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Vegetation-Soil Relationships in Wadi El-Rayan Protected Area, Western Desert, Egypt

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Abstract

The present study provides an analysis of the soil and vegetation composition at 10 sites in Wadi El Rayan Protected Area and concentrates on the environmental factors that affect plant species distribution. A total of 17 vascular plant species belonging to 13 botanical families was recorded. Poaceae, Chenopodiaceae, and Zygophyllaceae were the largest families identified. Chorological analysis revealed that 47% of the studied species are Pluri-regional, 41% are Bi-regional and 12% are Mono- regional. The recorded species extend their distribution all over the Saharo-Arabian (33%) followed by Irano-Turanian (24%), Mediterranean (22%), Palaeotropical (8%), Sudano-Zambezian (5%), Neotropical (5%), and Euro-Siberian (3%). The life-form spectrum revealed that the phanerophytes (35%) and geophytes helophytes (23%) are the most frequent, followed by chamaephytes (18%), therophytes (12%), hemicryptophytes (6%), and helophytes (6%). The dominant species were *Phragmites australis, Tamarix nilotica* and *Zygophyllum album*; while the co-dominant species were *Juncus rigidus, Nitraria retusa*, *Alhagi graecorum, Typha domingensis*, *Zygophyllum coccineum* and *Eucalyptus camaldulensis.* Variation in species diversity among different locations were evident, the Northeast of the Lower Lake(9 species), followed by the Southwest of the Lower Lake and the Northeast of the Upper Lake(6 species each) showed highest species richness, while the Southeast of the Lower Lake showed the lowest recorded species richness (one species). Detrended Correspondence Analysis (DCA) and Canonical Correspondence Analysis (CCA) Ordination techniques were used to examine the relationship between the vegetation and soil parameters; pH, electric conductivity, $CaCO_3$, organic matter and relative concentrations of cations.CCA analysis showed positive correlations of species and sites along the most important ecological gradients. Both ordination techniques clearly indicated the importance of these ecological factors on the distribution of the vegetation pattern in the area.

Keywords: Vegetation, Plant distribution, Wadi El Rayan, Soil, Desert, Egypt, Protected Area.

1. Introduction

Wadi El Rayan is located 140 km southwest of Cairo in the Fayoum Governorate on the Western Desert of Egypt. Its total area is 1759 Km² and it is classified by the Egyptian Environmental Affairs Agency (EEAA) as a managed Protected Area for the conservation of wild species and the sustainable utilization of natural resources (Nels, 1995). Although the Western Desert is characterized, in general, by poor plant diversity and cover (Boulos, 1975), Wadi El Rayan is rich with fauna and flora diversity (Osborn and Helmy, 1980; Saleh, 1987; Saleh *et al*., 1988a) and it also has unique geological and geomorphological features (Said, 1962). In 2011, Wadi El Rayan was recognized by the International Union for Conservation of Nature (IUCN) as one of the 20 Important Plant Areas (IPAs) in Egypt (Radford *et al*., 2011) and it was nominated by Egypt in 2012 as a wetland area of the Ramsar Convention (EEAA, 2012). The area is hyper-arid with low precipitation (mean annual precipitation of 10.1 mm of irregular rainfall) and hot summer (temperature is as low as 1.2°C in winter and as high as 48.4°C in summer) (Ayyad and Ghabbour, 1986; Saleh *et al*., 1988b). Wadi El Rayan depression has been used as a water reservoir for storing excess agricultural drainage water above the capacity of Lake Qarun. Two man-made lakes joined by a connecting channel, were constructed at two different levels (Zahran, 1970). Throughout time, Wadi El Rayan lakes have created a variety of habitats surrounding it, although the adverse consequences of their creation on the ecology of the area cannot be ignored (Saleh, 1987; Saleh *et al*., 1988a, b). The area became increasingly inhabited by people from adjacent villages and consequently a rapid economic development was established (IUCN, 1998). By February 2000, around 4840 feddans of reclaimed land were established. Irrigation water of these fields is

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pumped from the upper lake through pipeline running towards the west, entering the project area from the northwest and drains into the lower lake from southwest following the natural landscape gradient (Abdou, 2006).

