Journal of Coastal Conservation 4: 79-86, 1998

Vegetation zonation and management in the Damietta estuary of the River Nile

Khedr, Abdel-Hamid A.

Botany Department, Faculty of Science, Mansoura University, Box 34517, New Damietta, Egypt; Fax +20 57 325503

Abstract. The zonation of the vegetation along the saline and freshwater marshes of the Damietta estuary of the Nile River was studied from near the river mouth to 20 km upstream. Downstream, the estuarine water is almost stagnant and highly saline with high concentrations of nutrients. This makes the habitat unsuitable for euhydrophytes. Upstream, the vegetation consists mostly of freshwater macrophytes. 75 sampling plots were established in representative stands of the upshore and upstream vegetation zones. Classification and ordination of the data revealed seven vegetation types, indicated A - G. The dominant species of the saline marshes were *Phragmites australis, Tamarix nilotica* and *Arthrocnemum macrostachyum* (**A**), *Zygophyllum aegyptium* and *Polygonum equisetiforme* (**B**), *Cynodon dactylon* and *Suaeda vera* (C). In the freshwater marshes the dominants were: *Ludwigia stolonifera, Persicaria lapathifolia* (**D**), *Typha domingensis* (**E**), *Eichhornia crassipes* (**F**) and *Ceratophyllum demersum* (**G**). The first axis of the ordination axis obtained with Detrended Correspondence Analysis can be associated with the upstream gradient. It separates the salt marsh vegetation groups from those of the freshwater marshes. Plant species richness increased upshore along both saline and freshwater marshes. The concentration of dominance increased upstream.

Some aspects of proper management of estuarine vegetation are mentioned.

Keywords: Estuarine community; Multivariate analysis; Salinity; Species diversity.

Nomenclature: Täckholm (1974) and Bolous (1995).

Introduction

Estuaries have a unique combination of physical features, associated with their shape, catchment area, connection to the sea and tidal regime. Moreover, there is a great variety of human impacts: building of dams, impoundment, pollution, industrial and residential developments, recreation and other activities in both the estuary and its catchment area.

The construction of dams and barrages in the Nile River caused great environmental changes, including the destruction of many natural habitats and the formation of artificial ones like cultivated fields on river islands and aquaculture plots. Prior to the construction of the Aswan High Dam, the average sediment discharge at Aswan was 160 million ton/yr. Of this quantity 100 - 115 million m^3/yr was discharged into the sea (Sestini 1989). The construction of the dam in 1964 brought the downstream flow of the river and the sediment discharge to the Mediterranean Sea under full control. This, in turn aggravated coastal erosion and retreat of the delta shoreline (Kassas 1971; Sharaf El Din 1974; Smith & Abdel Kader 1988). Relative sea level rise at the delta (1-5 mm/yr) is also of importance (El Asmar 1991; Stanley 1990). The river mouth at the Damietta estuary, the study area, is one of the areas along the delta coast where erosion (18m/yr) is most pronounced (Frihy & Khafagy 1991).

Vegetation along delta shores is characterized by a range of physically distinct and dynamic habitats which are close to each other. Physical factors such as salinity, exposure and flooding vary greatly across the supralittoral zone. Sudden changes by floods and storms can remove large parts of the habitats. This can hamper recolonization because parent plants and seed banks are destroyed. The vegetation of the Mediterranean Nile delta coast of Egypt has been the subject of floristic and plant ecological studies for several years (e.g. Mashaly 1987; Khedr 1989, 1997; Zahran et al. 1990; Serag 1991; Shaltout et al. 1995; Khedr & El-Demerdash 1997). The Damietta estuarine environment differs from that of the Nile river and the Mediterranean delta coast in terms of physiography, nutrient levels and salinity. The topography (site elevation) of the estuarine marsh directly controls the submergence/emergence ratio of any site through its interaction with the tides. That, in turn, influences other factors such as soil salinity, soil type and texture which have their effects on the distribution of various plant species within the marsh.

The present study aims at identifying the plant communities of the Damietta estuary and their diversity and distribution. It also provides baseline information for future studies on vegetation succession.

Study area

The Nile River flows from Lake Tanganyika in Tanzania (3° S) to the Mediterranean Sea (31° 15' N) over a distance of ca. 6625 km. At Cairo the river separates into two branches, Damietta and Rosetta. Each of them measures ca. 240 km in length; the average width is 300 m (Said 1981). In 1989, a barrage was constructed to the south of the city of Damietta, the Faraskur Dam. It was built to renew the water of the estuary at different times every year. The length of the Damietta estuary is ca. 13 km. It is completely isolated from the Nile, further upstream by the Faraskur dam (Fig. 1).

At the Damietta mouth of the Nile, several constructions for coastal defence have been made: a pier, a sea wall and several groins. They should stabilize the estuary and protect the Ras El Barr beach resort. The Damietta estuary is characterized by very low tides. Thus, the water movement between the estuary and the sea is mainly controlled by the volume of fresh but polluted water from towns and agricultural fields and by the turbulence of the sea water.

Wind characteristics were recorded in the study area from 1850 to 1950 (Thabet 1963). Predominant winds come from the west to north sector in NW direction. The heaviest storms are from west to northeast. Both NW winds and storms generate strong waves that attack the delta coast. Wave heights range from 1-1.5 m and wave periods from 5-7 sec. Average annual rainfall is only 102mm, the winter being the rainy season. Monthly maximum/minimum temperatures vary from 31.3 / 21.5 °C in August to 18.4 / 8.2 °C in January. The maximum relative humidity, occurring in December, is 54%.

