COMMUNITY ECOLOGY 6(2): 143–154, 2005
1585-8553/$20.00 © Akadémiai Kiadó, Budapest

The coastal roadside vegetation and environmental gradients in the arid lands of Egypt

M. M. Abd El-Ghani[1] and N. A. El-Sawaf[2]

[1]*Corresponding author: The Herbarium, Faculty of Science, Cairo University, Giza 12613 Egypt*
E-mail: elghani@yahoo.com
[2] *Botany Department, Faculty of Science, Cairo University, Giza 12613 Egypt*

Keywords: Arid ecosystems, Coastal vegetation, Diversity, Egypt, Multivariate analysis, Plant communities, Vegetation-environment relations.

Abstract: A recent floristic and environmental survey was undertaken on the roadside verges along the main highway between El Arish and Rafah (31° 10'N, 33° 48'E and 31° 17'N, 34° 15'E) that extend for about 45 km on the northeastern Mediterranean coast of Sinai (Egypt). 63 stands were studied at 700-m intervals to represent the variation of vegetation, and to compile the floristic composition of the study area. Four main landform zones were distinguished (from the seashore inwards) and run parallel to the roadway: (A) coastal plain, (B) saline depressions, (C) sand plains and (D) sand dunes. There is a gradual increase in the total number of recorded species in the recognized landform units. Application of TWINSPAN analysis yielded 18 vegetation groups (VG) that comprised 7 main vegetation types (VT). These vegetation types were (I) *Artemisia monosperma* in the sand dunes, (II) *Artemisia monosperma-Echinops spinosus* in the sand plains, coastal plain and sand dunes, (III) *Cyperus capitatus-Ammophila arenaria* in the sand dunes, (IV) *Ammophila arenaria-Pancratium maritimum* in the coastal plain, (V) *Zygophyllum album*, (VI) *Arthrocnemum macrostachyum* and (VII) *Arthrocnemum macrostachyum-Zygophyllum album* in the saline depressions. Ordination techniques of Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) were used to examine the relationship between the roadside vegetation and the 8 studied environmental variables: total soluble salts (TSS), pH, calcium carbonate ($CaCO_3$), sand, fine fractions (silt and clay), distance from the seashore (DFS), landform units (LF) and altitude (Alt). Both ordination techniques indicated that soil salinity, calcareous sediments, soil texture, landform, altitude and distance from seashore were the most important factors for the distribution of the vegetation pattern along the road verges in the study area. These gradients were related closely to the first three CCA axes, and accounted for 72.4% of the species relationship among the stands. Low species richness in the vegetation types of the coastal plain and saline depressions may be related to their high soil salinity, while the high species diversity and the highest share of alien weeds of vegetation types characterized the sand dunes may be related to the high disturbance of their substrates as a result of agriculture practising, farming processes and other excessive human disturbances.

Nomenclature: Täckholm (1974) and Boulos (1999-2002).

Introduction

Human impact was recognised as the most important influence on the composition of the flora and vegetation. This impact had a dominant environmental factor in the arid environments of the world, particularly in the Middle East for thousands of years (Zohary 1983). The construction of roads was one of these impacts. The construction and use of highways, tracks, railways and airports involved many changes; some of them were direct and others were indirect. Direct influences include the destruction of the existing habitats and the provision of new ones that have special characteristics. These provided more or less continuous stretches of open habitats extending for hundreds of miles and forming a nation-wide network, with opportunities for rapid colonisation and spread.

The plant communities of the roadside vegetation were influenced not only by anthropogenic factors but also by geographical differentiation, physiography and topography (Ullmann et al. 1990). The advantage of roadsides for studies of species and vegetation performance along environmental gradients was widely encouraged (Ullmann and Heindl 1989, Wilson et al. 1992). Such studies were well-documented in North America (Lausi and Nimis 1985), in Europe (Stottele and Schmidt 1988, Heindl and Ullmann 1991), in North Africa (Shaltout and

Sharaf El Din 1988, Abd El-Ghani, 1998, 2000), in Saudi Arabia (Batanouny 1979, Fayed and Zayed 1989, Abd El-Ghani 1996), in the Judean Desert (Holzapfel and Schmidt 1990) and in New Zealand (Ullmann et al. 1995). In Egypt, desert highways, and the agricultural roads that traverse cultivated areas, were adequately inter-connected. Altogether, the present road-net amounts to 41.300 km, of which 19.6% were in Sinai Peninsula. Ranked second were those of the Nile Delta (18.7%), the Nile Valley (15.7%), while the least were in the Western Desert of the country (8%). The density of the road-net reached 41.2 km/1000 km^2. The rate of car traffic ranged between 1000-2000 vehicle/day on the regional roads to more than 6000 vehicle/day on the eastern and western international coastal highways (Iraqi et al. 2002). Outstanding proportion of alien species was documented to characterize the contemporary flora of Egypt (Abd El-Ghani and El-Sawaf 2004). In the northwestern roadsides along the Mediterranean coast and in the northern Oases of the Western Desert, the road verges were colonised almost exclusively by alien species; most of which were of Mediterranean origin and were introduced within the last 70 years (El Hadidi and Kosinová 1971).

Much attention has been paid to depict the flora, ecology, vegetation-environment relationships, phytogeography and plant biodiversity along the road verges in the western Mediterranean coastal land of Egypt (amongst others; Batanouny and Abu El-Souod 1972, Ayyad and Fakhry 1996, Salama et al. 2003), few similar studies in the eastern section were compiled (e.g., Danin et al. 1982, Zahran et al. 1996, Gibali 2000). The purpose of this study was to describe the flora and vegetation of El Arish-Rafah roadside verges on the northeastern Mediterranean coast of Sinai (Egypt), and to relate the floristic composition and the species diversity to the prevailing environmental conditions.

The study area

It is located between El Arish (31° 10'N, 33° 48'E) and Rafah (31° 17'N, 34° 15'E), and extends for about 45 km along the northeastern Mediterranean coast of Sinai (Fig. 1). The area was chosen for its high environmental diversity. It represents the easternmost part of the international coastal highway that links Egypt with the countries of North Africa in the west, and those of the eastern Mediterranean in the east. The natural vegetation is very sparse. A semi-steppe type of vegetation characterizes the study area. Kassas (1952) reported the major dominant landforms (littoral dunes, inland dunes, and salt marshes), but Danin (1983) listed further floristic subdivisions and brief habitat descriptions. The coastal belt of the sand dunes represents one of the salient features of the investigated area. The dunes of north Sinai absorb and store rainwater, the low lands between them being a permanent source of fresh water that can be tapped by digging shallow wells. As a result of population pressure, the demand for freshwater supplies was accordingly increased. Thus, water from the Nile is now transferred to Sinai Peninsula through El Salam Canal (Fig. 1).