Throughout the recent century, many researchers attempted to determine the factors controlling the plant species distribution (Glenn *et al*., 2002; He *et al*., 2007). The spatial distribution of plant species and communities in a small area of desert ecosystems is related to heterogeneous topography and landform pattern (Parker, 1991). The physiographic and edaphic factors play a paramount role in the distribution of plant communities in the Western Desert of Egypt (Ayyad, 1976). The distribution, pattern and abundance of plant species and communities in desert environments have been most often related to three groups of factors: rainfall (Kadmon and Danin, 1999), soil chemistry (Abd El-Ghani, 1998; Abd El-Ghani and Amer, 2003) and human impact including overgrazing and plant overcollection (Kassas, 1962). The distribution of species in saline and marshy habitat in many arid regions has been a subject of study by numerous authors (Kassas, 1957; Ungar, 1968; Maryam *et al*., 1995).The objective of the present study is to study the vegetation composition of Wadi El Rayan and to portray the relationship between the vegetation and the prevailing soil factors at the coastal zones of the lakes located in the study area.

2. Materials and Methods

2.1. Vegetation Sampling

Quantitative surveys of the vegetation in the study area were carried out between March and September 2013. Ten stands in the surrounding area of the lakes, including the upper and lower lakes and the connecting channel, were carefully identified ensuring a reasonable degree of physiographic and physiognomic homogeneity of habitat and vegetation. Also, care was taken to ensure a reasonable degree of physiographic and physiognomic homogeneity of both habitat and vegetation (Figure 1). At each stand, a total of five random quadrates were sampled (each of 10m × 10m; 50 quadrates in total), and a floristic list and count were recorded to determine flora density. Species richness was also determined according to Barbour *et al*. (1987).

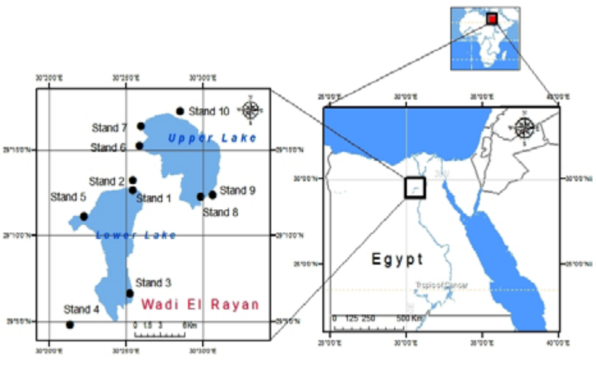


Figure 1. Egypt map focusing on Wadi El-Rayan and study stands

2.2. Soil Analysis

Surface soil samples (at depth of 25 cm, excluding the surface crust) were randomly collected at different stands to determine their physical and chemical characteristics.

Physical analysis: the soil texture was determined using a series of sieves: Soil samples were air-dried and passed manually through a 2-mm sieve to evaluate the gravel percentage. Particle size analysis was accomplished according to Piper (1950)to calculate the percentages of sand, silt, and clay and the classification of the soil texture type was accomplished according to the USDA soil texture triangle (USDA, 1993).

Chemical analysis: Calcium carbonate was measured by titration against 1.0 N HCl following Allen *et al*. (1976). Oxidizable organic carbon (as an indication of the total organic matter content) was measured according to Black (1965). Soil reaction (pH value), electrical conductivity, sulphates and chlorides were measured according to Jackson (1967). Bicarbonate was determined by titration using 0.1 N HCl (Allen *et al*., 1976). Extractable cations (Ca++ and Mg++) were determined (meq/L) by titration following Richard (1954),while,sodium and potassium ions (meq/L) were measured from air-dried soil using ammonium acetate solution at pH=7 (Allen *et al*., 1976).

2.3. Data Analysis

A floristic data; presence/absence data matrix of 10 stands and 17 species was applied for the classification by cluster analysis with the Community Analysis Package version (1.2) (Henderson and Seaby, 1999) using a Squared Euclidean Distance Dissimilarity Matrix with minimum variance (Ward's method) as the agglomeration criterion.

For vegetation classification, TWINSPAN (Two-Way Indicator Species Analysis; Hill, 1979) was applied using the Community Analysis Package software and the analysis was based on the Importance Values (IV) of the species. The diversity indices (Alpha diversity) were calculated at each site (Harper, 1999).

The vegetation and environmental factors were analyzed using ordination techniques. Classification (Siebert *et al*., 2002) and ordination (Pavlůet *et al*., 2003) are two possible ways to obtain results from multivariate data analysis.

All ordinations were performed using the CANOCO program (version 4.5) (TerBraak and Šmilauer, 2002; Hejcmanovā-Neźerková and Hejcman, 2006). Detrended Correspondence Analysis (DCA) was performed to detect the length of the environmental gradient. After DCA, Canonical Correspondence Analysis (CCA) was performed because the dataset was relatively heterogeneous and, therefore, the length of ordination axes in DCA was relatively long (Lepš and Šmilauer, 2003).

