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# Vegetation-Soil Relationships in Lake Borollus Protected Area, Egypt

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**Abstract:** The present study aims at investigating the vegetation-soil relationships in different habitat types in Lake Borollus protected area. The plant communities were investigated in 102 sampling stands representing the different habitat types. Multivariate analysis of the vegetation and soil variables led to the separation of six vegetation groups. These groups are named after their diagnostic perennial species, namely, *Suaeda vera-Sporobolus pungens*, *Arthrocnemum macrostachyum*, *Limbarda crithmoides*, *Arthrocnemum macrostachyum*, *Alhagi graecorum* and *Polygonum equisetiforme-Launaea resedifolia-Echinops spinosus*. The vegetation groups produced by TWINSPAN-classification are distinguishable and having a clear pattern of segregation on the Detrended Correspondence Analysis ordination planes. The Canonical Correspondence Analysis indicated that, the most effective soil variables controlling distribution and abundance of the identified vegetation groups are soil texture (clay & sand), moisture content, porosity, potassium, sodium and calcium cations, organic matter, calcium carbonate, electrical conductivity, sulphate and bicarbonate.

**Key words:** Mediterranean coast · multivariate analysis · importance value · soil variables

## INTRODUCTION

Wetlands occur in many geomorphological settings including river deltas, coastal and inland lakes, intertidal zones, river flood plains, inland depressions and flats [1]. On a global scale wetlands are found in all climates and in all continents except Antarctica. More than half of the world's total wetland area is found in tropical and subtropical regions, while a large proportion of the rest is boreal peatlands [2]. The term wetland envelops wide variety of habitats, from mangroves along tropical shorelines to peatlands that lies just south of the Arctic.

The wetlands in Egypt are considered one of the most prominent aquatic ecosystems, which are widely distributed all over the country. Lakes are the most conspicuous wetland habitat comprising six natural shallow brackish lakes and one artificial lake. The natural lakes constitute five Mediterranean northern lakes as located from east to west include: Bardawil, Manzala, Borollus, Idku and Mariut and one inland Lake Qarun which is situated at Fayium depression. The artificial Lake Nasser is located behind the Aswan High Dam south of Egypt. Lake Borollus was designated as a wetland nature reserve under the International Ramsar Convention Since 1998.

Previous studies on the Egyptian lakes, covered the fields of geography, hydrology, zoology and hydrobiology [3-10]. In the field of phytosociology, there are some studies on the lakes of Egypt [11-20]. The present study aims at: 1) Determination of an up-to-date vegetation structure and abundance and 2) Analysis of the spatial and temporal variations of environmental factors and assess the degree of correlations with the soil variables. Data are discussed in an attempt to determine the major soil variables controlling the distribution and abundance of vegetation in the different habitats of the protected area.

**The study area:** Lake Borollus protected area covers an area of about 460 km$^2$. The study area covered the main lake and its Delta Mediterranean coastal land in Kafr El-Sheikh Governorate. Lake Borollus occupies a central position along the Mediterranean coast of the Nile Delta. It is the second largest natural lake in Egypt after Lake Manzala. It is totally located in the northern part of Kafr El-Sheikh Governorate and extends at the Mediterranean Sea from the north, Baltim district from the east; El-Hamool, El-Riad and Sidi Salim districts from the south and Motobas district from the west (Fig. 1).

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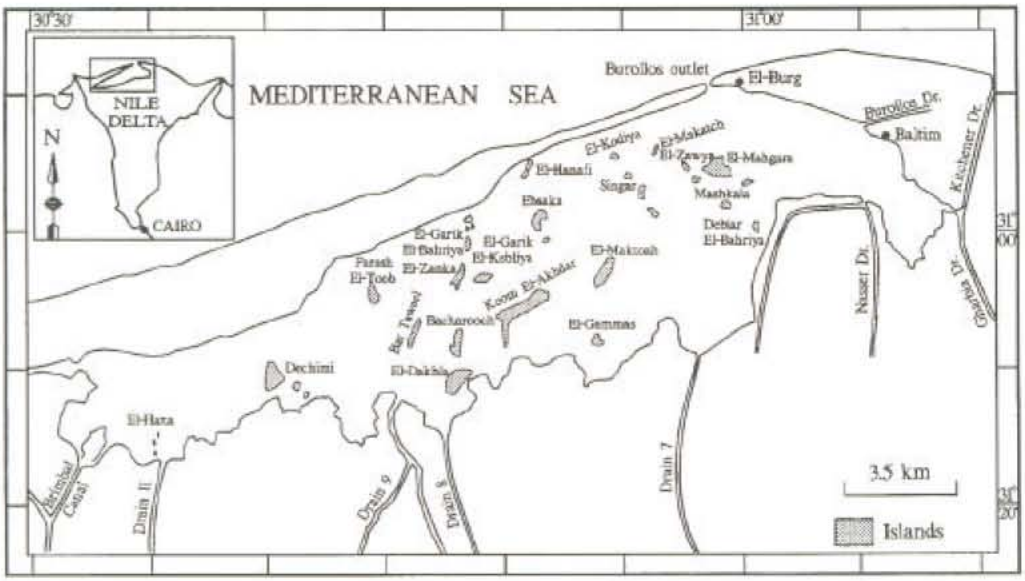


Fig. 1: Location map showing the study area

The depth of this lake varies between 0.2 m close to the shoreline and 2 m in the middle part and near the sea outlet. Four types of characteristic habitats or landforms [21] in Lake Borollus are distinguished: 1) shore landform (backshore flats, foreshore and barrier beach), 2) lake landform (main Lake Borollus, El-Burg inlet, shoreline and islands), 3) aeoline landform (sand sheets, sand hummocks and sand dunes) and 4) riverine landform (palaeochannels, marshes, natural levee and accretion ridges).