Desert reclamation and agricultural processes were practised in the study area. Date-palm plantations and irrigated gardens is another conspicuous feature along part of the seashore. In many instances, the land was ploughed and cultivated after the first rain of a season. Cultivation of barley, maize, tomato, sesame, grapes, peaches, pomegranates, olives, figs and watermelons was achieved. Nevertheless, spreader dykes were also conducted for cultivation of beans, wheat and other cereals just upstream of the dykes. Large-scale forestation with tamarisk (*Tamarix aphylla*) and *Acacia saligna* was carried out, mainly along roads traversing the dunes, to arrest sand dune encroachment (Weinstein and Schiller 1979).

According to UNESCO-FAO (1963), the climate of the study area is attenuated subdesertic. Recent records of climatic data for Rafah were incomplete and insufficient. Available records of the mean annual rainfall decrease in the east-west direction. It reached ca. 304 mm year $^{-1}$ at

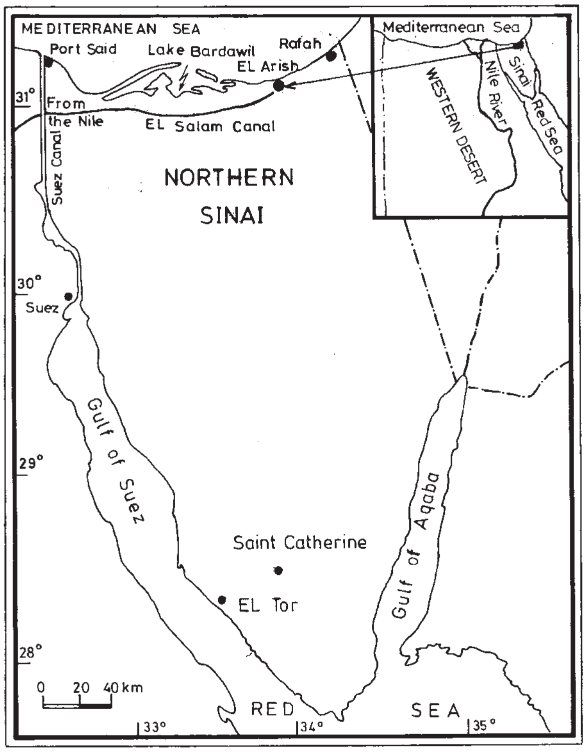

Figure 1. Location map of the study area.

Rafah and 96.8 mm at El Arish. The gradient in the annual rainfall is obvious, which was associated with an inverse evaporation gradient, indicating the increase of aridity from west of the study area to its east. Average daily maxima of the hottest month were 38.6°C at El Arish and 31.5°C at Rafah, while average daily minima of the coldest month were 7.3°C and 7.8°C, respectively. Frost may occur in January and February at El Arish, and fog and dew were also common and probably contribute much to the total sum of plant-available moisture. Average maximum relative humidity at El Arish was 70%, and the average minimum was 32%.

Methods

A quantitative survey of the roadside vegetation was made during the growing season May-June 2003. Generally, it was possible to distinguish, from the Mediterranean Sea inwards, four main landforms in which the plant communities were combined: (A) coastal plain, (B) saline depressions, (C) sand plains and (D) sand dunes. Only stands with an established cover of vegetation were sampled and highly disturbed verges were avoided. Stratified random sampling method was employed (Greig-Smith, 1983). The studied 63 stands (15 m × 15 m) were located systematically at ca.700-m intervals on the outer verge of the road to eliminate the disturbance, which may have been caused to the vegetation by the traffic. In each of the studied stands, presence or absence of plant species was recorded using 5 sample plots (each 3 m × 5 m) randomly positioned.

Three soil samples (0-20, 20-35, 35-50 cm) were collected from each stand. These samples were then pooled together to form one composite sample, air-dried, thoroughly mixed, and passed through a 2 mm-sieve to get rid of gravel and boulders. The portion finer than 2 mm was kept for physical and chemical analysis according to Jackson (1967). Soil texture was determined by the hydrometer analysis (Bouyoucos 1962), and the results used to calculate the percentages of sand, silt and clay. $CaCO_3$ percentage was estimated using 1N HCl. Soil reaction (pH) and total soluble salts (TSS) were evaluated in 1:5 soil-water extract using a glass electrode pH-meter and electric conductivity meter, respectively. An altimeter was used to determine the elevation (Alt) above sea level, and the distance from seashore (DFS) was determined either by walking or by other means.

In order to obtain an effective analysis of the vegetation and related environmental factors, both classification and ordination techniques were employed. Two-Way Indicator Species Analysis (TWINSPAN) using the default settings of the computer program PC-ORD for Windows version 4.14 (McCune and Mefford 1999) was used to classify a floristic presence/absence data matrix of 63 stands and 78 species. An ordered two-way table that expresses succinctly the relationships of the samples and species within the data set was constructed (Hill 1979). To assure the robustness of the resulting classification, we devised a second classification using squared Euclidean distance dissimilarity matrix with minimum variance (also called Ward's method) as agglomeration criterion (Orlóci 1978) of Multi-Variate Statistical Package for windows (MVSP) version 3.1 (Kovach 1999). This produced nearly identical results to the TWINSPAN analysis.

The computer program CANOCO version 4 for Windows (ter Braak and Šmilauer 1998) was used for all ordinations. Detrended Correspondence Analysis (DCA), an indirect gradient analysis technique, plots stands against axes based on species composition and abundance. Preliminary analyses were made by applying the default option of the Detrended Correspondence Analysis (DCA; Hill and Gauch 1980) in the CANOCO program, to check the magnitude of change in species composition along the first ordination axis (i.e., gradient length in standard deviation (SD) units). In the present study, DCA estimated the compositional gradient in the vegetation data to be larger than 5 SD-units for the first axis, thus Canonical Correspondence Analysis (CCA) is the appropriate ordination method to perform direct gradient analysis (ter Braak and Prentice 1988). Ter Braak (1986) suggests using DCA and CCA together to see how much of the variation in species data was accounted for by the environmental data. Eight environmental factors were included: total soluble salts (TSS), pH, calcium carbonate ($CaCO_3$), sand, fine fractions (silt and clay), distance from the seashore (DFS), landform units (LF) and altitude (Alt). All the default settings were used for CCA, and a Monte Carlo permutation test (199 permutations; ter Braak 1994) was used to test for significance of the eigenvalues of the first canonical axis. Intra-set correlations from the CCA's were used to assess the importance of the environmental variables.

The TWINSPAN vegetation types were subjected to an ANOVA based on environmental variables to find out whether there were significant variations among types. Simple linear correlation coefficients were calculated to evaluate the relationship between the environmental factors, and Sørensen's coefficient of floristic similarity (CCs) between the identified landforms was also estimated. All the statistical analyses were carried out using SPSS version 10.0 for Windows. Species richness (alphadiversity) was calculated as the average number of species per stand.

