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Habitat and vegetation of Lake Edku, Egypt

Kamal H. Shaltout*, Magdi M. Ali, Loutfy M. Hassan*** and Tarek M. Galal*****

**Botany Department, Faculty of Science, Tanta University.*
*** Botany Department, Faculty of Science, South Valley University, Aswan*
**** Botany Department, Faculty of Science, Helwan University*

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The floristic features and plant communities of Lake Edku were analyzed using 150 sampled stands representing the apparent variation in habitats and vegetation. A total of 114 species of vascular plants were recorded. Life forms range from hydrophytes to phanerophytes, with the most species being therophytes, followed by geophytes-helophytes and hydrophytes. Four main habitats, differentiated into 11 zones, were recognized in this lake; 1- lake proper (includes shoreline, water edge and open water), 2- drain mouths (include terraces, slopes, water edge and open water), 3- islets, and 4- fish farms (include shoreline, water edge and open water). The vegetation of the drain and fish farm open waters is the most similar among the 11 zones. The drain slopes have the highest species richness), while the lake water edges have the lowest. Multivariate analysis of the vegetation and environmental variables of the 150 sampled stands led to the recognition of 15 vegetation groups. These groups were separated on the basis of the moisture gradient from the shoreline to the open water. They are named after their diagnostic species as follows: 1) *Eichhornia crassipes,* 2) *Echinochloa stagnina-Eichhornia crassipes,* 3) *Ceratophyllum demersum-Eichhornia crassipes,* 4) *Potamogeton pectinatus,* 5) *Cyperus articulatus,* 6) *Typha domingensis,* 7) *Phragmites australis,* 8) *Arundo donax,* 9) *Juncus acutus-Typha domingensis,* 10) *Phragmites australis-Typha domingensis,* 11) *Halocnemum strobilaceum-Sarcocornia fruticosa,* 12) *Rumex dentatus-Suaeda vera,* 13) *Bassia indica-Limbarda crithmoides,* 14) *Centaurea calcitrapa* and 15) *Cynodon dactylon-Medicago polymorpha.* The vegetation groups (i.e. communities) representing the open water zones were less diverse than those of the other groups particularly those of the shorelines.

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Key words: Diversity, flora, Lake Edku, Mediterranean coast, vegetation.

Introduction

Lake Edku is situated at the north west of the Nile Delta. The history of this lake was not known until the 9th century (Mahmoud, 1967). It is a shallow brackish water basin extending about 19 km south of Abu-Qir Bay from east to west. It is adjoining the Mediterranean coast at latitude 31° 15´ N and longitude 30° 15´ E. It has an average width of 6 km with an average depth of about one meter (Fig. 1). The present area of the lake is about 126 km^2 (El-Shenawy, 1994). The lake is directly connected with the Mediterranean Sea at its western extremity through a narrow channel (Boughaz EL-Maadiya). Lake Edku receives large quantities of drainage water (83-280 x 10^6 m^3 day^{-1}) released from agricultural land of Beheira Province via three main drains (Edku, El-Bouseily and Barzik) discharging into the eastern part of the lake through the extension of Edku Drain (Shriadah & Tayel, 1992). Seawater may also be introduced into the lake during windy days, invading the area of the lake-sea connection (Boughaz El-Maadiya). However, the normal flow of the lake water will expel quickly any seawater that may be introduced into the lake. The water level in the lake varies from that of the sea with a maximum of 0.6 m. Owing to the permanent connection of the lake with the sea, any considerable rise in its level or the level of the sea will soon set a lake sea current or sea lake current, respectively. Such fluctuations usually follow the amounts of water discharged into the lake by the drains (El-Masry, 1961).

Lake Edku is not stable because it is subjected to huge inputs of terrigenous and anthropogenic nutrients from drain discharge, sewage and agricultural runoff as well as reclamation programs. These nutritional conditions make the lake biologically productive. Several years ago, it was classified among the oligotrophic lakes (Gharib, 1999). The drainage water introduces large amounts of nutrients and terrestrial organic matter. Nowadays, many skin diseases appeared on the Edku fishermen from continuous exposure to the contaminated water (Shakweer *et al.*, 1993). The approximate number of fish boats in Lake Edku was about 1200 in 1997, while that of fishermen was about 3600 with a fish production of about 3000 kg $year^{-1}$ (Anonymous, 2000).

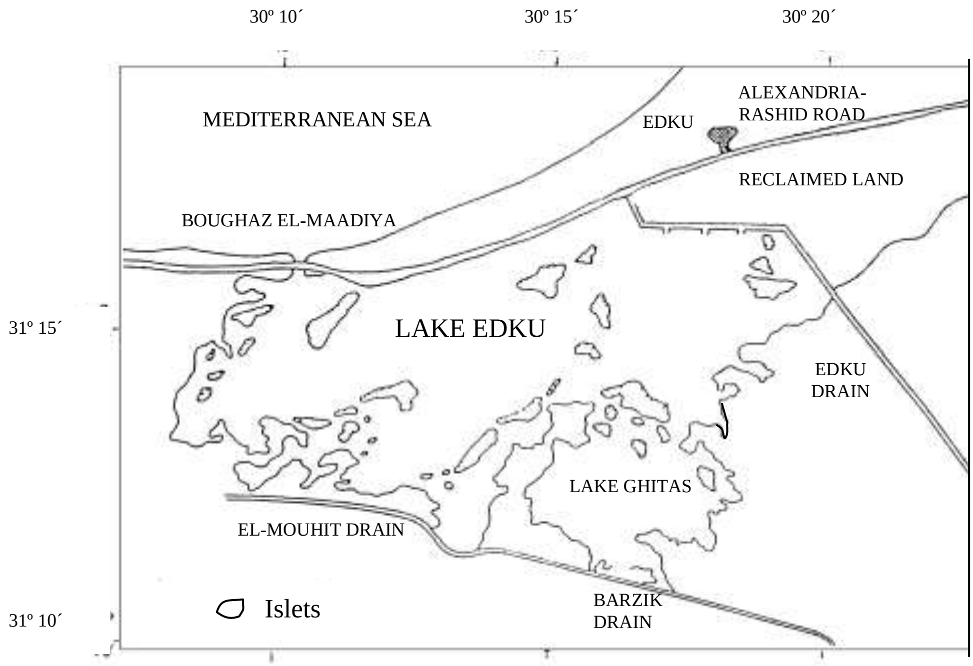

Fig. 1. Location map of Lake Edku (after El-Shenawy 1994).

Table 1. Long term averages (1950-1975) of the metereological data of two stations in the study area (Anonymous 1980).

Metereological variable	Rosetta		Dekheila	
	Range	Mean	Range	Mean
Maximum air temperature (ºC)	18.1-30.4	24.6	17.7-29.5	24.1
Minimum air temperature (ºC)	10.8-23.4	17.0	9.6-23.5	16.5
Mean air temperature (ºC)	13.0-26.3	19.8	13.6-26.4	20.2
Relative humidity (%)	65.0-72.0	69.0	62.0-71.0	66.0
Evaporation (mm day^{-1})	3.3-4.8	4.2	5.5-8.1	6.9
Rainfall (mm $month^{-1}$)	-	16.1	-	15.0

The climatic features prevailing in the study area (1950-1975) indicate that January is the coldest month, while August is the hottest. The mean minimum air temperature ranges between 16.5 °C at Dekheila and 17 °C at Rosetta, while the mean maximum ranges between 24.1 °C at and 24.6 °C (Table 1). Mean relative humidity ranges between 66% at Dekheila and 69% at Rosetta. Mean evaporation rate varies between 4.2 mm day^{-1} at Rosetta and 6.9 mm day^{-1}at Dekheila, while mean monthly rainfall ranges between 15 mm at Dekheila and 16.1 mm at Rosetta.