## MATERIALS AND METHODS

**Vegetation analysis:** One hundred and two stands were selected for sampling the vegetation types in the different habitats of the study area. The chosen stands were distributed to cover all local physiographic variations within the habitat types and to ensure sampling of wide range of vegetation variations. The stand size was 13×13 m in all habitats and the sampling process was carried out during March-September 2005. In each stand, relative density and relative frequency were estimated by using point-centered quarter method [22, 23], while relative cover was estimated by applying the line intercept method [24]. The abundance of species as expressed by the relative values of density, frequency and cover were calculated for perennial species and summed up to give an estimate of its importance value (out of 300). The annual species were only listed. Identification and nomenclature were according to Tackholm [25] and Boulos [26].

**Soil analysis:** Five soil samples were collected from profile 0-50 cm depth of each sampled stand and then mixed to form a composite soil sample. Soil texture was determined by the hydrometer method. Moisture content was determined by using sealed tins for collecting soil samples in the field and then dried at 105°C in oven for 48 h. Soil porosity was determined as described by Zahran [27]. Calcium carbonate was estimated according to Jackson [28], while oxidizable organic carbon was determined using Walkely and Black rapid titration method as described by Piper [29]. Soil water extracts of 1:5 were prepared for determinations of soil reaction using pH meter Model HI 8519 and soil salinity (EC) using CMD 830 WPA conductivity meter. Soluble chlorides were determined by direct titration against silver nitrate solution (N/35.5) using 5% potassium chromate indicator [28]. Sulphates were obtained by the difference between cations and anions of soil extract according to Jackson [28]. Soluble carbonates and bicarbonates were determined by titration method using $H_2SO_4$ (0.1 N), phenol phthalein and methyl orange as indicators for carbonate and bicarbonate, respectively [30]. The extractable sodium and potassium cations were estimated using flame photometer [31]. While, extractable calcium and magnesium cations were determined using EDTA (0.01 N) as described by Jackson [28]. The sodium and potassium adsorption ratios were calculated to use as indices expressing the combined effects of the different ions in the soil [32].

**Data analysis:** Two trends of multivariate analysis were applied in the present study, namely classification and ordination. The classification technique applied here was Two-Way Indicator Species Analysis (TWINSPAN) [33]. The matrix of importance values of 41 perennial species was used in the TWINSPAN-classification of the sampled 102 stands. Alternatively, the ordination techniques applied here were Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) [34]. The simple linear correlation coefficient (r) was calculated for assessing the relationship between the estimated different soil variables. The relationship between vegetation groups and edaphic variables are carried out by the ordination diagram produced by CCA-biplot. All statistical treatments applied in the present investigation were according to Scedecor and Cochran [35] and Anonymous [36].

## RESULTS

**Classification of stands:** The dendrogram resulting from the application of TWINSPAN classification of 41 perennial species recorded in 102 sampled stands indicated the distinction of six vegetation groups (Fig. 2 & Table 1).

Group A comprises 4 stands codominated by *Suaeda vera* (IV = 96.01) and *Sporobolus pungens* (IV = 84.26). The most important and indicator species in this group is *Lycium schwienfurthii* (IV = 72.82). *Atriplex halimus* (IV = 18.04) is common species in this group.

Group B includes 5 stands dominated by the indicator species *Arthrocnemum macrostachyum* (IV = 92.06). The most important species in this group comprise *Juncus acutus* (IV = 52.80), *Suaeda vera* (IV = 52.56), *Atriplex portulacoides* (IV = 31.26) and *Halocnemum strobilaceum* (IV = 28.59).

Group C consists of 33 stands dominated by *Limbarda crithmoides* (IV = 95.54). The most important and indicator species in this group include *Alhagi graecorum* (IV = 32.63), *Arthrocnemum macrostachyum* (IV = 31.93), *Juncus acutus* (IV = 28.89) and *Atriplex portulacoides* (IV = 22.57). The grasses *Phragmites australis* (IV = 16.90), *Cynodon dactylon* (IV = 16.39) and *Juncus rigidus* (IV = 14.52) are common associates in this group.

Group D comprises 36 stands dominated by the indicator species *Arthrocnemum macrostachyum* (IV = 131.90). The other important and indicator species in this group include four halophytes: *Zygophyllum aegyptium* (IV = 34.99), *Halocnemum strobilaceum* (IV = 27.99), *Phragmites australis* (IV = 25.59) and *Juncus acutus* (IV = 20.71).

Group E include 18 stands dominated by *Alhagi graecorum* (IV = 138.20). The other important and indicator species comprise *Cynodon dactylon* (IV = 33.15), *Arthrocnemum macrostachyum* (IV = 29.86), *Cyperus capitatus* (IV = 24.58) and *Zygophyllum aegyptium* (IV = 19.44).

Group F consists of 6 stands codominated by *Polygonum equisetiforme* (IV = 56.29), *Launaea resedifolia* (IV = 55.46) and *Echinops spinosus* (IV = 45.62). The most important indicator species in this group comprise *Arthrocnemum macrostachyum* (IV = 43.30) and *Calligonum polygnoides* subsp. *comosum* (IV = 30.40).

