatus* L., *Solanum nigrum* L., *Asphodelus tenuifolius* Cav., *Bassia muricata* (L.) Asch., *Anagallis arvensis* L. (s.l.), *Conyza bonariensis* (L.) Cronquist and *Ambrosia maritima* L.

Although the autecology, synecology and ecophysiology of several coastal saltmarshes of the Western Desert have been dealt with in a large number of publications (e. g. Ayyad and El-Ghareeb, 1974, 1982; Fahmy, 1986; Shaltout and El-Ghareeb, 1992; Zahran et al., 1996), studies identifying the major environmental factors associated with vegetation patterns in the inland saltmarshes are scarce. What studies there are have attempted to elucidate, by various means, factors causing the differences in communities both within and between marshes. However, objective methodology and quantitative procedures have been applied in the present study using techniques involving classification and ordination. Recently, some studies in different parts of Egypt (Abd El-Ghani, 1998, 1999; Dargie and El-Demerdash, 1991; Moustafa and Zaghloul, 1996; Shaltout et al., 1995; Springuel et al., 1997), based on a multivariate approach to plant community analysis, were carried out.

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By the beginning of the 21st century, the plant life in the oases of Egypt will have completely changed: about 500,000 acres are expected to be reclaimed and cultivated after transferring the Nile water to these areas through the Toschka canal from Lake Nasser (South of Aswan on the Nile Valley) to Kharga Oasis, and ending in Farafra Oasis in the Western Desert. The purpose of this study is to document and describe the plant species composition of the inland saltmarshes in two geographically distant oases of the Western Desert of Egypt and to relate the species distribution patterns to some soil factors.

Study Areas

The two study areas are separated by a distance of about 600 km in a NW-SE direction (Figure 1). The Siwa Oasis is located in the northern part of the Western Desert of Egypt, some 65 km east of the Libyan frontier and 300 km south of the Mediterranean coast. It is limited by the longitudes 25°18’ - 26°05’E and the latitudes 29°05’- 29° 20’N. Groundwater is one of the Siwa Oasis’ most valuable resources. It is tapped from the Miocene fractured limestone through ca. 150 springs and flowing wells (total discharge is at least 200,000 $m^3 day^{-1}$). The water of Siwa springs is warm, varying between 26.5°C and 30°C. However, due to misuse of groundwater, a continuous rise of the level of subsoil water has been widespread. According to Misak et al. (1997), in 1962-1977 the rate of rise was 1.33 cm $year^{-1}$ while in 1977-1990 it measured 4.6 cm $year^{-1}$. Consequently, extensive patches have been converted into salt marshes as soils are subjected to deterioration and salinization. The oasis floor is below sea level, ranging from zero to -18 m, and displays numerous landscapes including salt marshes (*Sabkhas*), salt lakes, and cultivated lands (orchards). The bounding uplands are represented by the northern tableland (up to + 150 m) and the southern sand dunes (up to + 80 m). The climate exhibits extreme aridity with very low rainfall (average of 9.6 mm $year^{-1}$), high evaporation (17 mm day^{-1} in July to 5.2 mm day^{-1} in December) and high summer temperature (maximum 37.7°C in July). Intermittent floods, originating from the northern tableland, take place once every several years. During the last 60 years, floods have occurred in 1928, 1985 and 1987.

The Dakhla Oasis is located ca. 120 km west of the Kharga Oasis and about 300 km west of the Nile Valley, between longitudes 28°48’- 29°21’E and latitudes 25°28’ - 25°44’N. Nubian formations include porous sandstones that carry water to a hydrostatic head of about 120 m. The artesian groundwater is discharged to the surface through springs, shallow wells and modern deep wells in which the depth ranges from 300-1,220 m (Himida, 1966). A serious drop in the groundwater pressure of the existing wells, and a consequent drop in the discharge of the flowing wells, has been emphasized (Abu-Ziada, 1980). The lowest point of Dakhla Oasis is about 100 m above sea level, and its surface rises gradually towards the rim. Altitudes range from 110 to 140 m above sea level. Geological evidence indicates that a deposit of potential economic value of the lower phosphatic horizon exists at the south-east corner of Abu-Tartur plateau, at depths ranging from 150-250 m. Said (1962) reports also the occurrence of a number of mineral substances, including fibrous crystalline forms of ochre, bayrates, and epsomites. As to climate, the Dakhla Oasis belongs to the rainless part of Egypt. The hottest months are June, July, and August (with a mean maximum temperature of 37.7°C). The coldest month is January (with a mean minimum temperature of 4.0°C). The evaporation rate is the highest in June (24.8 mm day^{-1}) and lowest in January (7.7 mm day^{-1}).