Although many studies were conducted on the hydrography, chemical and biological characteristics of Lake Edku (Gharib & Soliman, 1998 and Gharib, 1999). Few detailed studies were carried out on its vegetation (Tadros & Atta, 1958; El-Masry, 1961 and El Shenawy, 1994)

The aim of the present work is to assess the habitat types of Lake Edku and to analyze its floristic features in terms of species composition, diversity, abundance and behavior of the common species. It aims also at identifying the plant communities and the environmental factors that affect their distribution using the multivariate analysis.

Materials and methods

a) Vegetation

One hundred and fifty stands were selected to represent the apparent variation in the vegetation physiognomy and habitat types of Lake Edku (lake proper, drains, islets and fish farms). The stand size was about 20 x 20 m in all habitats (approximates the minimal area of the plant communities) except for the drains and lake shores where the length and width of each stand varied according to the extension of plant cover and/or nature of lake shore or drain. Each stand was observed seasonally throughout one year (autumn 2002 to autumn 2003). During each visit, the stands were surveyed and the following data were recorded: list of species, determining the first and second dominant species, visual estimate of the total cover and the cover of each species (%), and the physical changes occurring in each stand (control of aquatic plants, grazing and firing). Identification and nomenclature were according to Täckholm (1974), Boulos & El Hadidi (1984), El Hadidi & Fayed (1994/1995) and Boulos (1995, 1999, 2000 and 2002). Life forms of the species were identified following the Raunkiaer scheme (Raunkiaer, 1937).

b) Data analysis

Wisconsin polar ordination (Bray & Curtis, 1957) and agglomerative clustering techniques were applied to ordinate and classify the zonal vegetation of the water bodies, based on Sørensen similarity coefficient (Kruscal, 1964). Two-way indicator species analysis (TWINSPAN) and Detrended Correspondence Analysis (DCA) were applied to the matrix of cover estimates of 112 species in 150 stands in Lake Edku (Hill, 1979a, b). The relationship between the vegetation and soil gradients was assessed using the ordination diagram produced by principal component analysis (PCA) (Kent & Coker, 1992). Species richness (alpha-diversity) for each vegetation group was calculated as the average number of species per stand. Species turnover (beta-diversity) was calculated as a ratio between the total number of species recorded in a certain vegetation group and its alpha diversity (Whittaker, 1972). Relative evenness or equitability (Shannon-Weaver index) of the importance value of species was expressed as $\hat{H} = -\Sigma^{s}_{i=1} Pi (\log Pi)$, where S is the total number of species and Pi is the relative importance value (relative cover) of the i^{th} species. The relative concentration of dominance is the second group of heterogeneity indices and is expressed by Simpson's index: $D= 1/C$ {$C = \Sigma^{s}_{i=1} (Pi)^2$, where S is the total number of species and Pi is the relative importance value (relative cover) of species} (Pielou, 1975 and Magurran, 1988). The simple linear correlation coefficient (r) was calculated for assessing the relationship between the estimated soil variables on one hand, and the community variables on the other hand. The variation in the soil variables in relation to the vegetation groups were assessed using one-way analysis of variance (ANOVA). These techniques were according to SPSS software (SPSS, 1999).

Results

Characteristics of the habitat types

One hundred and fourteen species belonging to 95 genera and 37 families were recorded in Lake Edku (Tables 2 & 3). The life form spectrum showed that therophytes represent 44.5% of the total species (Fig. 2), followed by geophytes–helophytes (19.3%), hydrophytes (12.6%), chamaephytes (10.9%), hemicryptophytes (7.6%) and phanerophytes (5%).

Four main habitats, differentiated into 11 zones, were recognized in this lake: 1-lake proper (includes shoreline, water edge and open water), 2-

drains (include terraces, slopes, water edge and open water), 3- islets, and 4- fish farms (include shoreline, water edge and open water) (Tables 2 & 3). Sixty-nine species (61.6% of the total species) were recorded along the lake shorelines, of them 17 were recorded only in this zone (*Atriplex leucoclada, Cakile maritima,* and *Raphanus raphanistrum*). Thirty-four species (30.4% of the total species) were recorded along the lake water edge, with only one unique species (*Atriplex dimorphostagia*). Lake open water had 24 species (21.4% of the total species), with only two unique species (*Persicaria lapathifolia* and *Marsilea aegyptiaca*). Sixty-five species (58% of the total species) were recorded along the drain terraces, 16 species of which were recorded only in this zone (*Bromus rubens, Convolvulus arvensis,* and *Portulaca oleracea*). Drain slopes had 28 species (25% of the total species), while drain water edge had 29 species (25.9% of the total species) and drain open water had 12 species (10.7% of the total species).

Twenty-four species (21.4% of the total species) were recorded in the lake islets, of which three were recorded only in this habitat (*Halocnemum strobilaceum*, *Scirpus litoralis* and *Sorghum virgatum*). 30 species (26.8% of the total species) were recorded along the shoreline of fish farms, of them two species were recorded only in this zone (*Cressa cretica* and *Amaranthus viridis*). The water edge of the Fish farms had 13 species (11.6% of the total species), while that of the open waters had 11 species (9.8% of the total species).

The application of the agglomerative clustering and similarity ordination techniques on the plant communities of the 11 zones indicate a distinction of four clusters (Figs. 3 & 4). Cluster A includes the open water of the drains and fish farms, cluster B includes the islets and water edges of the fish farms, cluster C includes three zones (water edges of drain and lake and lake open water) and cluster D includes four zones (shorelines of fish farms and lake, slopes and terraces of drains). The drain slopes had the highest species richness (18.5 species stand^{-1}), while lake water edge had the lowest species richness (5.2 species stand^{-1}) but the highest species turnover (6.5) (Table 4). The lake shoreline contributed the highest relative evenness (4.23) and relative concentration of species dominance (0.69). The open water of the fish farms had the lowest species turnover (1.3), relative evenness (2.4) and relative concentration of species dominance (0.11).

Table 2. Cover percentage of the therophytic species in relation to the different habitats in Lake Edku. LS: shoreline, LE: lake water edge, LO: lake open water, DT: drain terrace, DS: drain slope, DE: drain water edge, DO: drain open water, IS: islet, FF: fish farm shoreline, FE: fish farm water edge, FO: fish farm open water and r: values < 0.5.

Species	Lake proper			Drain				Islets	Fish farms		
	Ls	LE	LO	DT	DS	DE	DO		FS	FE	FO
Amaranthus hybridus L.	0.1										
Amaranthus viridis L.									0.1		
Ammi visnaga (L.) Lam.				r							
Anagallis arvensis L.				0.1							
Anethum graveolens L.	r										
Atriplex dimorphostegia Kar. & Kir.		r									
Atriplex semibaccata R.Br.	0.3	r		8.3				1.8	1.9		
Bassia indica (Wieght) A. J. Scott	4.6	r		0.3							
Beta vulgaris L.			0	0.1	0.3						
Bromus catharticus Vahl	0.1										
Bromus rubens L.				r							
Cakile maritima Scop.	r										
Chenopodium murale L.	0.3	r		2.1	13.8	0.1		r	0.6		
Cichorium endivia L.				0.9							
Conyza bonariensis (L.) Cronquist.	r			0.2							
Coronopus niloticus (Delile) Spreng.				0.1							
Cutandia dichotoma (Forssk.) Trab.	r										
Dactyloctenium aegyptium (L.) Willd.				0.1							
Digitaria sanguinalis (L.) Scop.	0.1			0.1							
Diplotaxis acris (Forssk.) Boiss.	r										
Eclipta prostrata (L.) L.	r			0.3							
Emex spinosa (L.) Cambd.	0.1										
Ethulia conoizoides L.f.	0.1	0.3	r								
Fumaria gaillardotii Boiss.				0.2							
Hordeum murinum subsp. *leporinum* (Link) Arcang.	0.6			0.3							
Lactuca serriola L.	0.1										
Lolium perenne L.	1.0			0.2					0.1		
Malva parviflora L.	1.1			0.9	0.4	0.1			0.1		
Medicago polymorpha L.	r			0.5	0.1				0.1		
Melilotus indicus (L.) All.	0.1			0.1	0.3				0.1		

Table 2. cont.