It is observed that, one biennial species namely, *Spergularia marina* is recorded in all six groups. Also, forty-seven annual plant species are recorded in the present study. These annuals are grouped according to their seasonality into three categories: (a) All-year annuals (8 species), e.g. *Senecio glaucus*, *Cakile maritima, Sonchus oleraceus* and *Chenopodium murale*; (b) Winter-spring annuals (33 species), e.g. *Frankenia pulverulenta*, *Lotus halophilus*, *Mesembryanthemum crystallinum*, *Malva parviflora*, *Juncus bufonius* and *Richardia tingitana*; and (c) Summer-autumn annuals (6 species), e.g. *Salsola kali*, *Corchorus olitorius* and *Bassia muricata*.

**Ordination of stands:** The Detrended Correspondence Analysis ordination diagrams of the stands and species, respectively are shown in Figs. 3 & 4. It is obvious that, groups A and F are separated from the other groups B, C, D and E, which are randomly scattered in the middle part of the diagram.

**Vegetation-soil relationships:** The soil variables of the six vegetation groups derived from TWINSPAN classification are presented in Table 2. The soil texture in all groups is formed mainly of coarse fraction (sand) and partly of fine fractions (silt & clay). The highest mean percentages of moisture content and porosity are recorded in group C while, the lowest mean values are recorded in group F, which is also attained the lowest mean values of calcium carbonate (6.00%), organic carbon (0.27%), pH value (8.06), electrical conductivity (0.59 ds $m^{-1}$), chloride (1.14 meq $L^{-1}$), sulphate (2.66

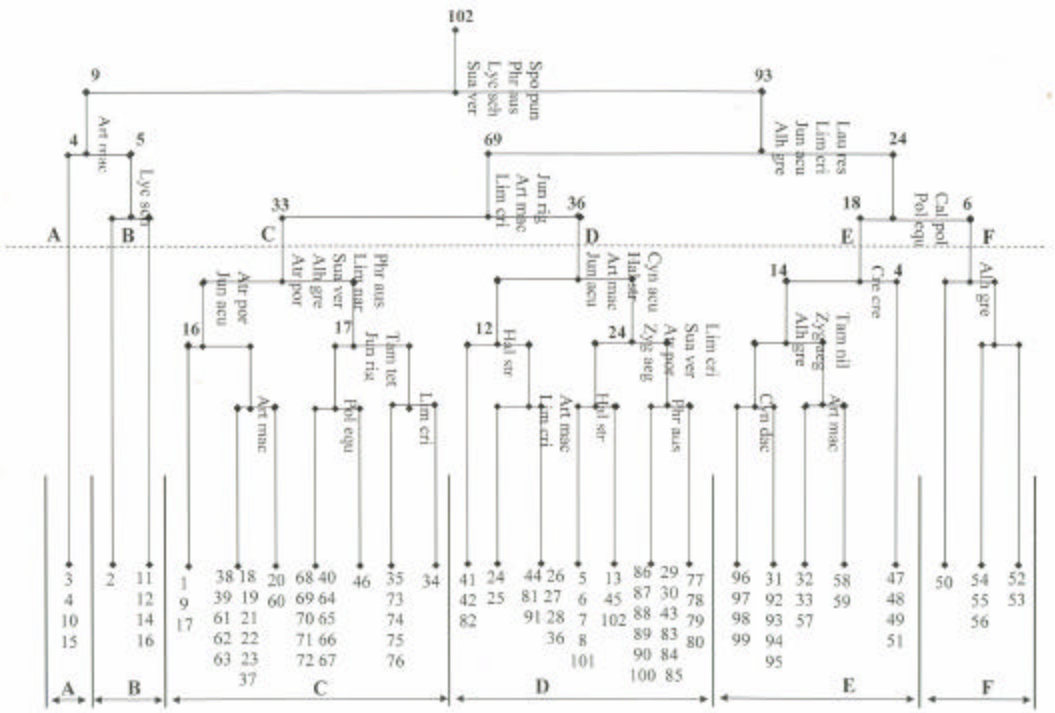

Fig. 2: Two Way Indicator Species Analysis dendrogram of 102 sampled stands based on the importance value of 41 perennial species with names abbreviated into the first three of each of the genus and species