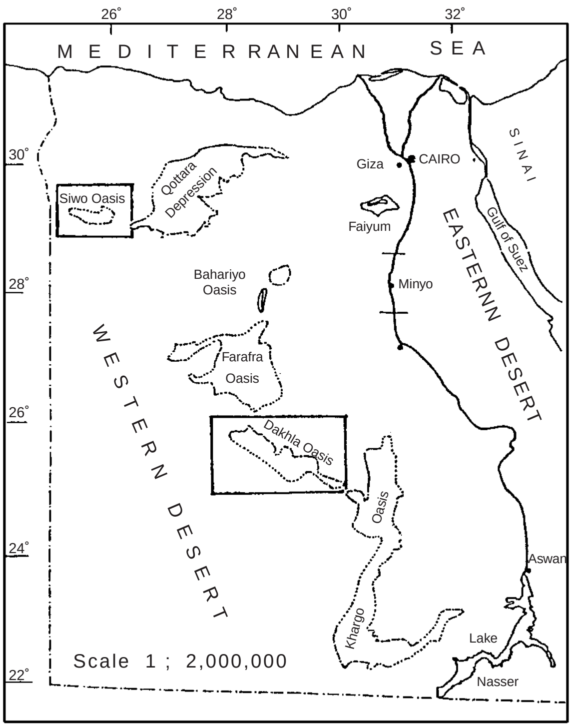

Figure 1. Location map of the study areas.

Materials and Methods

Data Collection

In total 157 stands, each 10 × 10 m and approximating the mean minimum area of the prevailing plant communities, were selected from sites representing the inland saltmarshes in the study areas (68 in Siwa and 89 in Dakhla). The first stand was located at least 50 m from the edge of the marsh, and the other stands were randomly distributed. In each stand, a reasonable degree of homogeneity was ensured. Within each stand, species present were recorded. Taxonomic nomenclature followed Täckholm (1974), updated by Boulos (1995, 1999). Plant cover was estimated quantitatively by the line intercept method (Canfield, 1941). For this purpose, 10 parallel lines each 10 m long were laid out in each stand. The cover data were transformed using a nine-point scale: 1=5-15, 2=16-25, 3=26-35, 4=36-45, 5=46-55, 6=56-65, 7=66-75, 8=76-85, 9=86-100%.

For each sampled stand, three soil samples were collected at profiles 0-50 cm. Soil texture was determined with the Bouyoucos hydrometer, and the results were used to calculate the percentage of fine fractions (silt and clay). Moisture content and organic matter were determined by drying and ignition at 600°C for 3 h, and total $CaCO_3$ by Collin's calcimeter (Wright, 1939). Soil-water extract (1: 5) was prepared for the estimation of total soluble salts (TSS in mS cm^{-1}) using a conductivity meter, and of soil reaction, using a pH meter.

Data Analysis

As a classification technique, the Two-Way Indicator Species Analysis (TWINSPAN), was applied to the two data sets (25 species × 68 stands for Siwa Oasis and 29 species × 89 stands for Dakhla Oasis), using species' cover estimates; where species that covered less than 5% were excluded. TWINSPAN is a divisive hierarchical programme that uses indicator species i.e., species with clear ecological preferences, to characterize and separate the classes (Hill, 1979; Okland, 1990). All default settings were used for TWINSPAN, except for the cut levels, where nine were chosen (0, 5, 10, 30, 40, 50, 70, 80 and 90). The non-parametric Mann-Whitney test was used to compare the means of all environmental factors for the two groups separated at each split in the classification. All statistical treatments followed Zar (1984), using student SYSTAT (STUSTATW programme version 5.0; Berk, 1994)

Detrended Canonical Correspondence Analysis (DCCA), or direct gradient analysis (Jongman et al., 1987), combined with calculation of t-values associated with the regression coefficients and a Monte Carlo permutation test (99 permutations) for the significance of the first canonical axis (*p*-value at 0.01-significance level), was used to ordinate vegetation with the environmental variables. Detrending-by-polynomials (ter Braak and Prentice, 1988) was used to correct the non-linear dependence between axes. The computer program CANOCO 3.12 (ter Braak, 1988, 1990) was used for all ordinations and the plots were drawn by CANODRAW 3.0 (Smilauer, 1993).

Results

In general, it was possible to distinguish two habitats in which the plant communities were combined: (a) wet-moist group and (b) dry-mesic group.