Methods

Vegetation analysis

The field survey was carried out in 1995, in April and May, the period of maximum vascular plant species diversity. Along the main channel of the Damietta estuary, 75 sample plots (10m ×10m) were established in 21 transects (20m to 100m long), most of them on the slope and terrace of the estuary, some on the slope, water edge and in open water zones in freshwater marshes at the front of the Faraskur barrage. Each plot was homogeneous in terms of physiographic position and vegetation structure. All plant species were recorded in the plot; the cover of the perennial species was estimated with the line intercept method (Canfield 1941) and the relative cover of each species was calculated. Cover data were transformed into an ordinal scale (van der Maarel 1979).

Soil and water analysis

In each plot, soil samples were taken at four places,

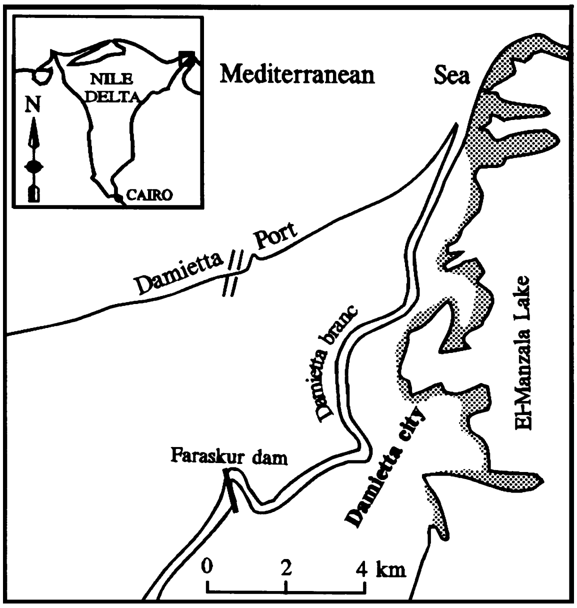

Fig. 1. Map showing the Damietta estuary of the Nile River.

collected from each horizon down to 25 cm. The samples were mixed per plot and air dried, then passed through a 2-mm sieve.

Soil texture, soil moisture content and calcium carbonate content were determined following the procedures of the United States Salinity Laboratory staff (Anon. 1954) and Jackson (1962). Soil pH and electrical conductivity (EC) were measured with a digital pH-meter (model 5995) and YSI conductivity meter (model 35) respectively. Oxidizable organic carbon was determined using the Walkley and Black rapid titration method (Black 1965). Soil extracts of 5 gm soil samples were prepared using 2.5/0 v/v glacial acetic acid. From these extracts the following elements were analysed: Na, K and Ca (flame photometry), Mg (atomic absorption spectrophotometry) and P (molybdenum blue method). All these procedures were according to Allen et al. (1974). The N-total was determined using the micro-Kjeldahl method. The height of the estuary banks was estimated with help of a cross-section prepared in the field using a clinometer.

Water samples were collected four times from January to October, 1995, from the main channel of the estuary and from the Nile river at 10 fixed sites, usually 2km apart, along the salinity gradient. Salinity was determined *in situ* with an electric conductivity meter (YSI, Model 35). Total-P, total-N and total alkalinity were analysed according to Allen et al. (1974).

Data analysis

The data set – 75 plots×37perennial plant species– was classified with TWINSPAN – Two-Way Indicator Species Analysis (Hill 1979a). The groups of plots were identified as vegetation types on the basis of their indicator species.

In order to reveal the gradient structure of the data set, Detrended Correspondence Analysis (Hill 1979b) was applied. The DCA axes were regressed against environmental variables, notably upstream and upshore distance of the plots. Differences in the edaphic variables between the vegetation types were tested statistically with Tukey's studentized test of unequal means (Anon. 1993).

Species richness was calculated per vegetation type as mean number of species per plot. Species turnover, i.e. species replacement along the main environmental gradient, was calculated as the ratio between the total number of species recorded in a certain type and its species richness (Wilson & Shmida 1984). Evenness refers to the distribution of cover values assigned to each species (van der Maarel 1988). It is usually measured in an indirect way, as heterogeneity diversity relative to its maximum, e.g. Shannon's H' relative to its maximum H'_{max} for a given S ($E = H'/H'_{max}$), where $H' = -\Sigma P_i \ln P_i$. The Simpson-index was used to calculate the relative concentration of dominance within each plot ($C = \Sigma P_i^2$), where P_i is the relative cover of the ith species (see Pielou 1975).

Results

The results of the water analyses in the main channel of the Damietta estuary showed a general decrease in salinity values (Fig. 2a). Water salinity (EC) decreased gradually from 38.4 ± 7.4 mS/cm near the river mouth to 26.0 ±6.1 mS/cm at the Faraskur barrage. Then it abruptly dropped in front of the barrage (Nile water samples) to 0.9 ±0.1mS/cm. The water of the Damietta estuary is highly eutrophic. Total alkalinity, total N and total P were relatively high in the middle section of the estuary (Fig. 2c-d). Total-P values varied from 1.0 ±0.48 mg/l to 33.2 ±3.9 mg/l and total nitrogen ranged from 0.85 ±0.21 mg/l to 16.0 ±3.87 mg/l. Total alkalinity was relatively high, ranging from 1.3 ±0.4 meq/l to 4.9 ±0.3 meq/l.