Species	Lake proper			Drain				Islets	Fish farms		
	Ls	LE	LO	DT	DS	DE	DO		FS	FE	FO
Mesembryanthemum crystallinum L.	0.6	r			0.1				0.9	0.1	
Mesembryanthemum nodiflorum L.	0.2				0.1						
Phalaris minor Retz.	r				0.1						
Poa annua L.				0.1							
Polypogon monspeliensis (L.) Desf.	0.3	r		0.4	0.3			0.1	0.2		
Portulaca oleracea L.				0.1							
Ranunculus sceleratus L.	r	0.7	0.1	0.1	0.1	0.3	0.8		0.9		0.6
Raphanus raphanistrum L.	0.1										
Reichardia tingitana (L.) Roth	0.1			r							
Rumex dentatus L.	0.2	0.1	0.1	0.1	1.8	0.1			0.4		0.1
Salsola kali L.	0.6										
Senecio glaucus subsp. *coronopifolius* (Maire) C. Alexander	0.1	r		0.1	0.3			r	0.1		
Setaria verticillata (L.) P.Beauv.	0.1			r				0.1			
Setaria viridis (L.) P.Beauv.				r							
Setaria x verticilliformis Dumort.				r				0.1			
Sisymbrium irio L.	0.1			r							
Soncuhs oleraceous L.	0.1			0.3	0.5	0.1					
Suaeda maritima (L.) Dumort.	0.6				0.1						
Torilis leptophylla (L.) Rchb. f.	r			0.2	0.1						
Trifolium resupinatum L.				0.2							
Urtica urens L.	0.2			0.2					0.1		
Vicia villosa subsp. *varia* (Host) Corb.	r										
Volutaria tubuliflora (Murb.)Sennen.	1.4										
Total	**38**	**10**	**4**	**34**	**15**	**5**	**1**	**6**	**13**	**1**	**2**

Table 3. Cover percentage of the perennial species in relation to the different habitats in Lake Edku. LS: shoreline, LE: lake water edge, LO: lake open water, DT: drain terrace, DS: drain slope, DE: drain water edge, DO: drain open water, IS: islet, FF: fish farm shoreline, FE: fish farm water edge, FO: fish farm open water and r: values < 0.5.

Species	**Lake proper**			**Drain**				**Islets**	**Fish farms**		
	Ls	**LE**	**LO**	**DT**	**DS**	**DE**	**DO**		**FS**	**FE**	**FO**
Phanerophytes											
Atriplex halimus L.	2.1			0.3	0.3	0.4					
Casuarina glaucus Miq.				0.1		0.1					
Cynanchum acutum L.	0.8	0.5		0.5		0.6		0.2	0.3		
Lycium shawii Roem. & Schult.	0.5										
Pluchea dioscoridis (L.) DC.	0.2	r		1.4	0.3	0.1		0.1	0.4		
Ricinus communis L.				0.3							
Tamarix nilotica (Ehrenb.) Bunge	r			5.4		r		r			
Chamaephytes											
Alhagi graecorum Boiss.	1.0			0.3					0.1		
Arthrocnemum macrostachyum (Moric.) K. Koch	0.1										
Atriplex leucoclada Boiss.	r										
Atriplex portulacoides L.	0.2	0.4						7.9	0.9	0.6	
Centaurea calcitrapa L.				13.2		0					
Halocnemum strobilaceum (Pall.) M. Bieb.								3.8			
Limbarda crithmoides (L.) Dumort.	1.8	0.5		2.6	1.1	0.7		3.0	0.5	2.6	
Polygonum maritimum L.				r							
Sarcocornia fruticosa (L.) A. J. Scott.	4.4	0.2	r	0.2	6.3	0.5		4.4	8.8	3.4	
Solanum nigrum L.	0.1			0.1							
Suaeda vera Forssk. Ex. J. F. Gmel.	8.2			1.2	5.0				22.8	1.5	
Suaeda vermiculata Forssk. Ex. J. F. Gmel.	0.2	r		0.5	0.8			0.1	1.7	1.9	
Symphyotrichum squamatum (Spreng.) Nesom	r	0.1	r	0.1	0.3				0.2		
Hemicryptophytes											
Convolvulus arvensis L.				r							
Cressa critica L.									0.1		
Frankenia hirsuta L.	0.1							0.1	0.1		
Ipomoea carnea Jacq.						0.1			0.3		
Lotus glaber Mill.	0.1			0.8		r					
Marsilea aegyptiaca Willd.			0.1								
Silybum marianum (L.) Gaertn.				r							
Spergularia marina (L.) Bessler	0.2			0.1	0.5			r	0.2		
Geophytes-Helophytes											
Arundo donax L.				8.3		3					
Asparagus stipularis Forssk.	0.1										
Cynodon dactylon (L.) Pers.	0.6			5.4				r			
Cyperus alopecuroides Rottb.	0.1	r			0.5						
Cyperus articulatus L.	5.0	2.2	0.6	0.1				0.1	0.2	1.5	

Table 3. cont.

Species	Lake proper			Drain				Islets	Fish farms		
	Ls	LE	LO	DT	DS	DE	DO		FS	FE	FO
Cyperus rotundus L.				0.1							
Echinocloa stagnina (Retz.) P.Beauv.	0.1	0.8	4.9	0.5	1.9	10.9	11.5			0.8	11.1
Juncus acutus L.	0.2	r		1.1		0.1		10.1	1.9	3.8	
Juncus rigidus Desf.				r		0.1					
Panicum coloratum L.	3.5	0.2	4.8							0.6	
Paspalidium geminatum (Forssk.) Stapf				0.5	0.3	2.0	0.2				
Persicaria lapathifolia (L.) Gray			r								
Persicaria salicifolia (Brouss. ex Willd.) Assenov	0.1	0.5	r			2	0				
Phragmites australis (Cav.) Trin.ex Steud.	6.3	37.4	16.9	0.3	6.1	11.5	0.2	5.4	1.9	2.8	
Polygonum equisetiforme Sm.	0.5			0.1							
Scirpus litoralis Schard.								0.7			
Scirpus maritimus L.										0.1	0.3
Sorghum virgatum (Hack.) Stapf								r			
Sporopolus pungens (Schreb.) Kunth	r										
Typha domingensis (Pers.) Poir.ex Steud.	7.1	20.1	7.0	1.2	0.1	8.1	0.8	33.1	3.1	35.0	1.6
Vossia cuspidata (Roxb.) Griff.		0.5	1.0								
Oxalis pescaprae L.											
Hydrophytes											
Azolla filiculoides Lam.	r	r	1.9			0	6.9				6.4
Ceratophyllum demersum L.		0.5	5.5				2.2				12.2
Eichhornia crassipes (C.Mast.) Solms		4.9	11.6			13.1	49.3				25.9
Epilobium hirsutum L.		0.1						0.1			
Ludwigia stolonifera (Guill & Perr.) P. H. Raven		0.1	0.6	0.1		1.0	0.5				1.5
Najas marina subsp. *armata* (H. Lindb.) Horn			0.1								0.1
Nymphaea lotus L.			1.3			1.6					
Potamogeton crispus L.		r	0.1			0.1	0.1				0.2
Potamogeton nodosus Poir.		r	r								
Potamogeton pectinatus L.		1.3	12.0			0.1	0				
Lemna gibba L.											
Total	**31**	**24**	**20**	**31**	**13**	**24**	**11**	**18**	**17**	**12**	**9**

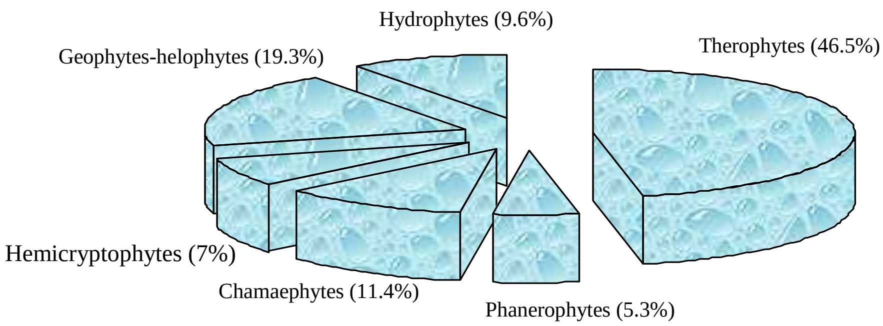

Fig. 2. Life form spectrum of the total recorded species in Lake Edku.