Classification of the Vegetation

Twenty-five plant species (after excluding species < 5% cover and single appearances) were recorded in Siwa Oasis. Based on the TWINSPAN outcome, Figure 2 was elaborated. The TWINSPAN analysis divided the stands into seven vegetation clusters, each cluster representing a specific plant community according to the most abundant characteristic species that reached the highest

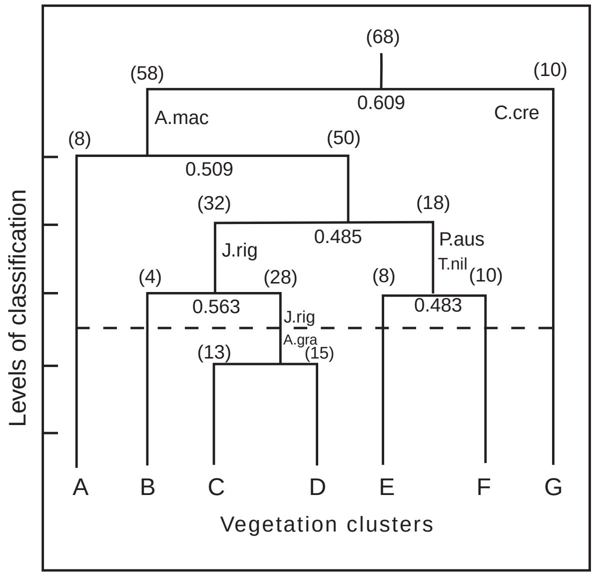

Figure 2. Dendrogram of the 7 vegetation clusters of the Siwa Oasis inland saltmarshes generated after the application of TWINSPAN classification technique. For indicator species abbreviations, see Appendix.

cover values. These included: (A) *Arthrocnemum macrostachyum*, (B) *Cladium mariscus*, (C) *Juncus rigidus*, (D) *Alhagi graecorum*, (E) *Tamarix nilotica*, (F) *Phragmites australis* and (G) *Cressa cretica*. Some clusters had a single characteristic species (A, B and G), while the others had three to four species. Three clusters were dominated by a single species (A, C and G), of which one was restrictred to the dry-mesic habitat. No one species was recorded in all clusters. The first TWINSPAN dichotomy differentiated the 68 stands into two main groups according to soil moisture content and fine material (silt and clay) with $p = 0.003$ and 0.001, respectively. A distinct community (*Cressa cretica*) associated with the driest saline habitat was separated on the right side of the dendrogram, while the left side remained heterogeneous. At the second hierarchical level, the wet-moist group was split into two subgroups related to the same factors mentioned above, in addition to soil salinity ($p = 0.0001$, 0.004 and 0.0001 for moisture content, fine material and soil salinity, respectively). Another distinct community (*Arthrocnemum macrostachyum*) of the wettest habitat was separated. Among the relatively less wet-moist group two further subdivisions, each characterized by the presence of its own vegetation, distinguished communities that differed primarily in calcareous deposits.

In Dakhla Oasis, twenty-nine species were recorded, representing the common plants growing in almost all the inland saltmarshes. Ten communities were obtained at the fourth division of the TWINSPAN classification (Figure 3). These included: (A) *Suaeda aegyptiaca*, (B) *Aeluropus lagopoides*, (C) *Suaeda vermiculata*, (D) *Alhagi graecorum*, (E) *Cressa cretica*, (F) *Juncus rigidus*, (G) *Tamarix nilotica*, (H) *Phragmites australis*, (I) *Typha* *domingensis* and (J) *Cyperus laevigatus*. The first level in the TWINSPAN separated the stands according to the soil moisture content (p = 0.003) and fine material (p = 0.005). At the second level, further divisions corresponded to additional partitioning of the moisture content, fine material, salinity, and calcareous deposits (p = 0.002, 0.004, 0.001 and 0.003, respectively). Lower levels distinguished communities that differed in pH and all the previously mentioned soil variables.

The wet-moist communities include the *Suaeda aegyptiaca* community, which is widespread on waste land that was formerly cultivated and left fallow due to salinization. The *Suaeda vermiculata* community showed similarities to that of *S. aegyptiaca*, but with frequent record of *Juncus rigidus*. The *Juncus rigidus* community forms thickets of dense growth, with a plant cover of more than 80% on average. It dominates the saline flats in the saline-neglected land that were formerly under cultivation and represents one of the most common halophytic communities in the Dakhla Oasis. The swampy vegetation types represented by *Phragmites australis* and *Typha domingensis* occupy the wettest stands within the study area. This habitat is characterized by a rich and continuous flow of fresh or brackish water from springs or irrigated land (Zahran and Willis, 1992). Some water-loving species were recorded: *Cyperus laevigatus, Scirpus*