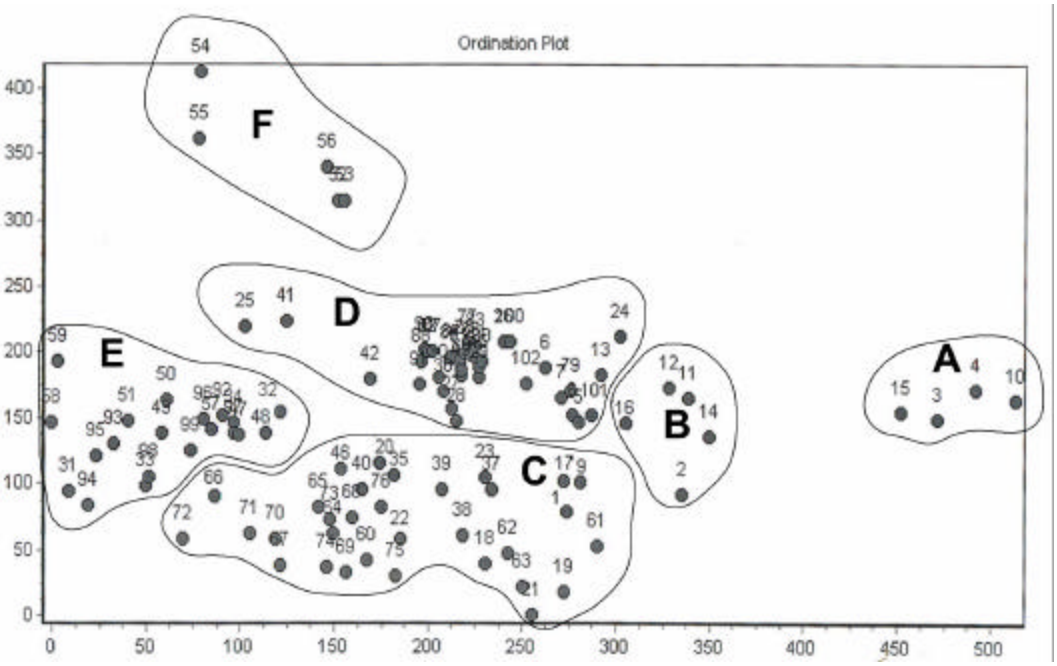


Fig. 3: Detrended Correspondence Analysis (DCA) ordination diagram of 102 sampled stands

Table 1: Mean and coefficient of variation (value between brackets) of the importance values (out of 300) of indicator and preferential species in the different vegetation groups resulting from TWINSPAN classification

| | Vegetation groups | | | | | |
|---|---|---|---|---|---|---|
| Species | A | B | C | D | E | F |
| *Aeluropus lagopoides* | - | - | 2.84 (2.16) | - | 7.14 (3.01) | 7.93 (1.69) |
| *Alhagi graecorum* | - | - | 32.63 (1.48) | 1.93 (6.00) | 138.20(0.32) | - |
| *Arthrocnemum macrostachyum* | 4.14 (0.71) | 92.06 (0.34) | 31.93 (1.02) | 131.90(0.39) | 29.86 (1.05) | 43.30 (0.86) |
| *Asparagus stipularis* | 8.20 (0.79) | 5.42 (1.89) | - | - | - | - |
| *Atriplex halimus* | 18.04 (1.17) | 1.62 (2.23) | 2.32 (3.33) | 1.52 (6.00) | - | - |
| *Atriplex portulacoides* | 1.37 (1.22) | 31.26 (0.64) | 22.57 (1.75) | 3.88 (3.05) | - | - |
| *Calligonum polygonoides* | - | - | - | - | 1.32 (2.50) | 30.40 (0.59) |
| *Carex extensa* | - | - | 0.59 (5.35) | - | - | - |
| *Cistanche phelypaea* | - | - | - | 1.39 (2.16) | 0.33 (4.36) | 0.15 (2.24) |
| *Cressa cretica* | 5.11 (2.00) | - | 4.33 (3.41) | - | 6.40 (2.11) | - |
| *Cynanchum acutum* | - | - | 1.48 (2.54) | 3.81 (3.51) | 2.37 (4.20) | 4.91 (2.24) |
| *Cynodon dactylon* | - | - | 16.39 (1.51) | 2.82 (3.94) | 33.15 (1.45) | - |
| *Cyperus capitatus* | - | - | - | 3.32 (6.00) | 24.58 (1.29) | 8.03 (2.24) |
| *Cyperus laevigatus* | - | - | 0.07 (5.32) | - | - | - |
| *Echinops spinosus* | - | - | - | - | 3.03 (3.08) | 45.62 (0.40) |
| *Elymus farctus* | - | - | - | 3.36 (3.55) | - | - |
| *Halocnemum strobilaceum* | - | 28.59 (0.98) | 2.96 (3.53) | 27.99 (1.38) | 5.12 (1.74) | 4.38 (1.46) |
| *Imperata cylindrica* | - | - | 0.17 (5.74) | - | - | - |
| *Juncus acutus* | 8.16 (1.81) | 52.80 (0.52) | 28.89 (1.51) | 20.71 (1.62) | 0.14 (3.28) | 0.23 (2.24) |
| *Juncus rigidus* | - | 0.29 (2.21) | 14.52 (1.49) | 2.97 (3.18) | - | - |
| *Launaea resedifolia* | - | - | - | 1.20 (3.43) | 5.83 (1.70) | 55.46 (0.65) |
| *Limbarda crithmoides* | 0.10 (2.10) | 15.20 (0.94) | 95.54 (0.50) | 12.43 (1.72) | - | - |
| *Limonium narbonense* | - | - | 3.77 (2.62) | - | - | - |
| *Lycium schwienfurthii* | 72.82 (0.48) | 7.71 (1.12) | - | - | 0.79 (4.36) | 5.83 (2.24) |
| *Nicotiana glauca* | - | - | 1.57 (2.96) | - | - | - |
| *Pancratium maritimum* | - | - | - | 2.63 (1.82) | - | - |
| *Panicum turgidum* | - | - | - | - | 2.63 (1.82) | - |
| *Phoenix dactylifera* | - | - | - | 1.08 (6.00) | - | - |
| *Phragmites australis* | - | 0.03 (2.00) | 0.02 (5.74) | - | - | - |
| *Pluchea dioscoridis* | - | - | 16.90 (1.81) | 25.59 (1.22) | 7.20 (1.83) | 9.07 (0.77) |
| *Polygonum equisetiforme* | - | - | 0.39 (4.81) | 0.45 (6.00) | - | - |
| *Scirpus litoralis* | - | - | 4.99 (3.23) | 2.28 (2.62) | 0.96 (2.39) | 56.29 (0.45) |
| *Scirpus maritimus* | - | - | 0.12 (4.09) | - | - | - |
| *Sporobolus pungens* | 84.26 (0.75) | 12.20 (1.45) | - | - | - | - |
| *Sporobolus spicatus* | - | - | - | - | - | 4.43 (2.24) |
| *Suaeda vera* | 96.01 (0.28) | 52.56 (0.48) | 2.14 (2.98) | 6.44 (2.67) | 0.38 (3.68) | - |
| *Tamarix nilotica* | - | - | 1.63 (3.09) | 4.60 (2.15) | 5.92 (1.52) | 16.55 (0.84) |
| *Tamarix tetragyna* | - | - | 3.35 (2.82) | 5.18 (2.55) | 5.44 (2.80) | - |
| *Typha domingesis* | - | 0.26 (2.23) | 0.73 (3.32) | - | - | - |
| *Urginea undulata* | 1.79 (2.00) | - | - | - | - | - |
| *Zygophyllum aegyptium* | - | - | 5.11 (3.25) | 34.99 (1.01) | 19.44 (1.74) | 7.28 (1.05) |