Results

Floristic relations

In total, 78 species from 31 vascular plant families were found; of which 24 are annuals and 54 perennials. There is a gradual increase in the total number of recorded species from 27 in the coastal plain to 43 in the sand dunes. The floristic similarities between the recognized four landforms (Table 1) showed significant positive correlations between saline depressions and the coastal plain in one hand, and between the sand plains and sand dunes in the other. The coastal and sand plains were negatively correlated with each other. Regarding species richness, the floristic composition in the recognized landforms showed remarkable differences. Chamaephytes were the predominant life form and constituted 32% of the recorded flora, followed by therophytes (31%) and hemicryptophytes (17%). In this context, chamaephytes, hemicryptophytes and cryptophytes altogether constituted the main bulk of the floristic structure of each of the recognized landform unit. It ranged from 49% and 51% in sand dunes and sand plains to 61% and 67% in the coastal plain and saline depressions, respectively.

Table 1. Sørensen's coefficient of floristic similarity (CCs) between the different landform units in the study area.

Landform unit	C	S	M	D
C				
S	-0.43*			
M	0.47**	0.005		
D	0.28	0.46**	0.30	
Total Number of species	27	41	28	43
% of alien weed species	12.5	19.1	15.7	26.6

None of the 78 species occurs at all the 63 studied stands. There were few highly frequent species and very many that were infrequent. Only 2 species (*Echinops spinosus* and *Zygophyllum album*) had a frequency of more than 50%, and 35 species (about 65% of the total) had a frequency more than 10%. This is similar to the distribution of frequencies reported for roadside vegetation in California (Frenkel 1970) and New Zealand (Ullmann et al. 1995). Some of the recorded species have wide ecological and sociological range of distribution such as *Cornulaca monacantha* and *Cyperus capitatus*, with 75 records and the highest occurrence among perennials (24%), while *Mesembryanthemum crystallinum* was recorded in 119 sample plots and showed the highest occurrence among annuals (38%). The results revealed that 37

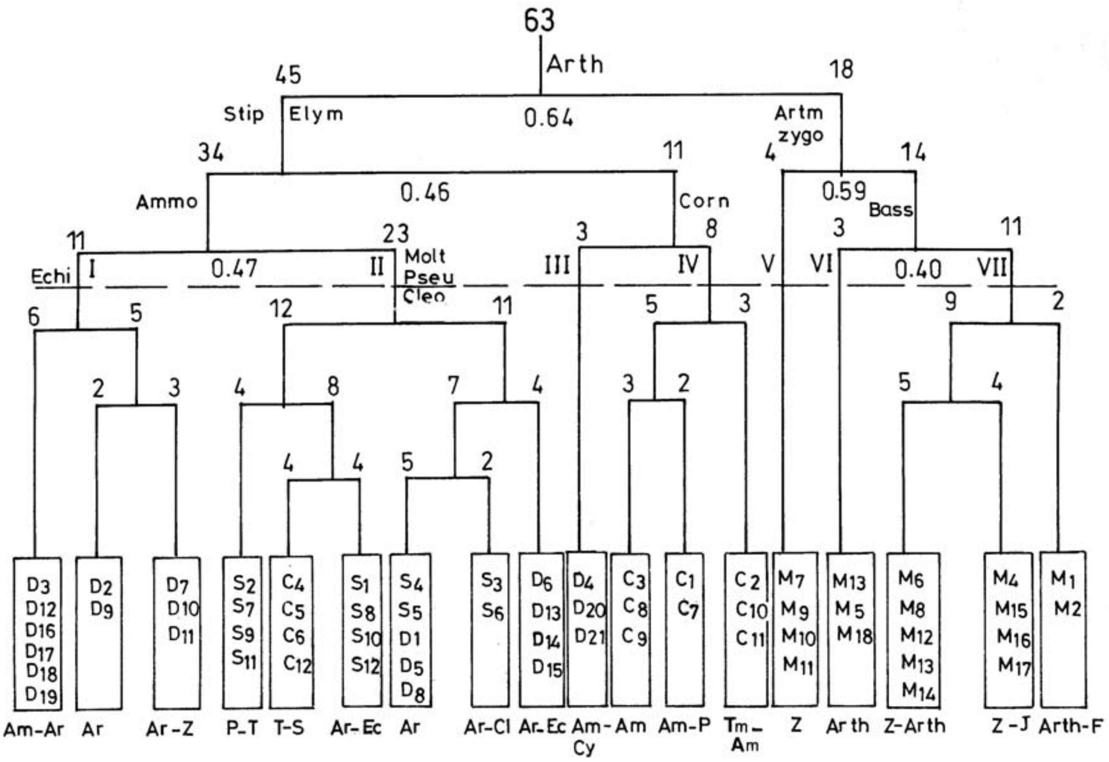

Figure 2. The dendrogram resulting from TWINSPAN analysis of 63 stands of the study area. The broken line denotes the level at which the dendrogram yields seven vegetation types (I-VII). Indicator species and vegetation group abbreviations are shown in the Appendix.

Table 2. Characteristics of the seven vegetation types (VT) and 18 vegetation groups (VG) derived after the application of TWINSPAN. For landform unit abbreviations, see Table 1. N = Number of stands recorded.

VT	VG	Characteristic species	Species richness	P%	N	Landform units			
						C	**S**	**M**	**D**
I	1	*Artemisia monosperma* *Ammophila arenaria*	5.2	100 75	6				6
	2	*Artemisia monosperma*	12.0	100	2				2
	3	*Artemisia monosperma* *Zygophyllum abum*	6.0	100 100	3				3
II	4	*Panicum turgidum* *Thymelaea hirsute*	7.2	100 100	4		4		
	5	*Silene succulenta* *Thymelaea hirsute*	8.0	75 50	4	4			
	6	*Artemisia monosperma* *Echinops spinosus*	12.0	100 100	4		4		
	7	*Artemisia monosperma*	15.8	80	5		2		3
	8	*Artemisia monosperma* *Cleome amblyocarpa*	12.5	100 100	2		2		
	9	*Echinops spinosus* *Artemisia monosperma*	16.2	100 75	4				4
III	10	*Cyperus capitatus* *Ammophila arenaria*	12.3	100 67	3				3
IV	11	*Ammophila arenaria*	12.7	100	3	3			
	12	*Ammophila arenaria* *Pancratium maritimum*	16.5	100 100	2	2			
	13	*Ammophila arenaria* *Tamarix nilotica*	13.0	100 67	3	3			
V	14	*Zygophyllum album*	8.7	100	4			4	
VI	15	*Arthrocnemum macrostachyum*	9.7	100	3			3	
VII	16	*Arthrocnemum macrostachyum* *Zygophyllum album*	6.4	100 100	5			5	
	17	*Zygophyllum album* *Juncus rigidus*	8.2	100 80	4			4	
	18	*Arthrocnemum macrostachyum* *Frankenia hirsuta*	6.0	100 100	2			2	

species (55.2% of the total) demonstrated a certain degree of consistency, where they were exclusively recorded or confined to a certain landform unit and do not penetrate elsewhere. These species were distributed as follows: 11 in the sand plains (e.g., *Panicum turgidum, Fagonia arabica* and *Convolvulus lanatus*), 3 in the coastal plain (e.g., *Agathophora alopecuroides, Solanum elaeagnifolium* and *Euphorbia paralias*), 13 in the saline depressions (e.g., *Arthrocnemum macrostachyum, Juncus rigidus, Halocnemum strobilaceum* and *Suaeda aegyptiaca*) and 10 in the sand dunes (e.g., *Cynodon dactylon, Bassia indica, Chenopodium murale, Amaranthus graecizans* and *Rumex pictus*).