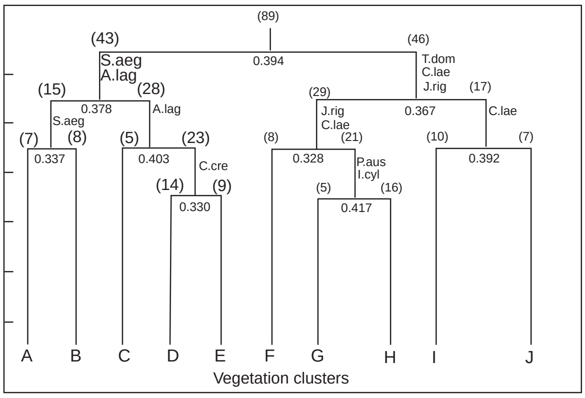

Figure 3. TWINSPAN dendrogram of the 89 stands in Dakhla Oasis inland saltmarshes. For indicator species abbreviations, see Appendix.

maritimus and *Cyperus rotundus*. The *Phragmites australis* community inhabits the shallow swamps that result from the flow of springs or drainage water, while *Typha domingensis* community forms dense growth in the deeper water fringed with *Phragmites australis* growth towards the periphery of the swamp.

The dry-mesic communities include *Aeluropus lagopoides*, which was not recorded from the Siwa Oasis and occupied the flat saline stands covered with a thin crust of salts. Whereas the *Cressa cretica* community inhabits saline fallow land with occasional deposition of sheets of sand, the *Alhagi graecorum* community occurs in sand plains overlying saltmarsh beds, and the *Tamarix nilotica* community occupies the saltmarshes with deep sand deposits. The latter plant was considered one of the climax types of the saltmarsh vegetation (Abu-Ziada, 1980). It is subjected to destructive cutting for fuel and other household purposes in almost all of the Egyptian oases. The floristic composition of the *Cressa* community is the poorest while those of *Alhagi* and *Tamarix* are the richest.

Soil-Vegetation Relationship

Soil characteristics of each of the seven vegetation clusters of the Siwa Oasis saltmarshes identified by TWINSPAN were summarized in Table 1. The mean values of the soil variables show high significant variation between clusters, except soil reaction. The ordination diagram produced by DCCA is shown in Figure 4. The length and the direction of an arrow representing a given environmental variable provides an indication, of the importance and direction of the gradient of environmental change for that variable, within the set of samples measured. The Monte Carlo permutation test showed that both the overall effect of the environmental variables on species and the first canonical axis are significant (p = 0.01). Soil salinity, organic matter, moisture content and fine material were higher in the *Arthrocnemum macrostachyum* and *Juncus rigidus* communities than in any of the other communities (significant at p = 0.0001). Both communities are established on the wettest stands of the shallow depressions and form monotypic stands with high cover values (80-90%). Whereas the *Arthrocnemum* community showed the lowest number of

Table 1. Means of the soil characteristics (± 1SD) of the stands of Siwa Oasis supporting the 7 vegetation clusters (A-G) derived after the application of TWINSPAN.

Soil variables	Vegetation clusters							F (ratio)	p
	A	B	C	D	E	F	G		
pH	7.52 ± 0.4	7.52 ± 0.3	7.61 ± 0.55	7.79 ± 0.42	7.77 ± 0.46	8.01 ± 0.33	7.43 ± 0.42	2.06	0.07
TSS mS cm^{-1}	8.24 ± 2.01	1.7 ± 0.94	6.24 ± 2.82	4.1 ± 1.48	3.62 ± 1.58	2.12 ± 0.62	2.68 ± 0.57	15.32	0.0001
$CaCO_3$ %	12.36 ± 4.04	20.35 ± 2.8	18.25 ± 7.64	16.42 ± 7.9	9.91 ± 2.75	13.01 ± 4.14	14.98 ± 2.2	3.24	0.008
OM %	4.7 ± 3.29	0.75 ± 0.87	5.07 ± 3.25	3.44 ± 2.22	2.97 ± 1.31	3.19 ± 2.25	1.88 ± 1.18	3.03	0.012
MC %	15.66 ± 6.1	2.52 ± 0.77	12.06 ± 5.03	6.84 ± 5.46	4.55 ± 1.62	10.33 ± 7.37	2.80 ± 1.44	7.67	0.0001
S + C %	16.25 ± 6.52	9.75 ± 2.5	18.31 ± 6.68	15.07 ± 4.54	12.0 ± 2.73	13.7 ± 5.49	9.3 ± 2.5	8.17	0.005

TSS = total soluble salts; OM = organic matter; MC = moisture content; S + C = silt + clay.