Table 2: Mean and standard error of the different soil variables at 0-50 cm depth in the sampling stands obtained by TWINSPAN classification

| | Vegetation groups | | | | | |
|---|---|---|---|---|---|---|
| Soil variables | A | B | C | D | E | F |
| Sand (%) | 89.42±1.21 | 84.76±3.46 | 84.05±1.67 | 83.70±3.31 | 93.64±0.70 | 91.80±0.30 |
| Silt (%) | 3.85±0.92 | 4.70±0.48 | 3.82±0.88 | 7.89±2.13 | 1.33±0.18 | 3.00±0.43 |
| Clay (%) | 6.73±0.84 | 10.54±3.16 | 12.08±1.14 | 8.41±1.39 | 5.03±0.65 | 5.20±0.37 |
| Moisture content (%) | 1.40±0.19 | 7.64±2.45 | 9.81±1.23 | 9.08±2.01 | 1.52±0.38 | 0.33±0.03 |
| Porosity (%) | 37.13±0.56 | 38.31±1.37 | 39.72±0.44 | 39.03±0.75 | 36.87±0.76 | 36.75±0.63 |
| Ca $CO_3$ (%) | 9.63±2.97 | 7.75±2.04 | 12.42±2.03 | 13.67±2.50 | 6.24±1.58 | 6.00±0.39 |
| Organic carbon (%) | 0.92±0.12 | 1.32±0.21 | 0.89±0.12 | 0.72±0.14 | 0.29±0.03 | 0.27±0.03 |
| Organic matter (%) | 1.58±0.21 | 2.27±0.37 | 1.53±0.21 | 1.14±0.23 | 0.50±0.05 | 0.46±0.06 |
| pH | 8.29±0.09 | 8.34±0.06 | 8.25±0.03 | 8.34±0.04 | 8.09±0.07 | 8.06±0.17 |
| EC (ds $m^{-1}$) | 1.82±0.61 | 8.00±3.02 | 4.67±0.54 | 4.73±0.77 | 1.86±0.39 | 0.59±0.15 |
| $Cl^-$ (meq $L^{-1}$) | 7.33±2.50 | 34.36±12.45 | 12.32±2.34 | 22.09±4.75 | 5.61±1.62 | 1.14±0.16 |
| $SO^{4-}$ (meq $L^{-1}$) | 4.39±1.97 | 18.38±10.28 | 17.80±2.09 | 10.78±1.58 | 5.72±1.34 | 2.66±0.55 |
| $CO^{3-}$ (meq $L^{-1}$) | 0.29±0.12 | 0.28±0.05 | 0.32±0.04 | 0.17±0.04 | 0.30±0.04 | 0.13±0.05 |
| $HCO^{3-}$ (meq $L^{-1}$) | 1.88±0.23 | 1.88±0.15 | 2.32±0.13 | 1.44±0.08 | 1.97±0.10 | 1.29±0.21 |
| $Na^+$ (meq $L^{-1}$) | 10.10±3.75 | 40.35±11.53 | 16.27±3.34 | 7.06±2.20 | 26.69±5.39 | 1.05±0.23 |
| $K^+$ (meq $L^{-1}$) | 1.08±0.20 | 1.51±0.18 | 1.03±0.07 | 0.45±0.06 | 0.76±0.09 | 0.31±0.04 |
| $Ca^{++}$ (meq $L^{-1}$) | 1.80±0.35 | 6.84±4.56 | 12.35±1.45 | 3.79±0.63 | 4.33±0.56 | 2.12±0.46 |
| $Mg^{++}$ (meq $L^{-1}$) | 0.90±0.27 | 6.20±4.06 | 3.10±0.38 | 1.64±0.39 | 3.36±0.45 | 1.74±0.54 |
| SAR | 8.30±2.62 | 20.14±3.17 | 6.71±1.43 | 4.05±0.96 | 13.79±2.86 | 0.85±0.25 |
| PAR | 0.94±0.12 | 0.91±0.18 | 0.41±0.03 | 0.29±0.03 | 0.41±0.04 | 0.23±0.03 |