Vegetation classification

Classification of the presence-absence data set of 78 species recorded in 63 stands using the TWINSPAN analysis yielded 18 vegetation groups (VG) at level 6 of the hierarchy (Fig. 2; Table 2). These groups could be categorized at level 3 of the classification into 7 major vegetation types (VT). These types named after the first and second dominant species as follows: (I) *Artemisia monosperma* in the sand dunes, (II) *Artemisia monosperma-Echinops spinosus* in the sand plains, coastal plain and sand dunes, (III) *Cyperus capitatus-Ammophila arenaria* in the sand dunes, (IV) *Ammophila arenaria-Pancratium maritimum* in the coastal plain, (V) *Zygophyllum album*, (VI) *Arthrocnemum macrostachyum* and (VII) *Arthrocnemum macrostachyum-Zygophyllum album* in the saline depressions. One-way ANOVA test showed significant differences (F-ratio=8.8; p=0.001) between the recognized landforms and the evolved vegetation types. The total number of recorded species and species richness of the 7 vegetation types (VT) differ significantly between stands (Table 3). While VT (II) had the highest total number of species (56), VT (III) and (V) had the lowest (13 and 14, respectively). The highest species richness of 16.7±4.8 was found in VT (II), but the lowest (6.9±2.2) was in VT (IV).

Table 3. Mean values, standard deviation (± SD) and ANOVA F-values of the environmental variables and species richness in the stands representing the seven vegetation types (I-VII) obtained by TWINSPAN. TSS= total soluble salts, Alt= altitude and DFS= distance from seashore. * p<0.01.

Environmental variables	Total mean	TWINSPAN vegetation types							F-ratio
		I (n= 11)	II (n= 23)	III (n= 3)	IV (n= 8)	V (n= 4)	VI (n= 3)	VII (n= 11)	
Sand (%)	93.7 ± 4.1	96.9 ± 0.9	95.8 ± 3.1	96.8 ± 0.9	87.6 ± 2.1	93.8 ± 1.6	91.9 ± 5.1	91.1 ± 3.5	12.7 *
Silt (%)	2.7 ± 2.6	1.0 ± 0.4	1.0 ± 1.3	0.9 ± 0.4	4.5 ± 1.8	2.4 ± 0.5	4.7 ± 5.5	4.8 ± 3.9	4.7 *
Clay (%)	3.6 ± 2.5	2.1 ± 0.7	2.7 ± 2.1	2.3 ± 0.9	7.9 ± 1.8	3.8 ± 1.1	3.4 ± 2.7	4.1 ± 1.9	10.4*
$CaCO_3$ (%)	1.9 ± 0.6	1.1 ± 0.2	2.8 ± 0.3	1.8 ± 0.2	2.6 ± 0.1	1.6 ± 0.009	1.2 ± 0.006	1.1 ± 0.007	59.6*
pH	7.8 ± 0.3	7.7 ± 0.4	7.8 ± 0.3	7.8 ± 0.5	7.9 ± 0.4	7.7 ± 0.3	7.9 ± 0.2	7.8 ± 0.3	0.6
TSS (meq/l)	1.1 ± 1.5	0.8 ± 0.01	2.1 ± 0.01	7.2 ± 0.1	7.3 ± 0.2	18.1 ± 0.1	24.5 ± 0.3	41.9 ± 1.0	106.8*
Alt (m)	25.5 ± 3.6	27.7 ± 10.3	30.4 ± 15.5	36.7 ± 11.5	8.1 ± 9.9	23.7 ± 4.8	20.0 ± 10.0	24.4 ± 6.1	4.1*
DFS (m)	107.7 ± 85.3	179.1 ± 98.5	98.3 ± 94.9	193.3 ± 11.5	21.9 ± 8.4	117.5 ± 25.0	76.7 ± 15.3	100.0 ± 31.6	4.3*
Species richness	10.2 ± 4.3	13.6 ± 2.7	16.7 ± 4.8	12.7 ± 0.6	6.9 ± 2.2	8.7 ± 2.2	9.7 ± 2.1	7.1 ± 1.5	6.5*
Total number of species	19 ± 3.5	18	56	13	24	14	17	22	42.4*

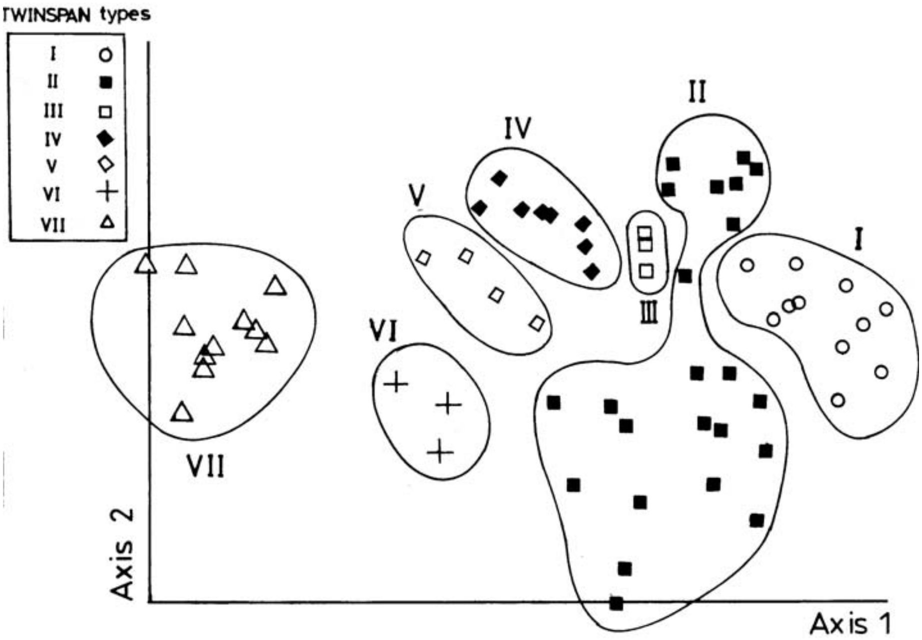

Figure 3. Ordination diagram of Detrended Correspondence Analysis (DCA) of 63 stands, with their TWINSPAN vegetation types.