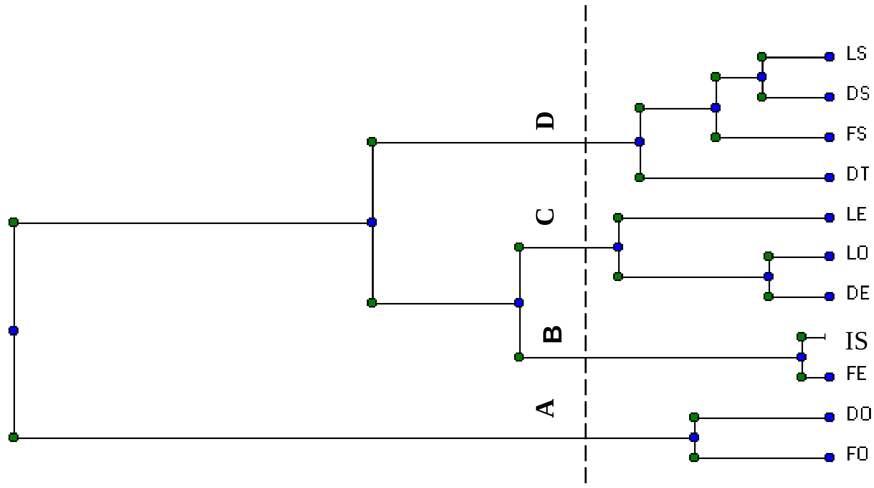

Fig. 3. Dendrogram resulting from the application of the agglomerative clustering technique on the 11 zones of Lake Edku. LS: lake shoreline, LE: lake water edge, LO: lake open water, DT: drain terrace, DS: drain slope, DE: drain water edge, DO: drain open water, IS: islet, FF: fish farm shoreline, FE: fish farm water edge, and FO: fish farm open water.

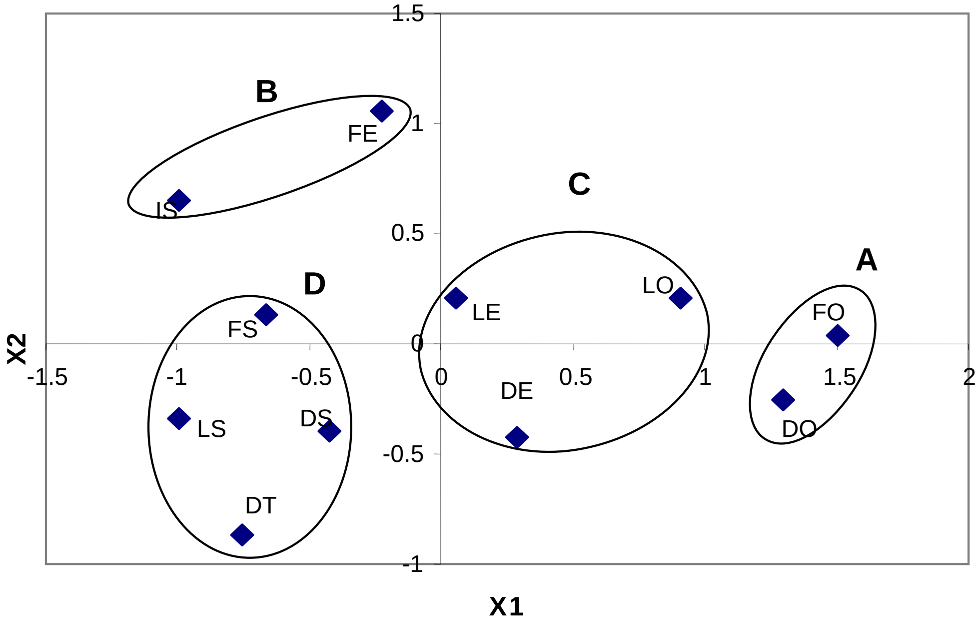

Fig. 4. Similarity ordination of the 11 zones of Lake Edku.

Table 4. Variation in some diversity indices calculated for the 11 zones of Lake Edku. The maximum and minimum values are underlined.

Soils of the lake shoreline had the highest value of clay (8.7%) and the lowest of nitrate (0.46 mg 100 gm^{-1}), while drain terraces had the highest of magnesium (0.65 mg 100 gm^{-1}) and drain slopes had the lowest of sulphate (6.65 mg 100 gm^{-1}) (Table 5). Soils of the islets had the highest values silt (36.3%), sulphates (23.15 mg 100 gm^{-1}) and calcium (0.52 mg 100 gm^{-1}), but the lowest of sand (56.3%) and $CaCO_3$ (4.9%). On the other hand, the shorelines of the fish farms had the highest values of sand (87.1%) and $CaCO_3$ (26%), but the lowest of silt (7%), calcium (0.16 mg 100 gm^{-1}) and magnesium (0.14 mg 100 gm^{-1}). The fish farm water edge had the highest values of water pH (8.0), bicarbonates (0.55 mg l^{-1}) and calcium (2.8 mg l^{-1}) (Table 6). On the other hand, the drain water edge had the lowest values of water calcium (1.79 mg l^{-1}), magnesium (4.14 mg l^{-1}) and sodium (0.44 mg l^{-1}), but the highest of nitrates (0.4 mg l^{-1}).

Some species have significant positive correlation with some soil variables (Table 7) such as *Typha domingensis* with bicarbonates and calcium (r = 0.97 and 0.96, respectively) and *Echinochloa stagnina* with phosphates and nitrates (r = 0.94 and 0.97, respectively). Some other species have significant negative correlation with some soil variables such as *Limbarda crithmoides* with $CaCO_3$ (r = -0.87) and *Polypogon monspliensis* with sulphates (r = -0.88).

Vegetation analysis

The application of TWINSPAN on the cover estimates of 112 species recorded in the 150 sampled stands in Lake Edku, led to the recognition of 15 vegetation groups (Fig. 5). The application of DCA on the same set of data indicates a reasonable segregation among these groups along the ordination plane of axes 1 and 2 (Fig. 6). The vegetation groups are named after the first and occasionally the second dominant species (Table 8). Five of these groups are represented by > 10% of the sampled stands, they are arranged according to their commonness as follows: *Ceratophyllum demersum-Eichhornia crassipes* (VG 3), *Typha domingensis* (VG 6), *Phragmites australis* (VG 7), *Potamogeton pectinatus* (VG 4) and *Juncus acutus-Typha domingensis* (VG 9). On the other hand, three groups are represented by > 10-5% of the sampled stands: *Echinochloa stagnina-Eichhornia crassipes* (VG 2), *Eichhornia crassipes* (VG 1) and *Rumex dentatus-Suaeda vera* (VG 12). In addition seven groups are represented by < 5% of the sampled stands: *Bassia indica-Limbarda crithmoides* (VG 13),

Table 5. Means of the soil characteristics of the different zones in Lake Edku. The minimum and maximum values are underlined. The F-value and its probability (P) are indicated.