Table 3: Pearson-moment correlation (r) between the soil variables in the study stands

| | Sand | Silt | Clay | M.c | Por. | $CaCO_3$ | O.c | pH | EC | $Cl^-$ | $SO4^{--}$ | $CO3^{--}$ | $HCO3^-$ | $Na^+$ | $K^+$ | $Ca^{++}$ | $Mg^{++}$ | SAR | PAR |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sand | 1.00 | | | | | | | | | | | | | | | | | | |
| Silt | -0.913 | 1.00 | | | | | | | | | | | | | | | | | |
| Clay | -0.867 | 0.588 | 1.00 | | | | | | | | | | | | | | | | |
| M.c | -0.683 | 0.577 | 0.678 | 1.00 | | | | | | | | | | | | | | | |
| Por. | -0.328 | 0.191 | 0.418 | 0.472 | 1.00 | | | | | | | | | | | | | | |
| $CaCO_3$ | -0.718 | 0.735 | 0.518 | 0.486 | 0.288 | 1.00 | | | | | | | | | | | | | |
| O.c | -0.668 | 0.685 | 0.481 | 0.583 | 0.273 | 0.744 | 1.00 | | | | | | | | | | | | |
| PH | -0.268 | 0.253 | 0.228 | 0.291 | 0.134 | 0.146 | 0.099 | 1.00 | | | | | | | | | | | |
| EC | -0.646 | 0.565 | 0.588 | 0.685 | 0.496 | 0.497 | 0.730 | 0.101 | 1.00 | | | | | | | | | | |
| $Cl^-$ | -0.690 | 0.669 | 0.554 | 0.735 | 0.394 | 0.463 | 0.678 | 0.210* | 0.909 | 1.00 | | | | | | | | | |
| $SO4^{--}$ | -0.481 | 0.338 | 0.536 | 0.499 | 0.506 | 0.379 | 0.530 | -0.041 | 0.751 | 0.474 | 1.00 | | | | | | | | |
| $CO3^{--}$ | 0.071 | -0.103 | -0.018 | 0.101 | -0.060 | 0.092 | 0.010 | 0.207 | -0.016 | -0.080 | 0.056 | 1.00 | | | | | | | |
| $HCO3^-$ | -0.329 | 0.290 | 0.294 | 0.327 | 0.306 | 0.378 | 0.360 | 0.324 | 0.269 | 0.201 | 0.231 | 0.070 | 1.00 | | | | | | |
| $Na^+$ | -0.729 | 0.711 | 0.580 | 0.753 | 0.395 | 0.538 | 0.743 | 0.192 | 0.927 | 0.972 | 0.579 | -.049 | 0.211 | 1.00 | | | | | |
| $K^+$ | -0.643 | 0.503 | 0.661 | 0.646 | 0.491 | 0.400 | 0.632 | 0.179 | 0.790 | 0.692 | 0.706 | -0.010 | 0.334 | 0.721 | 1.00 | | | | |
| $Ca^{++}$ | -0.104 | -0.082 | 0.301 | 0.164 | 0.388 | 0.031 | 0.111 | -0.142 | 0.338 | 0.045 | 0.710 | 0.130 | 0.254 | 0.040 | 0.420 | 1.00 | | | |
| $Mg^{++}$ | -0.395 | 0.292 | 0.427 | 0.462 | 0.538 | 0.218 | 0.386 | 0.119 | 0.766 | 0.649 | 0.686 | -0.154 | 0.151 | 0.629 | 0.568 | 0.403 | 1.00 | | |
| SAR | -0.703 | 0.749 | 0.481 | 0.699 | 0.202 | 0.596 | 0.754 | 0.256 | 0.754 | 0.861 | 0.370 | 0.085 | 0.220 | 0.909 | 0.601 | -0.173 | 0.326 | 1.00 | |
| PAR | -0.481 | 0.478 | 0.371 | 0.399 | 0.084 | 0.334 | 0.517 | 0.291 | 0.389 | 0.471 | 0.157 | 0.086 | 0.183 | 0.516 | 0.682 | -0.196 | 0.037 | 0.662 | 1.00 |

Abbreviations: M.c = Moisture content, EC = Electrical conductivity, Por. = Porosity, PAR = Potassium adsorption ratio, O.c = Organic carbon, SAR = Sodium adsorption ratio.

Significant at $p < 0.05 = 0.195$, Significant at $p < 0.01 = 0.254$, Significant at $p < 0.001 = 0.321$.

meq $L^{-}$), carbonate (0.13 meq $L^{-1}$), bicarbonate (1.29 meq $L^{-1}$), sodium (1.05 meq $L^{-1}$), potassium (0.31 meq $L^{-1}$), sodium adsorption ratio (0.85) and potassium adsorption ratio (0.23). While group A attained the lowest mean values of calcium (1.80 meq $L^{-1}$) and magnesium (0.90 meq $L^{-1}$).

The highest mean values of calcium carbonate (13.67%) is attained in group D, pH value (8.3) in both of groups B & D and potassium adsorption ratio (0.94) in group A. Group C attained the highest mean values of carbonate (0.32 meq $L^{-1}$), bicarbonate (2.32 meq $L^{-1}$) and calcium (12.35 meq $L^{-1}$). Group B attained the highest mean values of organic carbon (1.32%), electrical conductivity (8.00 ds $m^{-1}$), chloride (34.36 meq $L^{-1}$), sulphate (18.38 meq $L^{-1}$), sodium (40.35 meq $L^{-1}$), potassium (1.51 meq $L^{-1}$), magnesium (6.20 meq $L^{-1}$) and sodium adsorption ratio (20.14).

As shown in Table 3, clay fraction has positive significant correlations with all soil variables except soluble carbonate content, carbonate content has no any significant correlations with all soil variables except pH value, sand fraction has negative significant correlations with all soil variables except calcium cation, moisture content, chloride and sodium adsorption ratio showed positive significant correlations with all soil variables except calcium cation, potassium cation and electrical conductivity exhibited positive significant correlations with all soil variables except pH value, calcium carbonate, organic carbon and sodium cation have positive significant correlations with all soil variables except pH and calcium cation, silt fraction showed positive significant correlations with all soil variables except soil porosity and calcium, as well as soil porosity, sulphate and magnesium have positive significant correlations with all soil variables except pH value and potassium adsorption ratio.