Characteristics of the vegetation groups presented in Table 3 showed that 17 out of the 18 groups occurred only in one landform, while VG (7) dominated by *Artemisia monosperma* was represented in the sand plains and the sand dunes. Whereas the vegetation groups of *Ammophila arenaria-Pancratium maritimum* and *Echinops spinosus-Artemisia monosperma* have the highest species richness (16.5±1.5 and 16.2±2.4 species, respectively), those of *Artemisia monosperma-Ammophila arenaria* (5.2±1.7), *Artemisia monosperma-Zygophyllum album* and *Arthrocnemum macrostachyum-Frankenia hirsuta* (6.0±2.0 for each) had the lowest.

A Detrended Correspondence Analysis (DCA) ordination plot of the 63 stands on axes 1 and 2 is shown in Fig. 3, with the 7 TWINSPAN vegetation types superimposed. The stands were spread out at 5.3 SD-units of the first axis (eigenvalue= 0.71), expressing the high floristic variation among the vegetation types, and indicating that complete turnover in species composition took place (Hill 1979). Stands of VT (I) were separated toward the positive end of DCA axis 1, while those of VT (VII) were separated out along the other end. DCA axis 2 with eigenvalue of 0.39 and a gradient length of 3.11 was less important. The species-environment correlation was high: 0.96 and 0.67 for DCA axes 1 and 2, showing that the spe-

Table 4. Mean values, standard deviation (± SD) and ANOVA F-values of the environmental variables and species richness in the stands representing the seven vegetation types (I-VII) obtained by TWINSPAN. TSS: total soluble salts, Alt: altitude and DFS: distance from seashore. * p<0.01.

	DCA axis			CCA axis		
	1	2	3	1	2	3
Eigenvalues	0.71	0.39	0.30	0.67	0.30	0.29
Species-environment correlation coefficient	0.96	0.67	0.51	0.97	0.92	0.83
Sand	-0.07	0.08	0.04	0.09	0.15	0.004
Silt (%)	-0.30	-0.06	-0.09	0.30	-0.10	-0.13
Clay	-0.12	0.10	0.11	0.04	-0.27*	-0.47*
$CaCO_3$	-0.002	0.03	-0.03	-0.06	-0.31*	-0.34
pH	-0.12	0.01	0.10	-0.09	-0.20	-0.30
Total soluble salts (meq/l)	-0.92*	-0.10	0.01	0.97*	0.06	0.07
Landform (LF)	-0.005	0.61*	0.32	0.05	0.95*	-0.28
Altitude (m)	0.32	0.06	-0.16	-0.24*	0.48*	0.74*
Distance from seashore (m)	0.25	0.41*	-0.001	-0.18	0.78*	0.30

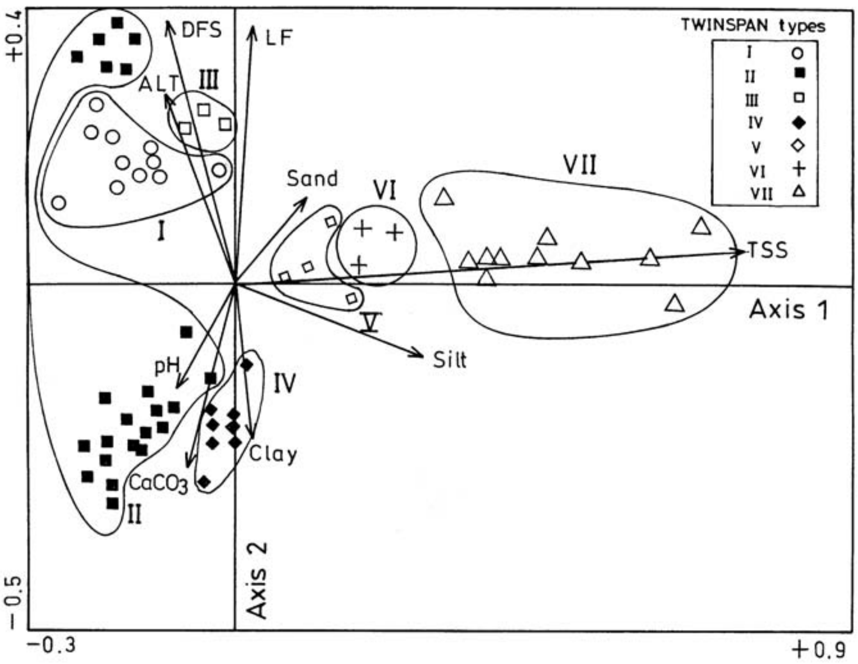

Figure 4. Ordination biplot yielded by Canonical Correspondence Analysis (CCA) of the 63 stands with their TWINSPAN vegetation types and soil variables.

cies data were strongly related to the measured environmental variables. A well-defined gradient in soil salinity (r = –0.92) was found on axis 1, reflected in the species composition from stands with high to stands with low saline content. The vegetation types (V), (VI) and (VII) of the saline depressions appeared on the left side of axis 1, while those of other landforms appeared on the right side. Plot scores of DCA axis 2 were positively correlated (r = 0.61) with landform, indicating a gradient from coastal plain on the seashore to sand dunes inwards in the desert.

Vegetation-environment relationships

The soil variables of the stands comprising the 7 vegetation types differ significantly according to the one-way ANOVA (Table 3). The soil of VT (I) had the highest content of sand, but the lowest content of clay, $CaCO_3$, and total soluble salts. The soil of VT (II) had the highest content of $CaCO_3$, while the soil of stands which constitute VT (III) had the lowest silt content (0.9%), the farthest from the seashore (193.3m) and at the highest altitudes (36.7 m above sea level). The soil of VT (IV) occupy the

Table 5. Matrix of product moment correlation coefficients (r values) between the environmental variables. ** $p < 0.01$, * $p < 0.05$. For abbreviations and units, see Tables 3 and 4.

Sand								
Silt	-0.81**							
Clay	-0.78**	0.28*						
$CaCO_3$	0.57**	-0.52**	-0.40**					
pH	-0.13	0.15	0.06	-0.1				
TSS	-0.38**	0.44**	0.16	-0.76**	0.07			
Alt	0.58**	-0.39**	-0.54**	0.30*	-0.07	-0.12		
DFS	0.45**	-0.29*	-0.44**	0.36**	0.02	-0.10	0.64**	
Landform	0.29*	-0.44**	-0.20	0.27*	0.01	-0.13	0.19	0.75**
Variables	Sand	Silt	Clay	$CaCO_3$	pH	TSS	Alt	DFS

lowest altitude (8.1m above sea level) that were very close to the seashore (DFS=21.9m) and rich in clay content (7.9%). The soil of VT (V), (VI) and (VII) have the highest values of salinity (18.1, 24.5 and 41.9 meq/l, respectively).