Environmental variable		Lake shoreline	Drain terrace	Drain slope	Islets	Fish farm shoreline	F-value	P
Sand		72.2	70	62.9	56.3	87.1	4.00	0.008
Silt	%	19.1	23.8	31	36.3	7	5.23	0.001
clay	%	8.7	6.19	6.1	7.5	5.9	0.91	0.468
$CaCO_3$		20.6	13.4	19.4	4.9	26.0	6.88	0.001
pH		7.9	8.0	7.9	7.7	7.8	1.26	0.304
EC (mS cm^{-1})		5.3	7.8	8.3	10.7	2.3	2.17	0.091
HCO_3^-	mg 100 gm^{-1}	0.01	0.01	0.01	0.02	0.01	1.28	0.294
Cl^-	mg 100 gm^{-1}	0.62	0.93	1.65	1.21	0.21	1.56	0.206
SO^{--}_4	mg 100 gm^{-1}	7.60	8.70	6.65	23.15	9.55	7.59	0.001
PO^{---}_4	mg 100 gm^{-1}	3.51	3.28	5.40	3.77	3.22	1.26	0.301
NO^-_3	mg 100 gm^{-1}	0.46	0.73	1.15	0.54	0.56	1.84	0.141
NO^-_2	mg 100 gm^{-1}	1.08	1.10	1.23	0.98	0.83	1.01	0.412
Ca^{++}	mg 100 gm^{-1}	0.18	0.20	0.17	0.52	0.16	12.52	0.001
Mg^{++}	mg 100 gm^{-1}	0.15	0.65	0.17	0.46	0.14	20.67	0.001
Na^+	mg 100 gm^{-1}	0.92	1.45	1.57	1.67	0.27	1.42	0.245

Table 6. Means of the water characteristics of the different zones in Lake Edku. The minimum and maximum values are underlined. The F - value and its probability (P) are indicated.

Environmental variable		Lake water edge	Lake open water	Drain water edge	Drain open water	Fish farm water edge	Fish farm open water	F-value	P
Transparency (cm)		21.4	22.3	22.7	23.5	30.0	29.0	0.92	0.474
pH		7.8	7.7	7.9	7.9	8.0	7.8	2.49	0.036
E.C (mS cm^{-1})		2.9	2.7	1.3	3.0	2.2	1.9	1.08	0.377
HCO_3^-	mg l^{-1}	0.38	0.40	0.26	0.28	0.55	0.39	3.88	0.003
Cl^-	mg l^{-1}	1.02	1.05	0.38	1.07	1.15	0.61	1.23	0.303
SO^{--}_4	mg l^{-1}	265.25	256.35	228.39	284.19	321.10	287.28	1.37	0.240
PO^{---}_4	mg l^{-1}	7.23	6.63	7.59	7.52	8.51	7.32	0.67	0.650
NO^-_3	mg l^{-1}	0.14	0.18	0.40	0.14	0.15	0.15	1.99	0.086
NO^-_2	mg l^{-1}	2.14	5.03	1.61	1.51	2.16	0.99	0.21	0.959
Ca^{++}	mg l^{-1}	2.35	2.78	1.79	1.88	2.80	2.20	3.18	0.010
Mg^{++}	mg l^{-1}	4.63	5.36	4.14	9.93	8.10	5.30	0.96	0.445
Na^+	mg l^{-1}	1.10	1.25	0.44	1.40	0.97	0.76	0.56	0.730

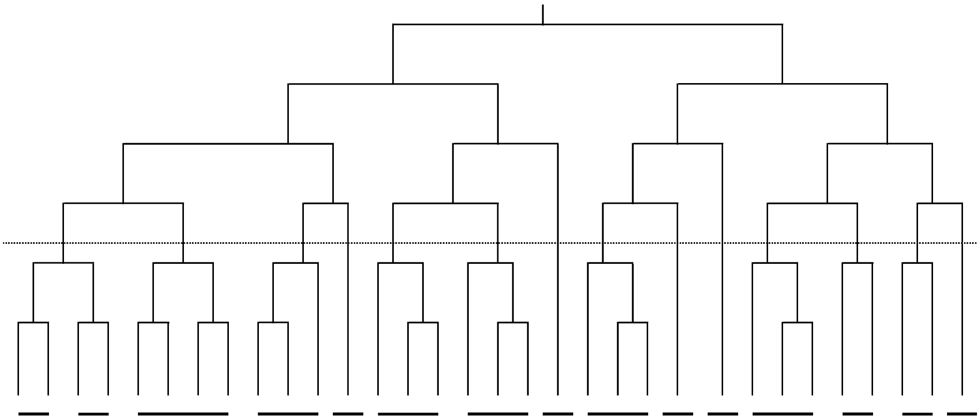

Fig. 5. Dendrogram resulting after the application of TWINSPAN on the 150 sampled stands in Lake Edku. The groups are: 1: *Eichhornia crassipes*, 2: *Echinochloa stagnina-Eichhornia crassipes*, 3: *Ceratophyllum demersum-Eichhornia crassipes*, 4: *Potamogeton pectinatus*, 5: *Cyperus articulatus*, 6: *Typha domingensis*, 7: *Phragmites australis*, 8: *Arundo donax*, 9: *Juncus acutus-Typha domingensis*, 10: *Phragmites australis-Typha domingensis*, 11: *Halocnemum strobilaceum-Sarcocornia fruticosa*, 12: *Rumex dentatus-Suaeda vera*, 13: *Bassia indica-Limbarda crithmoides*, 14: *Centaurea calcitrapa*, 15: *Cynodon dactylon-Medicago polymorpha*.

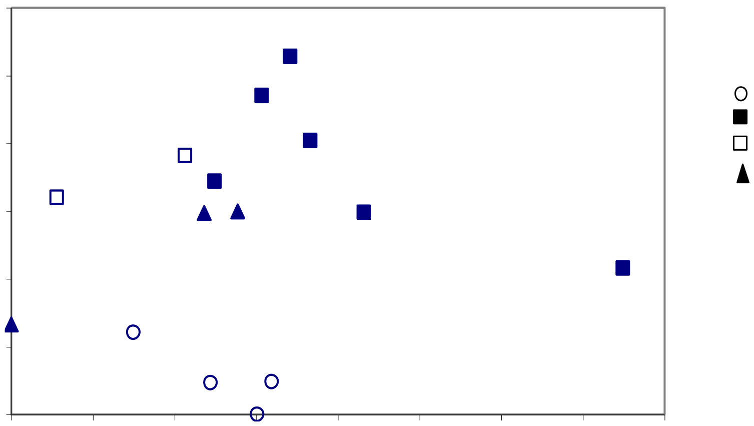

Fig. 6. DCA ordination of the 15 vegetation groups identified after the application of TWINSPAN on the 150 sampled stands in Lake Edku.

Table 7. Simple linear correlation coefficient (r) between some soil variables and the cover of the common species. * P< 0.05, ** P< 0.01, *** P< .001.

Centaurea calcitrapa (VG 14), *Phragmites australis-Typha domingensis* (VG 10), *Cyperus articulatus* (VG 5), *Halocnemum strobilaceum-Sarcocornia fruticosa* (VG 11), *Arundo donax* (VG 8) and *Cynodon dactylon-Medicago polymorpha* (VG 15).

Cynodon dactylon-Medicago polymorpha group (VG. 15) had the highest species richness (33 species $stand^{-1}$), while *Cyperus articulatus* group (VG. 5) had the lowest (2.7 species $stand^{-1}$) (Table 9). The highest species turnover (6.4) was that of *Typha domingensis* group (VG. 6), while the lowest (1.0) that was of *Arundo donax* and *Cynodon dactylon-Medicago polymorpha* groups (VG. 8 and 15, respectively). *Bassia indica-Limbarda crithmoides* group (VG. 13) had the highest relative evenness, relative concentration of species dominance (2.8 and 14.4, respectively), while *Arundo donax* group (VG. 8) had the lowest (0.2 and 1.1, respectively).