3. Results

3.1. Floristic Relations

In total, 17 plant species representing 13 families were identified throughout the surveys. The largest represented families were Poaceae (with three species), followed by Chenopodiaceae, and Zygophyllaceae (with two species for each) (Table 1).The life-form spectrum was dominated by phanerophytes (35%) and geophytes helophytes (23%), followed by chamaephytes (18%), therophytes (12%), hemicryptophytes (6%), and helophytes (6%) (Table 1).

Results of the chorological analysis (Table 2) show that the majority of the recorded species belong to the Saharo-Arabian chorotype (12 species; 33 %), followed by Irano-Turanian region (9 species / 24 %), Mediterranean region (8 species; 22 %), Palaeotropical (3 species; 8 %), Sudano-Zambezian (2 species; 5%), Neotropical (2 species; 5 %), and Euro-Siberian (1 species; 3 %). The relation between the frequencies of the recorded species and the number of the global phytogeographical regions show that the recorded species can be classified into 8 pluri-regional, 7 bi-regional and 2 mono-regional. Dominant species were *P. australis*, *T. nilotica* and *Z. album*, whereas the co-dominant species were *J. rigidus*, *N. retusa*, *A. graecorum*, *T. domingensis*, *Z. coccineum* and *E. camaldulensis*.

Variation in species richness was observed at different sites: Highest at Northeast of the Lower Lake (9 species), followed by the Southwest of the Lower Lake and the Northeast of the Upper Lake (6 species each); while the Southeast of the Lower Lake showed the lowest species richness (1species) (Table 3).

Examination of more detailed diversity indices enhanced the exploration of diversity in Wadi El Rayan. Table 3 shows different diversity indices along different stands. Stand 3 has the highest dominance value (=1) followed by stand 7 (=0.999). In contrary, the lowest Simpson's index value was recorded at stand 3 (=0) and highest at stand 4 (=0.574). Similarly, the highest Shannon's diversity index value was at stand 1 (=1.135) and lowest at stand 3(=0). The highest Buzas and Gibson's evenness index value was at stand 3(=1) and the lowest at stand 9 (=0.208). The highest Brillouin's index value was at stand 1 (=1.120) and the lowest at stand 3(=0). The highest Menhinick's richness index value was recorded at stand 4 (=0.570) and the lowest at stand 10 (0.012). Meanwhile, the highest Margalef's richness index value was recorded in stand 1 (=1.118) and the lowest at stand 3 (=0). Also, the highest equitability value was recorded at stand 5 (evenness index = 0.845) and the lowest value at stand 3 (=0). However, the highest Fisher's alpha index value was recorded at stand 4 (=1.359) and the lowest at stand 3 (=0.164). Berger-Parker dominance was the highest at stand 3 (=1), and the highest value of Chao1 index was recorded at stand 1 (=9).

The spatial distribution of some species showed wide ecological ranges; for example:

- *T. nilotica* and *P. australis* were commonly found around the two lakes.
- *J. rigidus* was distributed around the two lakes, with less representation around the Lower Lake (not recorded on its southern edge).
- *A. graecorum* was distributed at the edges of the Connecting Channel, northeast of the Lower Lake; southwest and northeast of the Upper Lake.
- *P. dactylifera* was sparse distributed around the two lakes.
- *I. cylindrica* and *P.dioscoridis* were distributed at the edges of the Connecting Channel and at the northeastern part of the Lower Lake.

Table 1.Recorded species, their families and life form at Wadi El Rayan.

No.	Species	Family	Life form
1	*Arthrocnemum macrostachyum (Moric.)k. Koch*	Chenopodiaceae	Chamaephytes
2	*Chenopodium murale* L.	Chenopodiaceae	Therophytes
3	*Pluchea dioscoridis* (L.)DC.	Compositae (Asteraceae)	Phanerophytes
4	*Cyperus laevigatus* L.	Cyperaceae	Geophytes Helophytes
5	*Imperata cylindrica* (L.) Raeusch.	Gramineae (Poaceae)	Geophytes Helophytes
6	*Phragmites australis* (Cav.)Trin. ex Steud.	Gramineae (Poaceae)	Geophytes Helophytes
7	*Polypogon monspeliensis* (L.) Desf.	Gramineae (Poaceae)	Therophytes
8	*Juncus rigidus* Desf.	Juncaceae	Geophytes Helophytes
9	*Alhagi graecorum* Boiss	Leguminosae (Fabaceae)	Hemicryptophytes
10	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	Phanerophytes
11	*Nitraria retusa* (Forssk) Asch	Nitrariaceae	Phanerophytes
12	*Phoenix dactylifera* L.,	Palmae (Arecaceae)	Phanerophytes
13	*Calligonum polygonoides* subsp. comosum *(L' Hér.)Soskov*	Polygonaceae	Phanerophytes
14	*Tamarix nilotica* (Ehrenb.) Bunge	Tamaricaceae	Phanerophytes
15	*Typha domingensis (Pers.) Poir. ex Steud.*	Typhaceae	Helophytes
16	*Zygophyllum album* L.f.	Zygophyllaceae	Chamaephytes
17	*Zygophyllum coccineum* L.	Zygophyllaceae	Chamaephytes