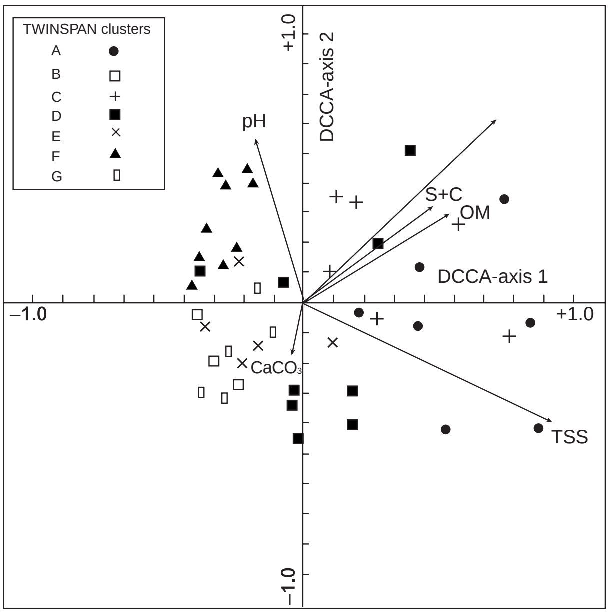

Figure 4. DCCA ordination of the first two axes showing the distribution of the stands of Siwa Oasis with their TWINSPAN clusters and soil variables.

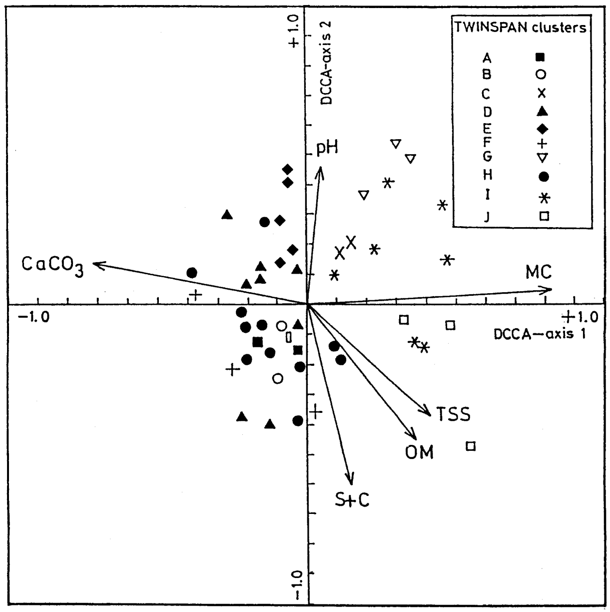

Figure 5. DCCA ordination of the first two axes showing the distribution of the stands of Dakhla Oasis with their TWINSPAN clusters and soil variables.

species, the *Juncus* community was richer. The stands of the swampy community of *Phragmites australis* were associated with high moisture content and pH and low levels of salinity. This community usually dominates the vegetation around the wells, where it forms a dense growth typical of reed swamps. It included species gowing in both wet-moist and dry-mesic conditions (e.g. *Chenopodium murale, Typha domingensis, Echinochloa colona, E. crusgalli, Sonchus maritimus* and *Frankenia pulverulenta*). The driest stands, with relatively high amounts of calcareous sediments, were occupied *by Cladium mariscus* and *Cressa cretica*. Zahran and Willis (1992) report that *Cladium mariscus* is a very rare halophyte, and its domination is recorded only in the Siwa Oasis, where it flourishes in the marshy land around the springs where the water level is very shallow (5 cm depth). We found it in the lime-rich saline flats far from the wells or at the feet of some sand dunes in the extreme western part of the oasis (Al-Maraqi area). The dry-mesic communities of *Alhagi graecorum* and *Tamarix nilotica* were associated with flat or convex plains. As a result of the high evaporation rate, a thick crust of salt on the soil surface is formed. However, soils of the dry-mesic communities were uniformly poor in environmental characteristics.

For Dakhla Oasis, a summary of soil data for each of the ten TWINSPAN clusters is presented in Table 2. This reveals a narrow spectrum of soil reaction and organic matter content. The percent of species-environment variance accounted for by the first two axes of DCCA (and their eigenvalues) are: (1) 39.8 (0.306) and (2) 21.9 (0.168). The species-environment correlations are slightly higher for the DCCA axes: 0.786 and 0.682 for axes 1 and 2, respectively. The first canonical axis primarily reflects soil moisture-lime content gradient, moisture content was most strongly correlated with this axis, and soil salinity and organic matter were also correlated. A Monte Carlo permutation test suggested that the relation between

Table 2. Means of the soil characteristics (± 1SD) of the stands of Dakhla Oasis supporting the 10 vegetation clusters derived from TWINSPAN analysis. For abbreviations and units, see Table 1.