Soils of *Cyperus articulatus* group (VG. 5) had the highest value of silt (43%), but the lowest of sand (54.9%), clay (2.1%) and sulphate (0.13 mg 100 gm^{-1}) (Table 10). *Arundo donax* group (VG 8) had the highest values of clay (14.1%) and nitrites (1.6 mg 100 gm^{-1}). Soils of *Phragmites australis-Typha domingensis* group (VG 10) had the highest values of sand (89.3%) and $CaCO_3$ (28.6%), but the lowest of silt (6%). On the other hand, *Halocnemum strobilaceum-Sarcocornia fruticosa* group (VG 11) had the highest values of salinity (14.2 mS cm^{-1}), chlorides (1.67 mg 100 gm^{-1}), calcium and magnesium (0.61 mg 100 gm^{-1}). *Centaurea calcitrapa* group

Table 8. Characteristics of the 15 vegetation groups derived after the application of TWINSPAN on the 150 sampled stands in Lake Edku. VG: vegetation group, N: number of stands, G/P: the percentage of the stands of each vegetation group in relation to the total number of stands, NS: number of species per group. The habitats are DT: drain terraces, DS: drain slopes, DE: drain water edge, DO: drain open water, LS: lake shorelines, LE: lake water edge, LO: lake open water IS: islets and P: presence of species, RC: relative cover.

VG	N	G/P (%)	NS	Habitat								First dominant species	P (%)	RC (%)	Second dominant species	P (%)	RC (%)
				DT	DS	DE	DO	LS	LE	LO	IS						
1	13	8.7	23				15.3		46.2	38.5		*Eichhornia crassipes*	100	62.4	*Echinochloa stagnina*	84.6	4.98
2	14	9.3	20			14.3				85.7		*Echinochloa stagnina*	100	31.1	*Eichhornia crassipes*	92.9	52.6
3	24	16.0	22				4.2		4.2	91.6		*Ceratophyllum demersum*	100	20.7	*Eichhornia crassipes*	100	19.3
4	17	11.3	16							100		*Potamogeton pectinatus*	100	41.3	*Panicum coloratum*	70.6	29.2
5	3	2.0	4					33.7	66.3			*Cyperus articulatus*	100	73.2	*Panicum coloratum*	66.6	21
6	19	12.7	23					10.5	42.1	31.6	15.8	*Typha domingensis*	100	65.1	*Phragmites australis*	94.7	30.4
7	19	12.7	21						57.9	42.1		*Phragmites australis*	100	91.1	*Typha domingensis*	63.2	2.9
8	1	0.7	4	100								*Arundo donax*	100	96.1	*Cynanchum acutum*	100	2.6
9	15	10.0	35					13.3	13.3		73.4	*Juncus acutus*	93.3	17.5	*Typha domingensis*	86.7	40.9
10	4	2.7	33			25		50	25			*Phragmites australis*	100	37.5	*Typha domingensis*	75	26.5
11	2	1.3	7								100	*Halocnemum strobilaceum*	100	79.7	*Sarcocornia fruticosa*	100	12.7
12	8	5.3	43	12.5	25			62.5				*Rumex dentatus*	87.5	2.1	*Suaeda vera*	50	46.4
13	5	3.3	57	40				60				*Bassia indica*	100	16.4	*Limbarda crithmoides*	100	9.2
14	5	3.3	34					100				*Centaurea calcitrapa*	100	41.3	*Atriplex semibaccata*	100	24.5
15	1	0.7	33					100				*Cynodon dactylon*	100	27.4	*Medicago polymorpha*	100	12.2

Table 9. Variation in some diversity indices of the 15 vegetation groups in Lake Edku. The maximum and minimum values are underlined.

Vegetation group	Total species	Species richness	Species turnover	Shannon index	Simpson index
1. Eichhornia crassipes	23	7.3	3.2	1.4	2.5
2. Echinochloa stagnina-Eichhornia crassipes	20	6.6	3	1.3	2.7
3. Ceratophyllum demersum-Eichhornia crassipes	22	8.2	2.7	2	6.8
4. Potamogeton pectinatus	16	5.9	2.7	1.5	3.6
5. Cyperus articulatus	4	2.7	1.5	0.8	1.7
6. Typha domingensis	23	3.6	6.4	0.7	1.9
7. Phragmites australis	21	3.6	5.8	0.5	1.2
8. Arundo donax	4	4	1	0.2	1.1
9. Juncus acutus-Typha domingensis	35	9.1	3.8	1.7	4.2
10. Phragmites australis-Typha domingensis	33	12.5	2.6	1.6	3.9
11. Halocnemum strobilaceum-Sarcocornia fruticosa	7	5	1.4	0.6	1.5
12. Rumex dentatus-Suaeda vera	43	14	3.1	2.1	4.1
13. Bassia indica-Limbarda crithmoides	57	24	2.4	2.8	14.4
14. Centaurea calcitrapa	34	15.2	2.2	1.7	3.8
15. Cynodon dactylon-Medicago polymorpha	33	33	1	2.8	10

Table 10. Mean of the soil characteristics of the 10 vegetation groups in Lake Edku. The maximum and minimum values are underlined. The F-value and its probability (P) are indicated.

(VG 14) had the highest values of sulphates (11.2 mg 100 gm^{-1}) and sodium (2.35 mg 100 gm^{-1}). The lowest value of nitrites (0.81 mg 100 gm^{-1}) was recorded in *Rumex dentatus-Suaeda vera* group (VG 12). *Cynodon dactylon-Medicago polymorpha* groups (VG 15) had the lowest values of salinity (0.27 mS cm^{-1}), chlorides, magnesium, sodium (0.02 mg 100 gm^{-1}) and calcium (0.03 mg 100 gm^{-1}).

Water of *Eichhornia crassipes* group (VG 1) had the lowest value of salinity (1.36 mS cm^{-1}), chlorides (0.43 mg l^{-1}) and calcium (1.72 mg l^{-1}) (Table 11). *Cyperus articulatus* group (VG. 5) had the highest values of salinity (12.1 mS cm^{-1}) and chlorides (3.58 mg l^{-1}), but the lowest of bicarbonates (0.17 mg l^{-1}). The highest value of calcium (3.05 mg l^{-1}) was recorded in *Typha domingensis* group (VG 6).

The correlation between the identified vegetation groups and the soil characteristics is indicated on the ordination diagram produced by Principal Component Analysis (Fig. 7). It is clear that sand, silt, nitrite, nitrate, sulphate, phosphate, calcium and magnesium are the most effective variables. *Cyperus articulatus* (VG 5), *Arundo donax* (VG 8) and *Centaurea calcitrapa* (VG 14) groups occupy an intermediate level along nitrite gradients and low levels along pH, sand and phosphate gradients. *Juncus acutus-Typha domingensis* group (VG 9) occupies a high level along magnesium gradient, intermediate levels along clay and $CaCO_3$ gradients and a low level along nitrate gradient. On the other hand, the halophytic group *Halocnemum strobilaceum-Sarcocornia fruticosa* (VG 11) extends along high level of nitrate gradient, intermediate levels along clay and $CaCO_3$ gradients and low levels along calcium and magnesium gradients. *Phragmites australis-Typha domingensis* group (VG 10) occupies a high level along clay gradient, an intermediate level along bicarbonate gradient and a low level along salinity gradient. *Rumex dentatus-Suaeda vera* (VG 12) and *Cynodon dactylon-Medicago polymorpha* (VG 15) groups extend along high levels of sand, pH and phosphate gradients and a low level along nitrite gradient. *Bassia indica-Limbarda crithmoides* group (VG 13) occupies intermediate levels along sulphate, nitrate and silt gradients and low levels along calcium, magnesium and salinity gradients.

Some soil variables have significant positive correlation with each other (Table 12) such as silt with salinity, chloride and sodium (r = 0.72, 0.74 and 0.75) and salinity with chloride, calcium and sodium (r = 0.99, 0.85 and 0.99). Some other variables have significant negative correlation such as

Table 11. Means of the water characteristics of nine vegetation groups in Lake Edku. The maximum and minimum values are underlined. The F - value and its probability (P) are indicated.