Table 2. The floristic regions of the flora around the lakes of Wadi El Rayan

Plant species	Floristic regions*
Alhagi graecorum	IR-TR + SA- AR + ME
Arthrocnemum macrostachyum	ME +SA-AR
Calligonum polygonoides sub. comosum	SA-AR + IR-TR
Chenopodium marale	Cosmopolitan
Cyperus laevigatus	Cosmopolitan
Eucalyptus camaldulensis	IR-TR
Imperata cylindrica	ME + IR-TR + SA-AR+PAL+NEO
Juncus rigidus	ER-SR + ME + IR-TR
Nitraria retusa	SA-AR + SU-ZA
Phoenix dactylifera	SA-AR + SU-AZ
Phragmites australis	ME + IR-TR + SA-AR + PAL + NEO
Pluchea dioscoridis	SU-ZA + SA-AR
Polypogon monospliensis	ME + IR-TR+ SA-AR
Tamarix nilotica	SA-AR + IR-TR
Typha domingensis	ME + IR-TR + PAL
Zygophyllum album	SA-AR + ME
Zygophyllum coccineum	SA-AR

*The floristic regions are abbreviated as follows: ME: Mediterranean, IR-TR: Irano-Turanian, SA-AR: Saharo-Arabian, ER-SR: Euro-Siberian, SU-ZA: Sudano-Zambezian, NEO: Neotropical, and PAL: Palaeotropical.

Table 3. Diversity indices along the study stands in Wadi El Rayan

	Stand 1	Stand 2	Stand 3	Stand 4	Stand 5	Stand 6	Stand 7	Stand 8	Stand 9	Stand 10
Taxa_S (species richness)	9	5	1	6	2	5	4	3	6	4
Dominance_D	0.487	0.843	1.000	0.426	0.603	0.915	0.999	0.995	0.920	0.978
Simpson_1-D	0.513	0.157	0.000	0.574	0.397	0.085	0.001	0.005	0.080	0.022
Shannon_H	1.135	0.335	0.000	1.119	0.586	0.203	0.006	0.018	0.223	0.062
Evenness_e^H/S	0.346	0.280	1.000	0.510	0.898	0.245	0.252	0.339	0.208	0.266
Brillouin	1.120	0.332	0.000	1.045	0.529	0.202	0.006	0.018	0.219	0.062
Menhinick	0.251	0.088	0.118	0.570	0.348	0.043	0.024	0.015	0.116	0.012
Margalef	1.118	0.495	0.000	1.062	0.286	0.422	0.293	0.190	0.633	0.259
Equitability_J	0.517	0.208	0.000	0.625	0.845	0.126	0.005	0.017	0.124	0.045
Fisher_alpha	1.306	0.580	0.164	1.359	0.469	0.490	0.354	0.252	0.731	0.313
Berger-Parker	0.679	0.915	1.000	0.604	0.727	0.956	0.999	0.998	0.959	0.989
Chao-1	9	5	1	7	2	5	4	3	6	4

3.2. Multivariate Analysis

3.2.1. Classification

Cluster analysis of species composition for each of the 10 studied stands is shown in Figure 2. Based on the results of the TWINSPAN analysis (using importance values 'IV' of the recorded species), the vegetation can be categorized into four vegetation groups (Figure 3), named after their leading dominant species: (A) *P. australis–T. nilotica*, (B) *J. rigidus*, (C) *A. graecorum*, and (D) *Z. album–N. retusa*. Different species of these groups can be easily linked to a habitat type: wetlands, Sabkha, sand sheets, sand dunes, desert areas edges of wetlands.