The correlation between vegetation groups and soil variables is indicated on the ordination diagram produced by Canonical Correspondence Analysis (CCA) of the biplot of species-soil variables (Fig. 5). The dominant, indicator and preferential perennial species of the halophytic vegetation groups B, C and D are separated at the upper side of CCA-biplot diagram and showed a close relationships with many effective soil variables such as potassium, organic matter, potassium and sodium adsorption ratios, sulphate, moisture content, clay fraction, electrical conductivity, sodium, calcium carbonate, bicarbonate, soil porosity and calcium cation. The dominant, codominant, indicator and preferential perennial species of the psammophytic vegetation groups A, E and F are segregated at the lower side of the CCA diagram and exhibited a clear relationship with sand fraction only.

## DISCUSSION

The phytosociological study dealt with the present work revealed that, the vegetation in Lake Borollus

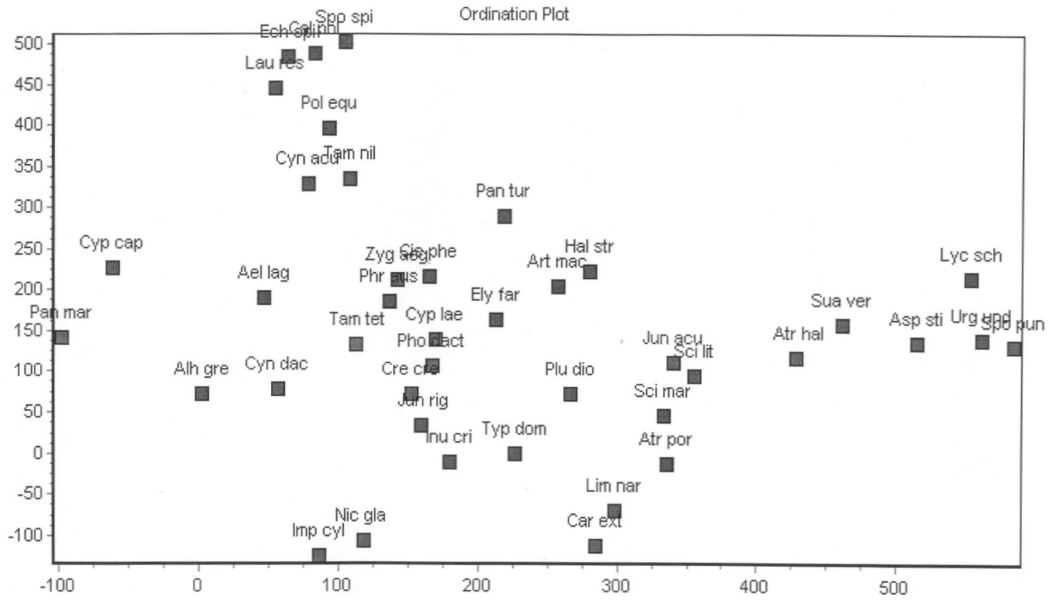


Fig. 4: Detrended Correspondence Analysis (DCA) ordination diagram of the species with names abbreviated into the first three letters of each of the genus and species (Table 1)

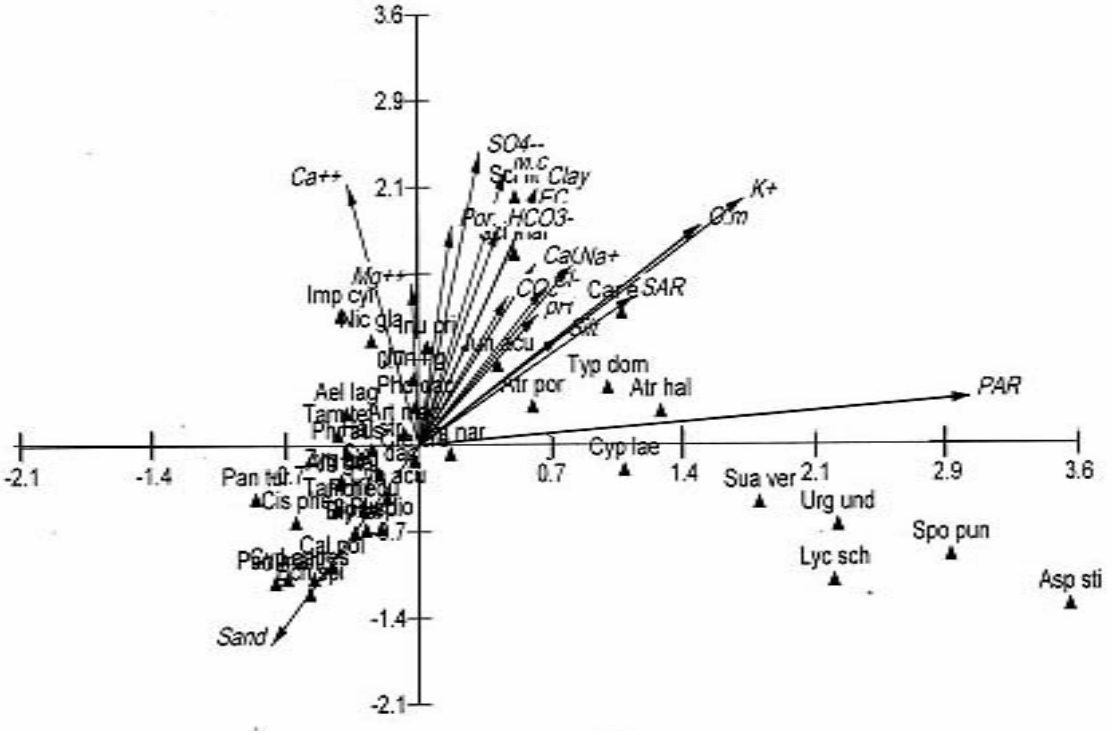


Fig. 5: Canonical Correspondence Analysis (CCA) ordination. The indicator and preferential species are abbreviated to the first three letters of each of the genus and species (Table 1)