Soil variables	Vegetation clusters										F (ratio)	*p*
	A	B	C	D	E	F	G	H	I	J		
pH	8.3 ± 0.5	7.9 ± 0.8	8.1 ± 0.5	8.1 ± 0.5	8.1 ± 0.4	8.2 ± 0.1	8.7 ± 0.3	8.0 ± 0.3	8.5 ± 0.6	7.8 ± 0.3	2.01	0.05
TSS	4.6 ± 1.5	4.3 ± 1.2	4.1 ± 1.4	2.3 ± 1.4	1.3 ± 1.4	3.2 ± 1.1	2.1 ± 0.7	2.3 ± 1.7	3.3 ± 4.0	4.7 ± 3.0	3.49	0.001
$CaCO_3$	28.2 ± 8.2	8.5 ± 3.2	15.3 ± 4.5	16.2 ± 5.5	17.0 ± 4.8	28.5 ± 7.9	13.8 ± 6.4	17.3 ± 8.8	11.4 ± 2.5	9.7 ± 4.4	8.49	0.0001
OM	1.6 ± 1.3	1.6 ± 1.1	1.2 ± 0.9	1.7 ± 1.4	1.1 ± 0.9	1.4 ± 0.6	0.3 ± 0.2	1.8 ± 1.7	1.5 ± 1.4	2.8 ± 2.5	1.58	0.134
MC	16.2 ± 5.5	6.4 ± 4.2	18.2 ± 7.1	6.5 ± 4.9	8.8 ± 6.3	17.8 ± 7.8	21.6 ± 7.9	7.3 ± 4.8	18.3 ± 7.3	20.5 ± 8.9	7.78	0.0001
S + C	13.7 ± 4.7	11.5 ± 4.9	11.6 ± 5.8	8.7 ± 5.1	6.7 ± 2.9	17.1 ± 5.9	12.8 ± 7.6	12.6 ± 4.3	9.2 ± 5.3	13.7 ± 6.2	2.70	0.008

vegetation variation and the environmental factors revealed by axis 1 was significant ($p = 0.01$). The second canonical axis reflects the gradient of soil reaction and fine fractions. Soil salinity and organic matter were inversely related to this axis (Table 2).

Inspection of the DCCA diagram (Figure 5) revealed that the *Alhagi graecorum* and *Tamarix nilotica* stands occupy more of the ordination space defined by the first two axes, while *Aeluropus lagopoides* stands occupy less. Notably, most of the wet-moist communities, except that of *Suaeda aegyptiaca*, were located in the right hand side and their stands were closely associated with pH, moisture content, salinity and fine materials. On the left hand side of the diagram, almost all the dry-mesic communities were separated. The stands of these communities were highly affected by $CaCO_3$, pH, fine materials and organic matter, while the stands of *Phragmites australis* and *Cressa cretica* communities were associated with soil reaction; stands of the *Cyperus laevigatus*, *Typha domingensis*, and *Suaeda vermiculata* communities were affected by soil salinity and moisture content.

Comparison of the weighted correlations between the soil variables in the two studied oases and the first two axes of DCCA is given in Table 3. These data indicated that the distribution of plant species is most strongly influenced by soil salinity and moisture content. In addition, the weighted correlations of the first axis with organic matter and fine material were high. Axis 2 was significantly correlated with soil reaction and moisture content.

Discussion

Although poor in species, the vegetation composition of the inland saltmarshes in western Egypt, is a mosaic of twelve plant communities. *Alhagi graecorum* Boiss., *Tamarix nilotica* (Ehrenb.) Bunge, *Cressa cretica* L., *Juncus rigidus* Desf. and *Phragmites australis* (Cav.) Trin. & Steud. are the ubiquitous species; indicating their wide range of ecological amplitude. Whereas communities of *Cyperus laevigatus* L., *Suaeda aegyptiaca* (Hasselq.) Zohary, *Typha domingensis* (Pers.) Poir. ex Steud., *S. vermiculta* Forssk. ex J.F. Gmel. and *Aeluropus lagopoides* (L.) Trin. ex Thwaites were recorded from the Dakhla Oasis, the *Cladium mariscus* (L.) Pohl and *Arthrocnemum macrostachyum* (Moric.) K. Koch. communities were recorded from the Siwa Oasis. Most of these communities have analogues in the northern (Ayyad and El-Ghareeb, 1982) and southern (Abu-Ziada, 1980; Sheded and Hassan, 1998) parts of the Western Desert of Egypt. Some of the dominant plant species are known to be of economic importance, for instance for mats and good-quality paper (Zahran et al., 1979), sustaining animal life (Boulos, 1983), sand dune fixation (Batanouny, 1979) and protection from coastal erosion (Zahran, 1977).