The TWINSPAN analysis resulted in the distinction of seven groups, called vegetation types A-G. These occurred in a zonation upstream from the river mouth up to the Faraskur barrage and along the freshwater marshes in the front of the barrage (Table 1).

Type **A** is found on the slope of the estuary which is subjected to changes in water level. Amongst the dominant species, *Arthrocnemum macrostachyum* (Table 1, col. A) was dominant on the exposed shores of low banks in the downstream part near the river mouth. *Phragmites australis* and *Tamarix nilotica* dominated where the bank was narrow and steep, especially in the upstream part of the estuary. Both *Phragmites australis* and *Tamarix nilotica* usually form mixed or monospecies stands.

Type **B** occupied the sand sheets upshore. The main dominant species is *Zygophyllum aegyptium*.

Type **C** occupies the dry terrace of the estuary. The indicator species, *Cynodon dactylon* and *Suaeda vera* show a clear zonation pattern upstream the Faraskur barrage, which becomes less pronounced along the freshwater marshes in front of the barrage.

Types **D**, **E**, **F** and **G** characterize the slope, water

Table 1. Relative cover values of perennial and annual species recorded in the vegetation types A-G distinguished in the Damietta estuary. Perennial species occurring in one type only with a cover < 5 % are listed below; < = cover < 1%. Indicator species characterizing subgroups in the TWINSPAN procedure are given in bold.

	Vegetation types						
	A	B	C	D	E	F	G
Perennials							
Arthrocnemum macrostachyum	25	11	1	-	-	-	-
Phragmites australis	55	4	7	10	-	-	-
Tamarix nilotica	30	-	1	-	-	-	-
Cynodon dactylon	<	2	40	2	-	-	-
Atriplex portulacoides	7	1	1	-	-	-	-
Halocnemum strobilaceum	<	6	-	-	-	-	-
Cynanchum acutum	<	2	<	-	-	-	-
Suaeda vera	2	2	27	1	-	-	-
Juncus acutus	<	-	3	7	-	-	-
Imperata cylindrica	1	-	4	-	-	-	-
Aster squamatus	<	-	<	-	-	-	-
Bassia indica	<	-	2	-	-	-	-
Inula crithmoides	1	8	<	-	-	-	-
Polygonum equisetiforme	-	22	3	-	-	-	-
Pluchea dioscoridis	-	4	1	5	-	-	-
Zygophyllum aegyptium	-	40	-	-	-	-	-
Alhagi maurorum	-	-	5	-	-	-	-
Persicaria lapathifolia	-	-	-	30	10	-	-
Ludwigia stolonifera	-	-	-	16	8	-	-
Scirpus littoralis	-	-	-	2	2	-	-
Cyperus articulatus	-	-	-	7	-	-	-
Echinochloa stagnina	-	-	-	-	15	17	-
Typha domingensis	-	-	-	-	35	3	-
Eichhornia crassipes	-	-	-	-	-	57	15
Saccharum spontaneum	-	-	-	-	-	5	-
Azolla filiculoides	-	-	-	-	-	3	15
Ceratophyllum demersum	-	-	-	-	-	-	40
Annuals							
Amaranthus lividus	-	-	10	50	-	-	-
Ammi majus	-	-	23	25	-	-	-
Anagallis arvensis	-	-	-	50	-	-	-
Avena fatua	-	-	17	-	-	-	-
Brassica rapa	-	-	7	25	-	-	-
Brassica tournefortii	-	-	10	25	-	-	-
Capsella bursa-pastoris	-	-	33	25	-	-	-
Chenopodium album	-	-	17	50	-	-	-
Chenopodium ambrosoides	-	-	3	50	-	-	-
Conyza bonariensis	-	-	-	50	50	-	-
Cutandia memphetica	25	40	-	-	-	-	-
Echinochloa colona	-	-	-	-	50	-	-
Cyperus rotundus	-	-	-	50	50	-	-
Euphorbia peplus	-	2	7	-	-	-	-
Ifloga spicata	-	40	-	-	-	-	-
Juncus bufonius	21	-	-	-	-	-	-
Malva parviflora	-	-	30	25	50	-	-
Mesembryanthemum crystallinum	11	80	-	-	-	-	-
Plantago major	-	-	-	-	50	-	-
Rumex dentatus	-	-	-	50	100	33	-
Salsola kali	-	40	-	-	-	-	-
Senecio glaucus	-	40	23	-	-	-	-
Solanum nigrum	-	-	10	25	-	-	-
Sonchus maritimus	-	-	17	25	-	-	-
Spergularia marina	21	-	10	-	-	-	-
Urospermum picroides	-	-	13	25	-	-	-
Urtica urens	-	-	10	-	-	-	-

Additional species with cover < 5%: **A**: *Ruppia maritima* 2; *Cyperus laevigatus* <; *Juncus subulatus* 2; *Juncus rigidus* 1; *Atriplex prostrata* 2; **C**: *Schinus terebinthifolius* 3; *Phoenix dactylifera* 3; *Cressa cretica* <; **F**: *Pistia stratiotes* 3; **G**: *Potamogeton pectinatus* 3.

edge and water zone along freshwater marshes in the front of the barrage. The indicator species are emergent creeping plants, e.g. *Ludwigia stolonifera* and *Persicaria lapathifolia* (**D**), *Typha domingensis* (**E**), the floating *Eichhornia crassipes* (**F**) and the submerged *Ceratophyllum demersum* (**G**), respectively.