The successive decrease of the eigenvalues of the first three CCA axes (Table 4) suggesting a well-structured dataset. The species-environment correlations were higher for the first three canonical axes, explaining 72.4% of the cumulative variance. These results suggest a strong association between vegetation and the measured environmental parameters presented in the biplot (Jongman et al. 1987). From the intra-set correlations of the environmental variables and the first three axes of CCA, it can be inferred that CCA axis 1 was positively correlated with salinity, and negatively with altitude, while CCA axis 2 was defined by landforms, distance from the seashore, altitude and clay. This fact becomes evident in the ordination biplot (Fig. 4). Contributions of salinity, landforms, altitude and clay; which were selected by the forward selection option in the program CANOCO; to the variation in species data were 36.8%, 17.2%, 14.4% and 6.9%, respectively. A test for significance with an unrestricted Monte Carlo permutation test found the F-ratio for the eigenvalue of CCA axis 1 and the trace statistics to be significant ($p = 0.01$), indicating that the observed patterns did not arise by chance. The ordination diagram produced by CCA in Fig. 4 showed that the pattern of ordination was similar to that of the floristic DCA (Fig. 3), with most of the stands remaining in their respective TWINSPAN vegetation types. Clearly, vegetation types (V), (VI) and (VII) were highly associated with soil salinity, those of VT (I) and (III) with altitude and the distance from the seashore, and those of VT (II) and (IV) with clay and lime content.

Table 6. Spearman rank correlations between species richness and stand scores of the first two axes of CCA, and the environmental variables. * $p < 0.01$.

Variables	Correlation	P
Axis 1	0.68	0.001*
Axis 2	0.06	0.78
Sand	0.07	0.56
Silt	-0.13	0.32
Clay	0.01	0.92
$CaCO_3$	-0.01	0.90
pH	0.20	0.11
TSS	-0.31	0.001*
Alt	-0.35	0.79
DFS	0.02	0.88
Landform	0.65	0.001*

The calculation of correlation coefficients (r) between the measured environmental variables (Table 5) indicated that sand, silt and $CaCO_3$ had the highest number of correlations. Soil texture was significantly correlated with altitude, distance from the sea and $CaCO_3$. It can also be noted that both altitude and the distance from the seashore showed significant positive correlation with each other, and with $CaCO_3$.

Diversity versus environment

The effects of environmental variables on species richness are shown in Table 6. The results showed that species richness was significantly correlated with the first axis (salinity-altitude gradient) of CCA ordination, but was unrelated to the second axis (landform- $CaCO_3$ gradient). Whereas soil salinity exhibited high significant negative correlation with species richness (p = 0.001), landforms were positively correlated with it (p = 0.001).

Discussion

We examined the vegetation-environment relationships in the different landforms along the roadside verges between El Arish and Rafah on the northeastern Mediterranean coast of Sinai. Both DCA and CCA were applied to assess the species distribution and the prevailing environmental conditions. The results of CCA showed well the relative positions of species and stands along the most important ecological gradients. Both ordination techniques indicated that soil salinity, calcareous sediments, soil texture, landform, altitude and distance from seashore were the most important factors for the distribution of the vegetation pattern along the road verges in the study area. The distribution of the vegetation types reflects these relations, with VT (V-VII) being typical of the saline silty stands, VT (I and III) and partly VT (II) showing a gradient of increasing altitude and distance from seashore, and VT (IV) and mostly VT (II) being found on more $CaCO_3$ and clay contents.

The 18 groups identified by TWINSPAN were considered to represent 7 vegetation types; each of definite floristic and environmental characteristics. Most of the characteristic species of the identified vegetation types were salt tolerant species, indicating the saline nature of the study area. The application of DCA to the same set of data supports the distinction between these types. Some of the identified vegetation types have very much in common with that recorded along the western Mediterranean coastal land (Shaltout and EL-Ghareeb 1992), in south Sinai region (El-Ghareeb and Shabana 1990, Abd El-Ghani and Amer 2003), in some wadis of the Eastern (Fossati et al. 1998) and Western Desert (Bornkamm and Kehl 1985, Abd El-Ghani 2000), and in the Negev Desert of Israel (Olsvig-Whittaker et al. 1983, Tielbörger 1997). Owing to the specific environment of the study area, many species with a nitrophilous (e.g., *Cynodon dactylon, Cakile maritima* and *Phragmites australis*), psammophilous (e.g., *Echinops spinosus, Cornulaca monacantha, Cyperus capitatus* and *Artemisia monosperma*), halophilous (e.g. *Arthrocnemum macrostachyum, Halocnemum strobilaceum, Agathophora alopecuroides, Juncus rigidus* and *Frankenia hirsuta*) and psammohalophilous (e.g., *Zygophyllum album, Ammophila arenaria* and *Tamarix nilotica*) character occurred in the distinguished vegetation types.

It has been emphasized that roadside zonation was based on structural criteria, such as vegetation height, density and dominance structure of plant communities rather than on floristic composition only (Kopecký 1978), features that were beyond the focus of this study. The arrangement of the 7 major vegetation types followed a general pattern in zones parallel to the roadway. Each type has indicator species with varying degrees of overlap between types (Table 3). The zonation of these physiognomic vegetation types (VT I-VII) from the roadside inward can be characterized according to the landform unit on which it occurred as follows:

A – Coastal plain are at the inner edge of the road verge, and are exposed to salt spray. Vegetation composition in this landform was dominated by *Ammophila arenaria-Pancratium maritimum* (VT IV) found very close to the seashore on the low-lying stands rich in fine sediments. Less frequent species include *Elymus farctus* and *Silene succulenta*.

B – Saline depressions are located on the outermost zone of the outer road verge that were relatively influenced by seawater, and forming wet saltmarshes. They were dominated by *Zygophyllum album, Arthrocnemum macrostachyum* and *Arthrocnemum macrostachyum- Zygophyllum album* (VT V, VI and VII, respectively). High salinity of this landform favours the growth of some salt tolerant species such as *Frankenia hirsuta, Juncus rigidus, Agathophora alopecuroides* and *Cyperus laevigatus*. Low species richness in the vegetation types of the coastal plain and saline depressions may be related to their high soil salinity. Our results indicated that species richness was negatively correlated with soil salinity and positively correlated with landform units. Such salinity stress on species diversity in the study area and related areas was reported by Moustafa and Klopatek (1995) and Shaltout et al. (1997).

C – Sand plains followed the saline depressions, and are away from the direct influence of the sea. The vegetation structure of this vegetation type occurred in two facies: (1) the farthest from the seashore, and inhabiting the deep sandy soil stands with low content of $CaCO_3$. It is dominated by *Panicum turgidum* and *Thymelaea hirsuta*, (2) the nearest to the seashore found on high soil contents of $CaCO_3$, pH and fine sediments. It represents the typical vegetation type dominated by *Artemisia monosperma-Echinops spinosus* (VT II). The relatively high species diversity of VT (II) may be explained in terms of the theory of substrate heterogeneity (Mellinger and McNaughton 1975), as this landform can be considered as ecotonal area that embraces the characteristics of both coastal plain and sand dunes. High species diversity due to substrate heterogeneity and local topographic variations in some Mediterranean plant communities was also confirmed (among others; Kutiel et al. 1979, Benhouhou et al. 2001, Al-Sodany et al. 2003).