protected area is classified into six vegetation groups as derived by TWINSPAN classification. Group A is codominated by *Suaeda vera* and *Sporobolus pungens*, group B is dominated by *Arthrocnemum macrostachyum*, group C is dominated by *Limbarda crithmoides*, group D is dominated by *Arthrocnemum macrostachyum*, group E is dominated by *Alhagi graecorum* and group F is codominated by *Polygonum equisetiforme*, *Launaea resedifolia* and *Echinops spinosus*.

The vegetation groups A, E and F represent the sand formation habitat type, while groups B, C and D represent the salt marsh habitat type in the study area. In the salt marshes, the dominant perennial species are *Arthrocnemum macrostachyum* and *Limbarda crithmoides*. The other indicator and common associated species in this habitat type include *Suaeda vera*, *Halocnemum strobilaceum*, *Juncus acutus*, *Atriplex portulacoides*, *Phragmites australis*, *Juncus rigidus*, *Zygophyllum aegyptium* and *Tamarix nilotica*. All of these halophytes constitute the major part of the vegetation composition of both littoral and inland salt marshes [37]. The vegetation groups which represent the sand formations can be subdivided into three groups according to their different habitat types as follows: group A (*Suaeda*, *vera-Sporobolus pungens*) representing saline sand flats, group E (*Alhagi graecorum*) representing sand bars and sand dunes and group F (*Polygonum equisetiforme-Launaea resedifolia-Echinops spinosus*) representing raised non-saline sand flats and sand dunes. The indicator and most common associate species of the sand formations comprise *Lycium schwienfurthii*, *Cyperus capitatus*, *Moltkiopsis ciliata*, *Calligonum polygonoides* subsp. *comosum*, *Asparagus stipularis* and *Elymus farctus*.

The vegetation groups identified in the salt marshes (B, C & D) in the present study seem to be related to class *Salicornietea europaeae* described by Zohary [38] which comprises all plant communities of the salt marshes in the circumference of Mediterranean coastal belt. Also, the recognized groups (*Arthrocnemum macrostachyum* and *Limbarda crithmoides*) which dominate the salt marshes in the present work are similar to *Salicornion alliance* described by Tadros and Atta [39]. On the other hand, the vegetation groups of the sand formations are related to different classes, orders, alliances and associations. The community type codominated by *Suaeda vera* and *Sporobolus pungens* (group A) seem to be related to alliance of *Plantaginion crassifoliae* with two associations of *Junceto-Schoenetum* and *Schoenetum nigricantis* described by Tadros [40], while *Alhagi graecorum* community type (group E) is related to alliance of *Atriplico-Suaedion palaestinae* described by Eig [41]. The community type codominated by *Polygonum equisetiforme, Launaea resedifolia* and *Echinops spinosus* (group F) are related to the associations of *Scolymetum hispanica* [42], *Panicetum turgidi* [43] and *Lasiuretum hirsuti* [44], respectively.

The application of DCA ordination in the sampled stands of the study area indicated that, groups A and F are clearly separated from the other groups (B, C, D & F). This is may be due to the dissimilarity between the floristic composition of the sampled stands in groups A & F and due to the similarities between the other four groups.

The most effective soil factors controlling the distribution of salt marsh vegetation in Damietta coastal land are calcium carbonate, organic carbon, sulphate, bicarbonate and potassium cation, while in the sand formations, the most important soil variables are water-holding capacity, soil salinity, chloride and magnesium cation [45]. Also Mashaly [46] reported that, the most decisive edaphic factors controlling the distribution of the halophytic vegetation in the salt affected lands in the coastal region are moisture availability and calcareous sedimentation, while in the sand formations, the most effective soil variables are moisture content, porosity, water-holding capacity, organic carbon, calcium carbonate, pH value, electrical conductivity, chloride, sulphate and calcium cation. In the northern lakes of Egypt, Khedr [12] reported that, the most important edaphic factors controlling the distribution of plant species in Lake Manzala islands were soil texture, moisture content, calcium carbonate and salinity. The zonation pattern of vegetation in Lake Borollus showed a gradient of edaphic factors such as soil salinity, clay, organic carbon, total nitrogen and potassium cation [16]. As reported by El-Bana *et al.* [17], the vegetation in Lake Bardawil coincided with some soil variables such as electrical conductivity, pH value, sodium and potassium cations. Meanwhile [19, 20] reported that, soil moisture, salinity and sedimentation were the main operative factors in the successional process of the vegetation in Lake Idku and Lake Mariut.

In conclusion the application of Canonical Correspondence Analysis (CCA-biplot) between the position of vegetation groups on the ordination planes and soil variables of their stands indicated that, potassium, organic matter, sulphate, moisture content, clay fraction, electrical conductivity, sand fraction, calcium, sodium, calcium carbonate, bicarbonate and soil

porosity were the most critical edaphic factors controlling the distribution and abundance of vegetation types in the salt marshes and sand formations of Lake Borollus protected area.

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