The Detrended Correspondence Analysis of the plots (Fig. 3) shows that the phytosociological groups obtained are clearly separated along the first axis of this ordination which represents a topographic gradient, particularly upstream. The existing upshore zonation is represented along axis 2.

Linear regression of the DCA axis I scores on the distance upstream (from the river mouth) and upshore (from water zone) showed a highly significant relation (a relation with distance from the river mouth). Regressions of both on DCA axis 2 scores showed very little relation, the greatest contribution to the regression being made by distance upshore.

Soils of type **A**, characterizing the wet saline marsh of the estuary, had the highest mean values of EC, Na and $CaCO_3$ and the lowest values of silt+clay and Mg (Table2). Soils of type **B** occupy the most elevated sites and showed the lowest mean values for moisture, organic carbon, P, Na and K. Soils of type **C** have the highest mean values of Mg.

The lowest mean values of soil-N and bank height were recorded in type **D**. Type **E** had the highest mean values for moisture and silt+clay. Soils of types **F** and **G**, occurring in the water zone, had the highest amounts of organic carbon and various nutrients (Table 2).

Coefficients of correlation between relative cover values of the dominant plant species and some edaphic

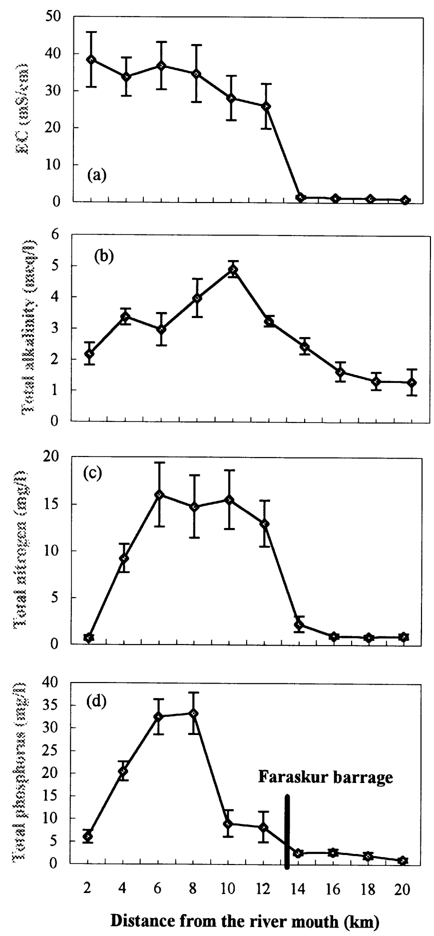

Fig. 2. Mean values (±SD) of seasonal changes in the concentration of (**a**) water salinity (EC); (**b**) total alkalinity; (**c**) total nitrogen and (**d**) total phosphorus along the Damietta estuary as a function of distance from the Mediterranean Sea.

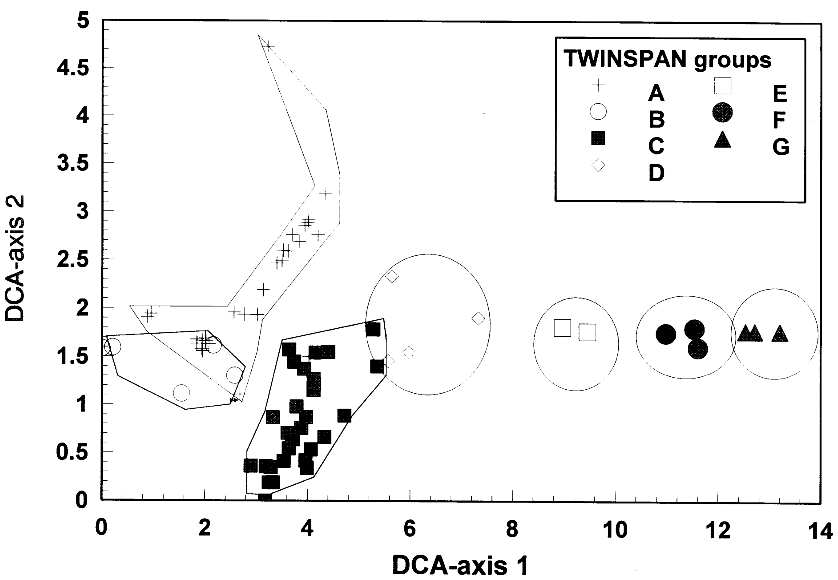

Fig. 3. Detrended Correspondence Analysis of the 75 vegetation plots, axes 1 and 2, with TWINSPAN groups superimposed.

Table 2. Mean and standard deviation of soil characteristics for the vegetation types A-G in the Damietta estuary. Letters added to mean values indicate which values are significantly different according to Tukey's studentized range test at $p < 0.05$.