D – Sand dunes represent the innermost zone of the outer road verge away from any influence of the sea, and are characterized by *Artemisia monosperma* (VT I), *Artemisia monosperma-Echinops spinosus* (VT II) and *Cyperus capitatus-Ammophila arenaria* (VT III). The vegetation composition of the coastal sand dunes in the present study has very much in common with that in Israel (Barbour et al. 1981, Tielbörger 1997), and in the western Mediterranean coast of Egypt (Ayyad 1973). The coastal sand dune system was a prominent feature in this study. However, its vegetation has been disturbed through grazing and over-exploitation for fuel wood, construction, and is being burnt to clear the way for cultivation. Consequently, the high species diversity and the highest share of alien weeds of vegetation types (I) and (III) characterizing sand dune vegetation in the study area may be related to the high disturbance of their substrates as a result of agriculture practising, farming processes and other excessive human disturbances.

References

Abd El-Ghani, M.M. 1996. Vegetation along a transect in the Hijaz mountains (Saudi Arabia). *J. Arid Environ.* 32: 289-304.

Abd El-Ghani, M.M. 1998. Environmental correlates of species distribution in arid desert ecosystems of eastern Egypt. *J. Arid Environ.* 38: 297-313.

Abd El-Ghani, M.M. 2000. Floristics and environmental relations in two extreme desert zones of western Egypt. *Global Ecol. Biogeogr.* 9: 499-516.

Abd El-Ghani, M.M. and W. Amer. 2003. Soil-vegetation relationships in a coastal desert plain of southern Sinai, Egypt. *J. Arid Environ.* 55: 607-628.

Abd El-Ghani, M.M. and N. El-Sawaf. 2004. Diversity and distribution of plant species in agro-ecosystems of Egypt. *Syst. Geogr. Pl.* 74: 319-336

Al-Sodany, Y.M., M.N. Shahata and K.H. Shaltout. 2003. Vegetation along an elevation gradient in Al-Jabal Al-Akhdar, Libya. *Ecol. Mediter.* 29: 35-47.

Ayyad, M. A. 1973. Vegetation and environment of the western Mediterranean coastal land of Egypt. I. The habitat of sand dunes. J. Ecol. 61: 509-523.

Ayyad, M.A. and A.M. Fakhry. 1996. Plant biodiversity in the Western Mediterranean Desert of Egypt. *Verh. Ges. f. Ökologie* 25: 65-76.

Batanouny, K.H. 1979. Vegetation along Jeddah-Mecca road: pattern and process affected by human impact. *J. Arid Environ.* 2: 21-30.

Batanouny K.H. and S. Abul-Souod. 1972. Phytosociological and ecological study of a sector in the Libyan Desert. *Vegetatio* 25: 335-356.

Barbour, M.G., A. Shmida, A.F. Johnson and B. Holton. 1981. Comparison of coastal dune scrub in Israel and California: Physiognomy, association patterns, species richness and phytogeography. *Israel J. Bot.* 30: 181-198.

Behhouhou, S. S., T.C.D. Dargie and O.L. Gilbert. 2001. Vegetation associations in the Great Western erg and the Saoura valley, Algeria. *Phytocoenologia* 31: 311-324.

Bornkamm, R. and H. Kehl. 1985. Pflanzengeographische zonen in der Marmarika (Nordwest-Ägypten). *Flora* 176: 141-151.

Boulos, L. 1999-2002. *Flora of Egypt. Volumes 1-3*. Al Hadara Publishing, Cairo.

Bouyoucos, G.J. 1962. Hydrometer method improved for making particle size analysis of soil. *J. Agron.* 54: 464-465.

Danin, A. 1983. *Desert Vegetation of Israel and Sinai.* Cana Publishing House, Jerusalem.

Danin, A., A. Weinstein and R. Karschon. 1982. The synanthropic vegetation of new settlements in northeastern Sinai. I. Composition and origin. *Willdenowia* 12: 57-75.

Dargie, T.C.D. and M.A. El Demerdash. 1991. A quantitative study of vegetation-environment relationships in two Egyptian deserts. *J. Veg. Sci.* 2: 3-10.

El-Ghareeb, R. and M.A. Shabana. 1990. Vegetation-environmental relationships in the bed of Wadi El-Sheikh of southern Sinai. *Vegetatio* 90: 145-157.

El Hadidi, M. N. and J. Kosinová. 1971. Studies on the weed flora of cultivated land in Egypt. 1. Preliminary survey. *Mitt. Bot. Staatssamml. München* 10: 354-367.

Fossati, J., G. Pautou and J.P. Peltier. 1998. Wadi vegetation of the North-Eastern desert of Egypt. *Feddes Repert.* 109: 313–327.

Fayed, A.A. and K.M. Zayed. 1989. Vegetation along Makkah-Taif road (Saudi Arabia). *Arab Gulf J. Scient. Res.* 7: 97-117.

Frenkel, R.E. 1970. *Ruderal Vegetation along Some California Roadsides.* University of California Press. Berkeley, CA.

Gibali, M.A. 2000. Plant life in Northern Sinai: Ecological and floristic studies. Unpublished Ph.D. Thesis, Fac. Sci., Cairo Univ.

Greig-Smith, P. (1983). *Quantitative Plant Ecology*. 3rd Ed. Blackwell, London.

Heindl, B. and I. Ullmann. 1991. Roadside vegetation in mediterranean France. *Phytocoenologia* 20: 111-141.

Hill, M.O. 1979. TWINSPAN – A Fortran program for arranging multivariate data in an ordered two-way table of classification of individuals and attributes. Ithaca, NY, Cornell Univ.

Hill, M.O. and H.G. Jr.Gauch. 1980. Detrended correspondence analysis: an improved ordination technique. *Vegetatio* 42: 47-58.

Holzapfel, C. and W. Schmidt. 1990. Roadside vegetation along transect in the Judean Desert, Israel. *Israel J. Bot.* 39: 263-270.

Iraqi, M.I. 2002. *Transport Sector in Egypt: Past, Present and Future Until 2010.* Academic Press (in Arabic).

Jackson, M.L. 1967. *Soil Chemical Analysis.* Prentice Hall of India, New Delhi.

Jongman, R.H., C.J.F. ter Braak and O.F.G. van Tongeren. 1987. *Data Analysis in Community and Landscape Ecology.* Pudoc Wageningen, The Netherlands.

Kassas, M. 1952. Habitat and plant communities in the Egyptian desert. I. Introduction. *J. Ecol.* 40: 342-351.

Kopecký, K. 1978. *Die Strassenbegleitenden Rasengesellschaften im Gebrige Orlické und seinem Vorlande.* Vegetace CSSR, A-10. Academia Praha, Praha.

Kovach, W.L. 1999. *A Multivariate Statistical Package for Windows, version 3.1. Users' Manual.* Kovach Computing Services, Pentraeth, Wales, UK.