Water variable	Vegetation group									F-value	P
	1	2	3	4	5	6	7	9	10		
Transparency (cm)	21.33	26.57	20.33	22	18.5	20.70	25.10	25	24	1.01	0.437
pH	7.93	7.82	7.73	7.74	7.5	7.80	7.70	7.75	7.80	0.85	0.561
E.C (mS cm^{-1})	1.36	1.46	2.80	2.86	12.10	2.50	2.40	2.83	1.85	3.28	0.002
CO_3^{--}	0.04	0.02	0.03	---	---	0.02	0.01	---	---	2.05	0.048
HCO_3^-	0.26	0.35	0.39	0.47	0.17	0.41	0.39	0.59	0.35	4.37	0.001
Cl^-	0.43	0.49	1.09	1.10	3.58	1.05	0.97	1.32	0.61	3.00	0.005
SO_4^{--}	250.7	253.7	270.9	266.7	350.9	276.5	269.2	333.4	255.2	1.29	0.259
PO_4^{---}	8.37	7.47	6.24	6.88	8.38	7.20	6.13	7.87	5.63	1.67	0.117
NO_3^- **mg l^{-1}**	0.30	0.15	0.14	0.13	0.14	0.13	0.14	0.14	0.15	0.99	0.443
NO_2^-	2.07	1.57	1.70	2.14	4.85	14.20	1.62	2.27	1.48	0.79	0.614
Ca^{++}	1.72	2.17	2.38	2.93	2.67	3.05	2.85	2.00	2.30	4.19	0.001
Mg^{++}	3.61	2.57	7.27	5.44	9.22	6.83	4.72	6.15	10.20	1.46	0.183
Na^+	0.54	0.60	1.39	1.31	4.77	1.08	1.35	1.10	0.47	1.39	0.208
K^+	0.01	0.02	0.01	0.02	0.03	0.02	0.02	0.02	0.01	2.44	0.019

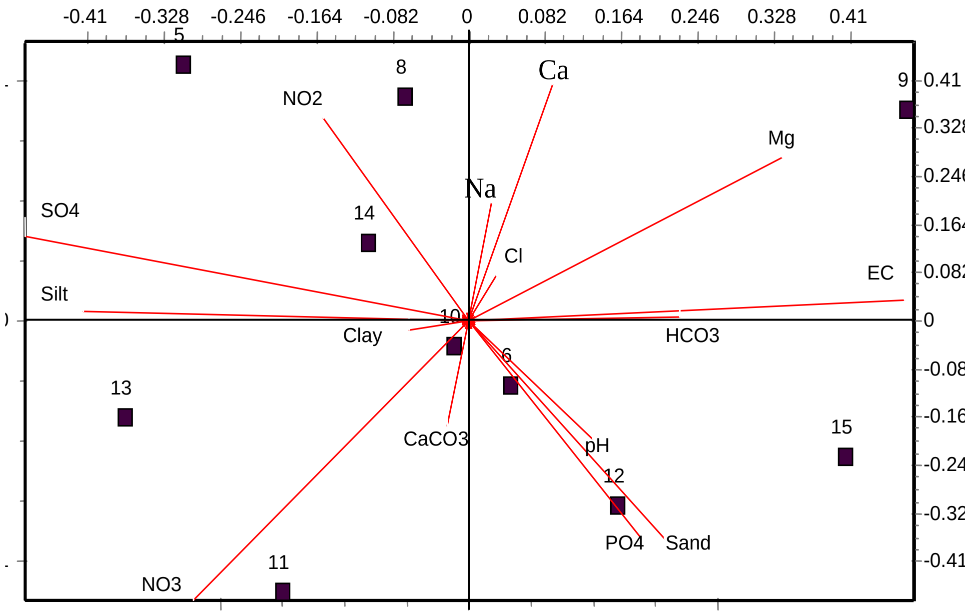

Fig. 7. PCA of the vegetation groups (represented by squares) and soil variables (represented by lines).

Table 12. Pairs of soil and community variables with significant simple linear correlation. * P< 0.05, ** P< 0.01, *** P< .001.

sand with silt, salinity, chloride and sodium (r = -0.97, -0.67, -0.69 and -0.68) and pH with calcium (r = -0.77). On the other hand, some community variables have significant positive correlation with each other such as species richness with relative evenness and relative concentration of species dominance (r = 0.92 and 0.86) and relative evenness with relative concentration of species dominance (r = 0.88). Regarding the community versus soil variables, the total species has significant positive correlation with sand (r = 0.64) and significant negative correlation with magnesium (r = -0.66). Species richness has significant positive correlation with pH (r = 0.63) and significant negative correlation with magnesium (r = -0.71). Relative evenness has significant positive correlation with pH (r = 0.65), but significant negative correlation with magnesium (r = -0.77).

Discussion

One hundred and fourteen species belonging to 95 genera and 37 families were recorded in Lake Edku. This number represents 28.4% of the total species recorded in the northern lakes of Egypt and 47.5% of the species recorded in the deltaic lakes (Galal, 2005). Six of the species recorded in Lake Edku were not recorded in the other northern lakes (*Ethulia conoizoides, Torilis leptophylla, Casuarina glaucus, Limonium axillare, Oxalis pescaprae* and *Potamogeton nodosus*). Twenty-two species were recorded in the study of El-Masry (1961) on the same lake, of which six species were not recorded in the present study (*Alternanthera sessilis, Lemna minor*, *Limonium axillare*, *Wolffiela hyalina*, *Ruppia maritima* and *Spirodela polyrhiza*). The life form spectra provide information which may help in assessing the response of vegetation to variations in environmental factors (Ayyad & El-Ghareeb, 1982). Raunkiaer (1937) designated the Mediterranean climate type as a “therophyte climate” because of the high percentage (> 50% of the total species) of this life form in several Mediterranean floras (Raven, 1971). The present study indicated that therophytes were represented by 44.5% of the total recorded species, 19.3% were geophytes–helophytes and 12.6% were hydrophytes.

There is a high floristic similarity between shorelines, terraces, slopes and water edges of the different habitats of Lake Edku (Sørensen, 1948). On the other hand, there is a low floristic similarity between these zones on one hand, and the open water zones on the other hand. This indicates gradual species compositional changes throughout the shorelines, terraces, slopes and water edges in contrast with the open water zone. Similar conclusions have been made by El-Sheikh (1989), Shaltout & El-Halawany (1993) and Al-Sodany (1998). Moreover, the two-dimensional polar ordination (Bray & Curtis, 1957) based on the similarity degree between the species composition of the different zones indicates clear segregation between the cluster that represents the lake shoreline, terraces and slopes on one side, and the other clusters on the other side. This may be attributed to the difference in the moisture status of these zones comparing with the other ones. Similar conclusion was made by Al-Sodany (1998).

The biodiversity of fresh water bodies is among the most poorly known on the earth (WRI *et al.,* 1992), that is seriously threatened today. Diversity in fresh water ecosystems is distributed in a fundamentally different pattern from that in marine or terrestrial systems. Although the reparian vegetation along rivers has a fundamental importance in stream ecology (Cummins *et al.,* 1984), and has attracted the interest of botanists for many years, the factors that control its species richness are still poorly understood (Nilsson *et al.,* 1989). The trend of variation in some diversity indices is related to the estimates of importance value; using of plant cover as importance value has an advantage over other estimates such as density and frequency (Shaltout, 1985). Plant cover is an attribute of greater ecological significance, because it gives a better measure of plant biomass and could evaluate all plant life forms. Therefore, in the present study, the relative plant cover was used as an estimate of the importance value of species, and then used to estimate the diversity indices.

In Lake Edku, the drain slopes have the highest value of species richness, while the lake water edge had the lowest. The high diversity of the shorelines compared with the open water zones may be related to the intermediate position of the communities of the shorelines along the prevailing environmental gradients, and the fact that these habitats usually rich in species. Moreover, high diversity of such habitats is associated with the increase in annuals during spring (El-Kady *et al.,* 2000). In addition, habitat heterogeneity and human manipulation of land seem to be acceptable reasons for the higher diversity of these habitats. On the other hand, the low species diversity of the open water zones may be related to the homogeneity of the aquatic habitats compared with the terrestrial ones. Moreover, the low diversity of water zones may be due to the fact that most of its species are highly specific to the aquatic habitat and the same species occurs at nearly all sites. The high disturbance of these zones (cleaning practices, aquatic weed control, water pollution and excessive waste discharge) may also explain their low diversity (Grime, 1973). Similar conclusions were made by Shaltout & El-Halawany (1993) and Shaltout *et al.* (1994). In general, the aquatic weeds are aggressively colonizing ruderals which tend to form dense monodominant stands (Holzner, 1978). This increases their competitive ability resulting in lower species richness.