	A (n = 28)	**B** (n =5)	**C** (n =30)	**D** (n =4)	**E** (n =2)	**F** (n =3)	**G** (n =3)
Bank height (cm)	44.1 ± 13.3 ^{BC}	270.8 ± 89.4 $^{A-D}$	103.0±37.2 ^{AB}	40.0±14.7 ^{B}	–	–	–
Moisture content (%)	25.8±9.05 ^{BDE}	2.6 ± 1.31 ^{ADE}	16.9±11.8 ^{DE}	48.8±12.2 $^{A-CE}$	90.5±10.06 $^{A-D}$	–	–
Silt+clay (%)	7.5±1.78 $^{D-G}$	9.8±4.02	11.8±3.27	16.2±2.99	18.0±4.24	16.7±2.52	12.3±1.53
$CaCO_3$ (%)	14.7±5.0 $^{D-G}$	8.4±4.2	10.0±4.1	3.0±0.9	4.0±1.4	1.67±0.80	2.33±0.80
Organic carbon (%)	0.66±0.26 $^{D-G}$	0.54±0.28 $^{D-G}$	1.45±0.69 $^{D-G}$	3.18±1.4	3.10±0.39	5.13±0.67	5.87±1.16
EC (mS/cm)	14.2±4.26 $^{B-G}$	1.10±0.35	4.94±1.57	1.06±0.28	0.67±0.08	0.58±0.18	0.62±0.11
pH	8.06±0.21	8.00±0.16	8.07±0.16	8.10±18.0	7.85±0.07	7.77±0.15	7.67±0.06
N mg/100g soil	35.61±6.19 ^{FG}	17.3±4.89 ^{FG}	34.39±12.4 ^{FG}	15.10±3.54 ^{FG}	38.25±1.2 ^{FG}	92.67±30.0	115.7±15.0
P mg/100g soil	26.17±4.32	20.20±4.15 ^{FG}	23.74±7.42	25.05±5.33	30.05±1.34	37.97±5.62	35.40±6.55
Na mg/100g soil	1475±366 $^{B-G}$	54±14.4 ^{AC}	675±277 ^{AB}	155.3±34.39	145±22.63	242±62.55	213±16.26
K mg/100g soil	25.3±7.83 $^{CE-G}$	3.28±1.27 $^{C-G}$	51.6±14.9 ^{AB}	35.5±5.07 $^{BE-G}$	79.65±10.8	81.0±18.3	82.0±19.3
Ca mg/100g soil	13.8±8.23	5.2±0.89	11.0±3.06	3.95±1.02	4.35±1.22	1.87±0.65	2.33±0.80
Mg mg/100g soil	13.9±6.94 ^{C}	22.2±12.25 ^{C}	239.5±106 $^{ABD-G}$	36.95±3.01	24.0±4.24	17.7±3.49	14.93±4.99

factors are presented in Table 3. Bank height, soil conductivity and $CaCO_3$ appears to be the most important factors that correlate significantly with the distribution of the dominant species. For example, bank height shows a highly significant positive correlation with the distribution of *Z. aegyptium*, *P. equisetiforme* and *S. vera* and a negative one with wet salt marsh species (e.g. *Arthrocnemum macrostachyum* and *A. portulacoides*) and emergent creeping species (e.g. *Ludwigia stolonifera*) along freshwater marshes.

The total number of species varied from 34 in type **C** to 4 in type **G** (Table 4). Type **A** had the lowest mean values of both species richness (2.6 species/stand) and relative concentration of dominance (C' = 0.19). Type **D** showed the highest mean value of species richness (8.0 species/stand). The highest mean value of species turnover was recorded for type **A** (8.3). The relative concentration of dominance increased upstream; it was higher in vegetation types of the water zone (**F** and **G**) along freshwater marshes (C' = 0.45 and 0.38 respectively), compared with vegetation groups along saline marshes (Table 4).

Table 3. Correlation coefficients (r) between the relative cover values of the dominant species and some edaphic factors. (+) and (–) denote positive and negative values, respectively; (·) indicates non-significant values.

				Soil factor					
	Bank	Silt+	pH	$CaCO_3$	EC	Organic	N	P	
		height	clay (%)		(%)	mS/cm	carbon (%)	(mg/100g soil)	
Species	n								
Arthrocnemum macrostachyum	25	–*	·	·	·	+**	·	·	·
Atriplex portulacoides	12	·	·	·	+**	+**	·	·	·
Tamarix nilotica	9	–*	·	·	+*	+*	·	·	·
Phragmites australis	41	·	·	–*	·	·	·	·	·
Suaeda vera	16	+**	+*	·	·	·	·	·	·
Polygonum equisetiforme	8	+**	+*	·	·	–*	·	·	·
Pluchea dioscoridis	14	·	·	+*	+*	·	·	+*	·
Zygophyllum aegyptium	7	+**	·	·	·	–*	·	·	·
Cynodon dactylon	25	·	·	+*	·	·	·	·	·
Ludwigia stolonifera	6	–*	·	·	+**	·	+*	·	+*
Persicaria lapathifolia	6	–*	+**	·	·	·	+*	+*	·

*, ** denotes significant correlation at $p < 0.05$ and $p < 0.01$, respectively.

Table 4. Diversity indices for vegetation types A - G.