Kutiel, P., A. Danin and G. Orshan. 1979. Vegetation of the sandy soils near Caesarea, Israel. I. Plant communities, environment and succession. *Israel J. Bot.* 28: 20-35.

Lausi, D. and P.L. Nimis. 1985. Roadside vegetation in boreal South Yukon and adjacent Alaska. *Phytocoenologia* 13: 103-138.

McCune, B. and M.J. Mefford. 1999. *PC-ORD for Windows. Multivariate Analysis of Ecological Data. Version 4.14. User's Guide.* MjM Software, Oregon, USA.

Mellinger, M.V. and S.J. McNaughton. 1975. Structure and function of successional vascular plant communities in Central New York. *Ecol. Monogr.* 45: 161-182.

Moustafa, A. A. and J.M. Klopatek. 1995. Vegetation and landforms of the Saint Catherine area, southern Sinai, Egypt. *J. Arid Environ.* 30: 385-395.

Olsvig-Whittaker, L., M. Shachak and A.Yair. 1983. Vegetation patterns related to environmental factors in a Negev Desert watershed. *Vegetatio* 54: 153-165.

Orloci, L. 1978. *Multivariate Analysis in Vegetation Research.* 2nd ed. W. Junk b.v. Publishers. The Hague, Boston.

Salama, F.M., M.M. Abd El-Ghani, S.M. El-Naggar and K.A. Baayo. 2003. Floristic composition and chorological analysis of the Sallum area, west Mediterranean, Egypt. *J. Union Arab Biol. Cairo 13 (B)*: 27-47.

Shaltout, K.H. and A. Sharaf El-Din. 1988. Habitat types and plant communities along a transect in the Nile Delta region. *Feddes Repert.* 99: 153-162.

Shaltout, K.H. and R. El-Ghareeb. 1992. Diversity of the salt marsh plant communities in the western Mediterranean region of Egypt. *J. Univ. Kuwait (Sci.)* 19: 75-84.

Shaltout, K.H., E.F. El-Halawany and M.M.El-Garawany. 1997. Coastal lowland vegetation of eastern Saudi Arabia. *Biodiv. and Conserv.* 6: 1027-1070.

Stottele, T. and W. Schmidt. 1988. *Flora und Vegetation an Strassen und Autobahnen der Bundesrepublik Deutschland.* Forsch. Strass. Verkehr. 529. Bonn.

Täckholm, V. 1974. *Students´ Flora of Egypt.* 2nd ed. Cairo University Press, Cairo.

ter Braak, C.J.F. 1986. Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* 67: 1167-1179.

ter Braak, C.J.F. 1994. Canonical community ordination. Part 1. Basic theory and linear methods. *Ecoscience* 1: 127-140.

ter Braak, C.J.F. and I.C. Prentice. 1988. A theory of gradient analysis. *Adv. Ecol. Res.* 18: 271-317.

ter Braak, C.J.F. and P. Smilauer. 1998. *CANOCO Reference Manual and User's Guide to CANOCO for Windows: Sotware for Canonical Community Ordination (version 4).* Microcomputer Power, Ithaca, NY.

Tielbörger, K. 1997. The vegetation of linear desert dunes in the north-western Negev, Israel. *Flora* 192: 261-278.

Ullmann, I., P. Bannister and J.B. Wilson. 1995. The vegetation of roadside verges with respect to environmental gradients in southern New Zealand. *J. Veg. Sci.* 6: 131-142.

Ullmann, I. and B. Heindl. 1989. Geographical and ecological differentiation of roadside vegetation in temperate Europe. *Bot. Acta* 102: 261-340.

Ullmann, I., B. Heindl and B. Schug. 1990. Naturräumlische Gliederung der Vegetation auf Strassenbegleitflächen im westlischen Unterfranken. *Tuexenia* 10: 197-222.

UNESCO-FAO 1963. Carte bioclimatique de la zone mediterranéenne. *Arid Zone Res.* 21.

Weinstein, A. and G. Schiller. 1979. Afforestation and tree planting in Sinai. II. Northeastern Sinai. La-Yaaran 29:13-16 (Hebrew), 32 (English).

Wilson, J.B., G.L. Rapson, M.T. Sykes, A.J. Walker and P.A. Williams. 1992. Distributions and some climatic correlations of some exotic species along roadsides in New Zealand. *J. Biogeogr.* 19: 183-194.

Zahran, M.A., K.J. Murphy, I.A. Mashaly and A.A. Khedr. 1996. On the ecology of some halophytes and psammophytes in the Mediterranean coast of Egypt. *Verh. Ges. f. Ökologie* 25: 133-146.

Zohary, M. 1983. Man and vegetation in the Middle East. In: W. Holzner, M.J.A. Werger and I. Ikusima (eds.), *Man's Impact on Vegetation,* Junk, The Hague, The Netherlands.

Appendix

Abbreviations of indicator species

Species	Abbreviation
Ammophila arenaria (L.) Link	Ammo
Arthrocnemum macrostachyum (Moric.) K.Koch	Arth
Bassia indica (Wight) A.J. Scott	Bass
Cleome amblyocarpa Barratte & Murb.	Cleo
Cornulaca monacantha Delile	Corn
Echinops spinosus L.	Echi
Elymus farctus (Viv.) Rumemark ex Melderis	Elym
Moltkiopsis ciliata (Forssk.) I.M. Johnst.	Molt
Pseudorlaya pumila (L.) Grande	Pseu
Stipagrostis scoparia (Trin. & Rupr.) de Winter	Stip
Zygophyllum album L.f.	Zygo

Landform unit abbreviations

C=Coastal plain
S= Sand plain
M= Saline depressions
D= Sand dunes

Abbreviations of vegetation groups (VG)

(VG)	Species	Abbreviation
1	*Ammophila arenaria-Artemisia monosperma*	Am-Ar
2	*Artemisia monosperma*	Ar
3	*Artemisia monosperma-Zygophyllum album*	Ar-Z
4	*Pancratium maritimum-Thmelaea hirsuta*	P-T
5	*Thmelaea hirsuta-Silene succulenta*	T-S
6	*Artemisia monosperma-Echinops spinosus*	Ar-Ec
7	*Artemisia monosperma*	Ar
8	*Artemisia monosperma-Cleome amblyocarpa*	Ar-Cl
9	*Artemisia monosperma-Echinops spinosus*	Ar-Ec
10	*Ammophila arenaria-Cyperus capitatus*	Am-Cy
11	*Ammophila arenaria*	Am
12	*Ammophila arenaria-Pancratium maritimum*	Am-P
13	*Ammophila arenaria-Tamarix nilotica*	Tm-Am
14	*Zygophyllum album*	Z
15	*Arthrocnemum macrostachyum*	Arth
16	*Zygophyllum album-Arthrocnemum macrostachyum*	Z-Arth
17	*Zygophyllum album-Juncus rigidus*	Z-J
18	*Arthrocnemum macrostachyum-Frankenia hirsuta*	Arth-F