Table 3. Weighted correlation matrix of stand ordination along the first two DCCA axes with soil variables in the study areas. For abbreviation and units see Table 1.

Soil variables	Siwa Oasis		Dakhla Oasis	
	Axis 1	Axis 2	Axis 1	Axis 2
pH	- 0.152	0.530	0.038	0.286
TSS	0.832	-0.394	0.325	-0.255
$CaCO_3$	-0.014	-0.173	-0.439	0.072
OM	0.496	0.293	0.297	-0.297
MC	0.666	0.628	0.547	0.025
Silt + clay	0.453	0.305	0.101	-0.370
Species-environment correlation	0.832	0.626	0.786	0.682
% Cumulative variance	44.2	63.9	39.8	61.7

Succulence is a common phenomenon in the vegetation of saline habitats (Fahmy, 1986). Five growth forms can be distinguished: (a) rhizomatous growth form, e.g. *Juncus rigidus*, *Typha domingensis*, *Cyperus laevigatus* and *Cladium mariscus*, (b) stoloniferous growth form as in *Aeluropus lagopoides* and *Phragmites australis*, (c) non-succulent perennial herb growth form e.g. *Cressa cretica*, (d) non-succulent frutiscents as in *Tamarix nilotica* and *Alhagi graecorum* and (e) succulent frutiscents as in *Arthrocemum macrostachum*, *Suaeda aegyptiaca* and *Suaeda vermiculata.*

The distribution of the reed swamp vegetation in the two oases is remarkable. Their growth was usually confined to the areas around the waterholes of the springs. The present study revealed that *Typha domingensis* has a very limited range of distribution in the saltmarshes of the Siwa Oasis and did not form a discrete community. Simpson (1932) stated that "*Typha domingensis* is more sensitive to salt than *Phragmites australis* as the latter forms well into Lake Mariut while *Typha* is present only where the Lake receives fresh water from Mahmudiya canal." Analysis of the soil samples representing swamps showed that the *Typha domingensis* and *Phragmites australis* communities were confined to levels of salinity lower than any of the other wet-moist habitat communities. Available records for the groundwater analysis indicated that the contents of the total soluble salts in the spring water of the Siwa Oasis were much higher (1,900-8,200 ppm; Zahran, 1972) than those of the Dakhla Oasis (440 ppm; Worsley, 1930). This mayexplain, to some extent, the formation of a well-defined community of *Typha domingensis* in the northern Oasis than in the southern. This conclusion is consistent with that of Zahran and Girgis (1970) in Wadi El-Natrun, and Girgis et al. (1971) in the Moghra Oasis.

The vegetation distribution pattern in the study areas was mainly related to gradients in salinity, soil moisture, and fine fractions. Concentration of calcareous deposits, especially in the Dakhla Oasis, was also important. That the distribution of species in saline and marshy habitats relates to salinity in many arid regions has been discussed by several authors, Caballero et al., 1994; Flowers, 1975; Kassas, 1957; Maryam et al., 1995 and Ungar, 1968 among others. Ungar (1965, 1974) indicates that the distribution of inland halophytes in the United States is mainly dependent on the salinity gradient, while local climate, topography, soil moisture and biotic factors are less important. Ragonese and Covas (1947) describe the interrelation of the salinity gradient and vegetation in the northern Argentinian saltmarshes. Abu-Ziada (1980) also notes strong relationships between the vegetation pattern and the soil moisture-salinity gradients in the Kharga and Dakhla Oases. In their account of the northern and eastern Mediterranean coastal saltmarshes, Zahran et al. (1996) demonstrate the distribution of some halophytic species as best correlated along a gradient of a dozen soil variables, the most important being salinity, moisture content, soil texture, organic matter, and calcium carbonate. However, the concrete role of particular ecological factors varies between different ecosystems. In the present study, soil salinity and its variation from one habitat to another is the primary determinant of the plant community composition. The role of soil moisture as a key element in the distribution of the plant species in the saltmarshes is known in other adjacent countries: Zohary and Orshan (1949) in the Dead Sea region of Israel, El-Sheikh and Yousef (1981) in Al-Kharg springs and El-Sheikh et al. (1985) in an inland saltmarsh of the Al-Qassim area of Saudi Arabia, and Winter (1990) in a Jordanian saltpan of Al Azraq Oasis.