Group	*N* species	Richness	Turnover	Evenness	Dominance
A	22	2.6	8.3	1.95	0.19
B	17	7.1	2.4	1.65	0.26
C	34	6.0	5.7	2.25	0.24
D	25	8.0	3.1	1.73	0.23
E	11	6.6	1.7	1.44	0.25
F	7	4.3	1.6	1.08	0.48
G	4	3.3	1.2	1.12	0.38

Discussion

The Damietta estuary of the Nile River can be considered a more or less natural estuary according to the estuarine classification of Pritchard (1967). The water salinity decreases upstream, which may be attributed to the low river flow, due to regulation. The high concentration of nutrients in the middle section of the estuarine water compared with that of the Nile water and near the river mouth in the present study can be attributed to sewage disposal and industrial effluents from neighbouring towns. This effect was also recorded in other areas (Tebbut 1977; Raymont 1980; Saad & Abbas 1955; Abdel-Hamid et al. 1992; Shaaban-Dessouki et al. 1994). The Damietta estuary is virtually uninhabitable for euhydrophytes. Regulation of the estuary by the Faraskur barrage causes stable water levels and some flush-outs with Nile water every year. This results in a highly eutrophic status of the estuarine water.

The vegetation zonation along the Damietta estuary has been poorly documented up to now. In the present study, classification and ordination techniques clearly separated the vegetation of the saline marshes from that of fresh water marshes. Despite the upshore sequence of plant communities in the Damietta estuary is seldom repeated from one transect to the next up the river. The communities generally show a distinct zonation pattern upstream. The gradient in soil salinity (EC), $CaCO_3$, moisture content, soil-P and silt percentage are among the most important gradients which correlate with the distribution of wetland vegetation (Shaltout 1983; Haase 1990; Sharaf El-Din et al. 1993 and El-Demerdash 1996).

This study shows that considerable variation in soil-N concentration is found between different positions along the gradient. Although nitrogen accumulation is suggested to be related to the successional trends on each part of the gradient, the zonation within each successional stage is probably related to variation in salinity and nitrogen availability which both increased towards the lower end of the gradient (de Leeuw et al. 1991). With increasing nitrogen accumulation in sandy soils during succession, also plant biomass is often increasing (Berendse 1990). Higher amounts of soil-P were found in substrates at lower elevation than at higher elevations. Tentative explanations include the possible entry of phosphorus into the low zone with sedimentation during tidal flooding (Vince & Snow 1954) and low rates of phosphorus uptake in the low zone where total plant density is low.

Regarding the relationship between soil characteristics and plant distribution, soil salinity (EC), moisture content and bank elevation are important factors determining the vertical zonation on salt marshes. Similar results were obtained in several other studies of salt marshes (e.g. Armstrong et al. 1955; Adam 1990; de Leeuw et al. 1991). However, Dawe & White (1982) considered soil salinity not to be a major determinant of zonation within a marsh, because soil salinity is dependent upon a number of factors, including salinity of the inundating water and type and texture of the soil. The prevalence of vegetative reproduction in species of saline conditions (Odum 1958) – and freshwater marshes in this study – may be a factor for zonation since clone formation will increase the scale of vegetation pattern. Some species occur throughout the upstream range (e.g. *Phragmites australis*, *Cynodon dactylon* and *Juncus acutus*) tend to occur near the river, changing from halophytic to glycophytic ecotypes. The distribution of these species seems to be related to inundation rather than salinity. Other species of the Damietta estuary which are found on landward locations near the river mouth, come down towards the river edge on upstream locations, e.g. *Suaeda vera* and *Pluchea dioscoridis*, suggesting salinity control of distribution. It was reported by Odum (1988) for estuarine marshes and by Partridge & Wilson (1989) for marine marshes, that water salinity was the dominant factor controlling plant distribution. The same conclusion was reached experimentally (Rozema et al. 1985; Ewing et al. 1989). However, in the study area, the high correlation of ordination axes with distance upstream coincides with the steady decrease in salinity. Bunt et al. (1982) found that some plant species may be absent either in completely saline or fresh water sites. Such distributions are rare in the study area e.g. with *Bassia indica*.

The upstream limit of some salt marsh species may reflect a lack of substrate at suitable elevations, since banks upstream are often steep. For example, *A. macrostachyum*, *S. vera* and *Juncus acutus* were observed several km further upstream than the furthest occurrences of these species, suggesting that bank morphology rather than water characteristics cause the final upstream limit.

Species richness increased upshore from the low- to high-elevated banks along the fresh and saline water marshes. The results of this study agree with Odum's (1988) suggestion that there is lower plant species diversity in salt marshes than in freshwater marshes. At the higher elevations of the marsh, more opportunities exist for variation in replacement of species and a greater diversity of higher plants is often encountered. Moreover, the disturbed dredge banks along the fresh water marshes in the study area may even raise species richness artificially.

This study has demonstrated that, on the basis of floristic and soil characteristics, the estuarine vegetation of the Damietta branch of the Nile River is comparable to vegetation of other deltas in the Mediterranean littoral environment. Some dominant species e.g. *Polygonum equisetiforme*, *Suaeda vera* form special elements in the Damietta estuary since these species are not recorded as dominants elsewhere in the Nile Delta.

The severe coastal erosion reported in recent years at the Damietta river mouth (Frihy & Khafagy 1991; Jelgersma & Sestini 1992; El-Asmar 1994), call for a re-evaluation of the area's management. At present, various protective structures (a pier, a sea wall and several groins) have been built, partly to stabilize the estuary and partly to protect the Ras El Barr beach resort. However, it is important in any conservation proposals, particularly regarding shore vegetation, to avoid providing excessive physical protection in the belief that it may promote the preservation of biodiversity. Frequently, the opposite is true: physical disturbance may create habitat variation, which stimulates the conservation of biodiversity. Further work is required to evaluate the survivorship rate of the most common species along the estuarine banks, and this will help to avoid additional coastal erosion.