Phytosociologists have classified the various types of macrophyte communities; they used ordination techniques to simplify distribution patterns along the gradients of environmental variables (Gauch, 1982; Springuel & Murphy, 1991; Grillas, 1990 and Spink, 1992). The classification of the vegetation of Lake Edku using TWINSPAN analysis led to identify 15 vegetation groups. These groups were separated along the DCA ordination axes reflecting moisture and salinity gradients. The moisture gradient starts with communities representing the open water (*Eichhornia crassipes* and *Ceratophyllum demersum*), water edge (*Cyperus articulatus* and *Typha domingensis*), shoreline (*Rumex dentatus* and *Bassia indica*) and islets (*Juncus acutus* and *Halocnemum strobilaceum*). The salinity gradient starts with the less tolerant communities representing the open water zones to the south of the lake (*Eichhornia crassipes* and *Echinochloa stagnina*) and ends by the more tolerant communities to the north (*Potamogeton pectinatus* and *Typha domingensis*). These results are in accord with the study of Al-Sodany (1998) on the vegetation of canals, drains and lakes of the northern part of Nile Delta. The PCA ordination showed that the communities dominated by *Halocnemum strobilaceum, Sarcocornia fruticosa, Juncus acutus* and *Typha domingensis* are associated with high salinity and occupy high position along nitrate and magnesium gradients, intermediate position along clay and $CaCO_3$ gradients and low position along calcium and nitrate gradients. The communities dominated by *Phragmites australis* and *Typha domingensis* are associated with high sand and $CaCO_3$ and occupy high position along clay gradient, intermediate position along bicarbonates gradient and low position along salinity gradient. In addition, the communities dominated by *Eichhornia crassipes, Echinochloa stagnina* and *Ceratophyllum demersum* are associated with high transparency, pH and carbonate; but low salinity, chloride, sulphate and calcium (Zahran & Willis, 2003). The community dominated by *Potamogeton pectinatus* is associated with moderate salinity and sulphate and low nitrate (Guerguess, 1993).

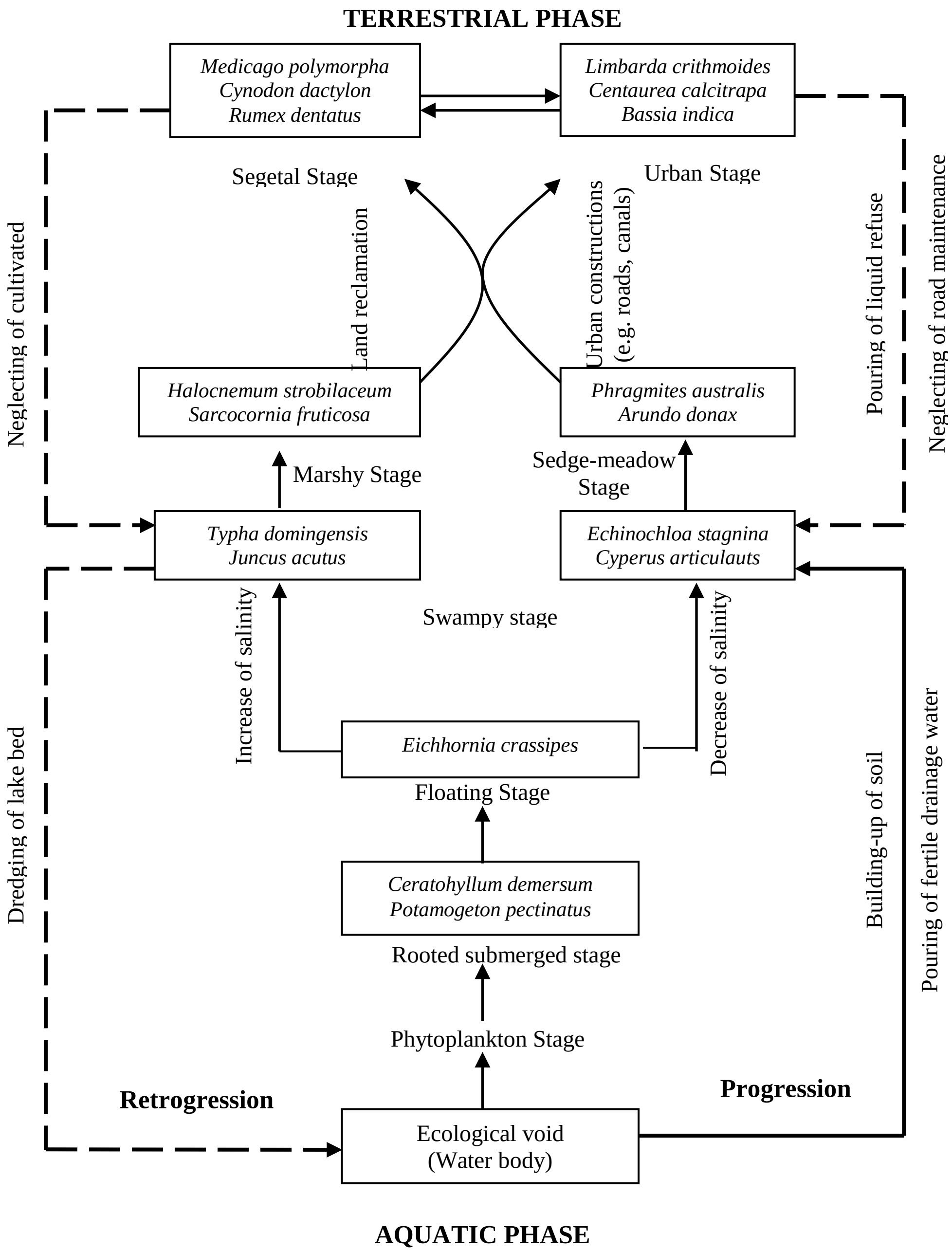

Fig. 8. Schematic representation of the presumed successional relationship between the communities dominating the different habitats in Lake Edku.

Correlation between soil factors and species diversity indices in Lake Edku indicates that the species richness increases with the increase of sand and pH, and with the decrease of silt, clay and calcium. This result explains why the aquatic weeds increased after the construction of Aswan High Dam (Al-Sodany, 1998). This Dam had led to changes in the quality of water as a result of reduction of suspended solids and the consequent use of fertilizers to compensate for the lack of these solids, changes of chemical characters of irrigation water, low current velocity in the Nile and decreasing the flow of water to the Mediterranean. The aforementioned changes seem to have provided habitat conditions that favor the growth and spread of aquatic plants (Batanouny & El-Fiky, 1984).

Soil moisture, salinity and sedimentation are the main operative factors in the successional process of the vegetation in Lake Edku, depending on the regional and local conditions of topography and landforms. Building-up of soil as well as continuous discharging of fertile drainage water into the lake increase the organic matter which favor the growth of swampy communities passing through the rooted submerged (*Ceratophyllum demersum* and *Potamogeton pectinatus*) and floating ones (*Eichhornia crassipes*). Retrogression may occur as a result of mechanical dredging of the lakebed **(Fig. 8)**. Decrease of salinity may lead to the formation of emergent communities (*Echinochloa stagnina* and *Phragmites australis*), while its increase enhances the growth of halophytic ones (*Halocnemum strobilaceum* and *Sarcocornia fruticosa*). The urban stage characterized by ruderal communities (*Centaurea calcitrapa* and *Bassia indica*) may be developed as a result of urban constructions (roads, canals). On the other hand, the segetal stage characterized by segetal weeds (*Cynodon dactylon* and *Medicago polymorpha*) may also be produced as a result of land reclamation.

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