The high percentage of calcareous sediments, especially in the soils of Dakhla Oasis, together with the other factors (Anderson et al., 1990) gives a number of glycophytes a competitive advantage over halophytes, as they are tolerant to salt. Girgis (1974) suggested that the presence and relative abundance of glycophytes may be taken as a measure of the degree of halophytism in a plant community. However, in this study, a number of glycophytes were recorded. These include: *Salsola imbricata* subsp. *imbricata, Zygophyllum coccineum, Launaea capitata, Pulicaria crispa, Hyoscymus muticus* and *Tamarix aphylla*. Most of these species are of common occurrence in the Dakhla Oasis.

The zonation of the saltmarsh vegetation is a universal phenomenon. Concentric zonation of halophytic communities in small lakes and saltmarshes of the Egyptian Oases was described by Kassas (1971). Kehl et al. (1984) also describe the ring-shaped vegetation formations in NW-Egypt resulting from different habitat gradients. In his account of the vegetation and flora of Qara Oasis (-70 m, on the SW edge of Qattara depression), Abd El-Ghani (1992) recognized four concentric zones of plant communities bounding the oasis, established on land previously cultivated, but now salinized or desertified. A detailed account on the zonation of the vegetation in the present study in relation to different edaphic, topographic and climatic variations is the subject of a separate study (Abd El-Ghani et al., in preparation).

The oases of Egypt's Western Desert have the lowest population density in the country (ca. 120,000 in the large five oases according to the 1990 census) compared to their area which occupies about 13.4% of the total area of Egypt (Abd El-Ghani, 1985), but the population is increasing exponentially and agricultural development, specifically the expansion of alfa-alfa (*Medicago sativa* L.) cultivation as a principal cash-crop, wheat and barley as the main domestic cereals, and *Sorghum* spp. as fodder crop, are expected. A new agricultural strategy must be applied in the Egyptian Oases. This strategy should aim at minimization of the amount of water flowing into the lakes, hence avoiding more salinized lands, through: (i) the full utilization of the naturally flowing water in irrigation, (ii) the use of moderately saline water (3,000-5,000 ppm) of some drains for forestation projects, and (iii) the cultivation of trees and shrubs of a high ability to consume water, e.g. *Tamarix* sp., *Acacia* sp., *Eucalyptus* sp., and *Casuarina* sp.

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Appendix. Names and abbreviations of the indicator species displayed in Figures 3 and 6.

Alhagi graecorum Boiss.	A. gra
Aeluropus lagopoides (L.) Trin. ex Thwaites	A. lag
Arthrocnemum macrostachyum (Moric.) K. Koch	A. mac
Cressa cretica L.	C. cre
Cyperus laevigatus L.	C. lae
Imperata cylindrica (L.) Raeusch.	I. cyl
Juncus rigidus Desf.	J. rig
Phragmites australis (Cav.) Trin. & Steud.	P. aus
Suaeda aegyptiaca (Hasselq.) Zohary	S. aeg
Typha domingensis (Pers.) Poir. ex Steud.	T. dom
Tamarix nilotica (Ehrenb.) Bunge	T. nil

埃及內陸鹽性沼澤地之植物組成

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本文描述埃及內陸（埃及西部沙漠）相隔很遠的兩個沙漠綠洲，即 Siwa 及 Dakhla 的植物 — 環境關係。兩套數據（Siwa 綠洲有 25 品種 × 68 採樣點，Dakhla 綠洲則有 29 品種 × 89 採樣點）以多變數分析過程，即雙向指標品種分析法（TWINSPAN），detrended correspondence 分析法（DCA）及 detrended canonical correspondence 分析法（DCCA），產生該兩地區植物群落之分類；並且檢驗這些植物群落對若干環境因子如土壤反應、總可溶鹽份、碳酸鈣、有機物、水份及微量成份之適應。在兩個主要棲地（wet-moist 及 dry-mesic）發現十二個嗜鹽性植物群落 *Alhagi graecorum, Tamarix nilotica, Cressa cretica, Juncus rigidus* 及 *Phragmites australis* 在兩沙漠綠洲族群最旺盛。而 *Cyperus laevigatus, Suaeda aegyptiaca, Suaeda vermiculata, Typha domingensis* 及 *Aeluropus lagopoides* 諸群落在 Dakhla 綠洲；*Cladium mariscus* 及 *Arthrocnemum macrostachyum* 兩群落在 Siwa 綠洲被証實存在。對植物群落之分佈及組成影響最大的為：鹽份，水份及微量成份；然而在 Dakhla 綠洲碳酸鈣含量之影響似乎比 Siwa 綠洲大。我們呼籲訂定新的農業策略以避免鹽性地面積之擴大。

關鍵詞：埃及；嗜鹽植物；多變數分析；綠洲；植物群落學；鹽性沼澤；植物相；二級鹽份。