Acknowledgements. The author is grateful to Professor K. H. Shaltout, Tanta University who read an earlier draft of this manuscript and for his useful comments, and Dr. M.A. Deyab, Mansoura University, for assistance in some field trips. I would like to thank Dr. F. van der Meulen, University of Amsterdam, for his useful comments and suggestions which greatly improved the manuscript.

References

Anon. 1954. *Diagnosis and improvement of saline - alkaline soils.* U.S. Salinity Laboratory Staff, U.S. Agriculture Handbook No. 60, Washington, DC.

Anon. 1993. *SPSS for windows. Base system userÕs guide. Release 5.0.* Marija J. Norusis / SPSS Inc., Chicago, IL.

Abdel-Hamid, M.I., Shaaban-Dessouki, S.A. & Skulberg, O. M. 1992. Water quality of the river Nile in Egypt. I. Physical and chemical characteristics. *Arch. Hydrobiol*. 90: 283-310.

Adam, P. 1990. *Salt marsh ecology*. Cambridge University Press, Cambridge.

Allen, S.E., Grimshaw, H.M., Parkinson, J.A. & Quarmby, C. 1974. *Chemical analysis of ecological materials.* Blackwell, Oxford.

Armstrong, W., Wright, E.J., Lythe, S. & Gaynard, J.T. 1985. Plant zonation and the effects of spring neap tidal cycle on soil aeration in the Humber salt marsh. *J. Ecol.* 73: 323-339.

Berendse, F. 1990. Organic matter accumulation and nitrogen mineralization during secondary succession in heathland ecosystems. *J. Ecol.* 78: 413-427.

Black, C.A. 1965. Methods of soil analysis. Part 2. Soil Society of America, Madison, WI.

Boulos, L. 1995. *Flora of Egypt, checklist.* Al Hadra Publishing, Cairo.

Bunt, J.S., Williams, W.T. & Clay, H.J. 1982. Riverwater salinity and the distribution of mangrove species along several rivers in north Queensland. *Aust. J. Bot.* 30: 401-412.

Canfield, R. 1941. Application of the line interception method in sampling range vegetation. *J. For.* 39: 288-294.

Dawe, N.K. & White, E.R. 1982. Some aspects of vegetation ecology of the little Qualicum River estuary, British Columbia. *Can. J. Bot.* 60: 1447-1460.

de Leeuw, J., van den Dool, A., de Munck, W., Nieuwenhuize, J. & Beeftink, W.G. 1991. Factors influencing the soil salinity regime along an intertidal gradient. *Estuarine Coastal Shelf Sci*. 32: 87-97.

El-Asmar, H.M. 1991. *Old shorelines of the Mediterranean coastal zone of Egypt in relation with sea level changes.* Ph.D. Thesis, Mansoura University, Mansoura.

El-Asmar, H.M. 1994. Severe coastal damage along Ras El Bar, north of the Nile delta: An effect of the construction of detached breakwater system. *Egypt. J. Geol.* 38: 793-812.

El-Demerdash, M.A. 1996. The vegetation of the Farasan islands, Red Sea, Saudia Arabia. *J. Veg. Sci.* 7: 81-88.

Ewing, K., Earle, J.C., Piccinin, B. & Kershaw, K.A. 1989. Vegetation patterns in James Bay coastal marshes. II. Physiological adaptation to salt-induced water stress in three halophytic graminoides. *Can. J. Bot.* 67: 521-528.

Frihy, O. & Khafagy, A.A. 1991. Climate and induced changes in relation to shorelines migration trends at the Nile delta promontories, Egypt. *Catena* 18 (2): 197-221.

Haase, R. 1990. Community composition and soil properties in northern Bolivian savanna vegetation. *J. Veg. Sci.* 1: 345-352.

Hill, M.O. 1979a. *TWINSPAN-A FORTRAN program for arranging multivariate data in an ordered two way table by classification of individual and attributes.* Section of Ecology and Systematics, Cornell University, Ithaca, NY.

Hill, M.O. 1979b. *DECORANA - A FORTRAN program for detrended correspondence analysis and reciprocal averaging*. Section of Ecology and Systematics, Cornell University, Ithaca, NY.

Jackson, M.L. 1962. *Soil chemical analysis.* Constable and Co. Ltd, London.

Jelgersma, S. & Sestini, G. 1992. Implication of a future rise in sea-level on the coastal lowlands of the Mediterranean. In: Jeftic, L., Milliman, J.D. & Sestini, G. (eds.) *Climatic change and the Mediterranean. Environmental and societal impacts of climatic change and sea-level rise in the Mediterranean region*, pp. 282-303. Edward-Arnold, London.

Kassas, M. 1971. The river Nile ecological system, a study towards an international programme. *Biol. Conserv.* 4: 19-25.

Khedr, A.A. 1989. *Ecological studies on Lake Manzala, Egypt.* M. Sc. Thesis, Faculty of Science, Mansoura University, Mansoura.

Khedr, A.A. 1997. Aquatic macrophyte distribution in Lake Manzala, Egypt. *Int. J. Salt Lake Res.* 5: 221-239.

Khedr, A.A. & El-Demerdash, M.A. 1997. Distribution of aquatic plants in relation to environmental factors in the Nile delta. *Aquat. Bot.* 56: 75-86.

Mashaly, I.A. 1987. *Ecological and floristic studies of Dakahlia-Damietta region.* Ph.D. Thesis, Faculty of Science, Mansoura University, Mansoura.

Odum, W.E. 1988. Comparative ecology of tidal freshwater and salt marshes. *Annu. Rev. Ecol. Syst.* 19: 147-176.

Partridge, T.R. & Wilson, J.B. 1989. Methods for investigating vegetation / environment relations - a test using the salt marsh vegetation of Otago, New Zealand. *N. Z. J. Bot.* 27: 35-47.

Pielou, E.C. 1975. *Ecological diversity.* Wiley, Interscience, New York, NY.

Pritchard, D.W. 1967. What is an estuary? Physical view point. In: Lauff, G.H. (ed.) Estuaries. *Am. Acad. Adv. Sci.* 38: 3-5.

Raymont, J.E.G. 1980. *Plankton and productivity in the oceans. 2nd ed. Vol. 1. Phytoplankton*. Plenum Press, New York, NY.

Rozema, J., Bijwaard, P., Prast, G. & Broekman, R. 1985. Ecophysiological adaptation of coastal halophytes from foredunes and salt marshes. *Vegetatio* 62: 499-521.

Saad, M.A.H. & Abbas, M.H. 1985. Limnological investigations on the Rosetta branch of the Nile. II. Seasonal variations of nutrients. *Freshwater Biol.* 15: 655-660.

Said, R. 1951. *The geological evolution of the River Nile.* Springer-Verlag, New York, NY.

Serag, M.S. 1991. *Studies on the ecology and control of aquatic and canal bank weeds of the Nile Delta, Egypt.* Ph.D. Thesis, University of Mansoura, Mansoura.

Sestini, G. 1989. Nile Delta: a review of depositional environments and geological history. In: Wahteley, M.K.G. & Pickering, K.T. (eds) *Deltas: sites and traps for fossil fuels*, pp. 147-154. Blackwell, Oxford.

Sestini, G. 1992. Implications of climatic changes for the Nile delta. In: Jeftic, L., Milliman, J.D. & Sestini, G. (eds.) *Climatic change and the Mediterranean. Environmental and societal impacts of climatic change and sea-level rise in the Mediterranean region*, pp. 535-601. Edward-Arnold, London.

Shaaban-Dessouki, S.A., Soliman, A.I. & Deyab, M.A. 1994. Seasonal aspects of phytoplankton in Damietta estuary of the river Nile as a polluted biotope. *J. Environ. Sci.* 7: 259-253.

Shaltout, K.H. 1983. *An ecological study of Thymelaea hirsuta (L.) Endl. in Egypt.* Ph.D. Thesis. Tanta University, Tanta.

Shaltout, K.H., El-Kady, H.F. & El-Sodany, Y.M. 1995. Vegetation analysis of the mediterranean region of the Nile Delta. *Vegetatio* 166: 73-83.

Sharaf El Din, S.H. 1974. Longshore sand transport in the surf zone along the Mediterranean Egyptian coast. *Limnol. Oceanogr.* 19 (2): 182-189.

Sharaf El-Din, A., El-Kady, H. F. & Sodany, Y. 1993. Gradient analysis ofthe common species in the saline and marshy habitats in the Nile delta. *Feddes Repert.* 104: 387-394.

Smith, S.E. & Abdel Kader, A. 1955. Coastal erosion along the Egyptian delta. *J. Coastal Res.* 4: 245-255.

Stanley, D.J. 1990. Recent subsidence and north-east tilting of the Nile delta, Egypt. *Mar. Geol.* 94: 147-154.

Täckholm, V. 1974. *Students flora of Egypt.* Cairo University, Cairo.

Tebbutt, T.H.Y. 1977. *Principles of water quality control. Handbook*. 2nd. ed. Pergamon Press, London.

Thabet, R. 1963. *El-Gamil inlet, results of field measurements.* Suez Canal Authority Center, Ismaila. (In Arabic.)

van der Maarel, E. 1979. Transformations of cover-abundance values in phytosociology and its effects on community similarity. *Vegetatio* 39: 97-114.

van der Maarel, E. 1988. Species diversity in plant communities in relation to structure and dynamics. In: During, H.J., Werger, M.J.A. & Willems, J.H. (eds.) *Diversity and pattern in plant communities*, pp. 1-14. SPB Academic Publishing, The Hague.

Vince, S.W. & Snow, A.A. 1984. Plant zonation in an Alaskan salt marsh. Distribution, abundance and environmental factors. *J. Ecol.* 72: 651-667.

Wilson, M.V. & Shmida, A. 1984. Measuring Beta diversity with presence absence data. *J. Ecol.* 72: 1055-1064.

Zahran, M.A., El-Demerdash, M.A. & Mashaly, I.A. 1990. Vegetation types of the deltaic Mediterranean coast of Egypt and their environment. *J. Veg. Sci.* 1: 305-310.

Received 10 June 1996;
Revision received 6 December 1996;
Final revision received 12 September 1997;
Accepted 12 September 1997.