Statistical analysis of the physical properties of the soil showed a variation in soil texture: the most frequent type was sandy (70%) while the loamy sand was detected only at three stands (30%) (Table 4). The lowest recorded elevation was at El Modwara (-19m b.s.l) while the highest was at the northeastern part of the Upper Lake (16m a.s.l). The analyses of the chemical properties of the soil showed that it was slightly alkaline (with pH values ranging from 7.89 to 8.5); while the electrical conductivity values of soil extract showed a great variation ranging from 5.88 to 63.0 ds/m. The soil organic matter was low, ranging from 0.08 to1.2 % with the most frequent value of 0.61 %. However, significant differences in the soil chemical and physical characters were found (Table 5). The analyses of the soil chemical properties relationship with vegetation (Table 6) showed that the mean soil pH value for *P. australis* and *T. nilotica* was 8.14; 8.17 for *A. graecorum*; 8.19 for *J. rigidus*; and 8.5 for each of *P. monospeliensis, C. laevigatus and C. murale*. However, soil analyses showed that the soil was slightly alkaline, with pH values ranging from 7.89 at

Stand 10 (species: *J. rigidus*, *P. australis*, *T. nilotica and T. domingensis*) to 8.5 at Stand 1 (species: *A. graecorum*, *C. murale*, *C. laevigatus*, *I. cylindrica*, *J. rigidus*, *P. australis*, *P. dioscoridis*, *P. monspeliensis and T. nilotica)*. However, the most frequent value of soil pH in the study area was 8.11.

There was a great variation in Total Dissolved Solids (T.D.S) of different plant species. The mean T.D.S for *P. australis* was 11135.29 ppm; *T. nilotica*: 11212.16; *A. graecorum*: 6636.80; *Z. coccineum and A. macrostachyum:* 40320. However, high T.D.S variation across stands was measured ranging from 3763.2 ppm at Stand 9 (species: *A. graecorum*, *E. camaldulensis*, *J. rigidus*, *P. dactylifera*, *P. australis* and *T. nilotica*) to 40320 ppm at Stand 7 (species: *A. macrostachyum*, *P. australis*, *T. nilotica and Z. coccineum*).

Results showed that the study area is poor inorganic matter content, ranging from 0.08 % at Stand 4 (species: *C. polygonoides*, *N. retusa*, *P. dactylifera*, *P. australis*, *T. nilotica* and *Z. album)* to 1.2% at Stand 8, with the most frequent value of 0.61%. The study area showed a great variation of soil carbonate content, ranging from 3.81% at Stand 6 (species: *A. graecorum*, *J. rigidus*, *P. dactylifera*, *P. australis and T. nilotica*) to 37.9 % at Stand 1 (species: *A. graecorum*, *C. murale*, *C. laevigatus*, *I. cylindrica*, *J. rigidus*, *P. australis*, *P. dioscoridis*, *P. monspeliensis and T. nilotica)*, with the most frequent value of 7.16 %.

The soil calcium content ranged from19.3 meq/L at Stand 5 (species: *P. australis*and *T. nilotica*) to 115 meq/L at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum and A. macrostachyum*). While, the soil magnesium content ranged from 3.6 meq/L at Stand 9 (species: *A. graecorum*, *E. camaldulensis*, *J. rigidus*, *P. dactylifera*, *P. australis and T. nilotica*) to 107 meq/L at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum and A. macrostachyum*).

The soil sodium content ranged from 22.2 meq/L at Stand 4 (species: *C. polygonoides*, *N. retusa*, *P. dactylifera*, *P. australis*, *T. nilotica* and *Z. album*) to 590 meq/L at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*). The soil potassium content ranged from 2.8 meq/L at Stand 10 (species: *J. rigidus*, *P. australis*, *T. nilotica* and *T. domingensis*) to 8.1 meq/L at Stand 3 (*T. nilotica*), with the most frequent value of 3.2 meq/L. The data indicated that Stand 7 has the highest value of bicarbonate content (4.01 meq/L - species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*), while the lowest value was recorded at Stand 5 (1 meq/L - species: *P. australis* and *T. nilotica*), with the most frequent value of 2.11 meq/L. Soil collected at Stand 7 (species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*) showed the highest chloride content value (700 meq/L),while the lowest value was recorded at Stand 5 (33.1 meq/L - species: *P. australis* and *T. nilotica*). Furthermore, soil sulphate contents were highest at Stand 7 (114.8 meq/L – species: *P. australis*, *T. nilotica*, *Z. coccineum* and *A. macrostachyum*) and lowest at Stand 9 (6.79 meq/L – species: *A. graecorum*, *E. camaldulensis*, *J. rigidus*, *P. dactylifera*, *P. australis* and *T. nilotica*).

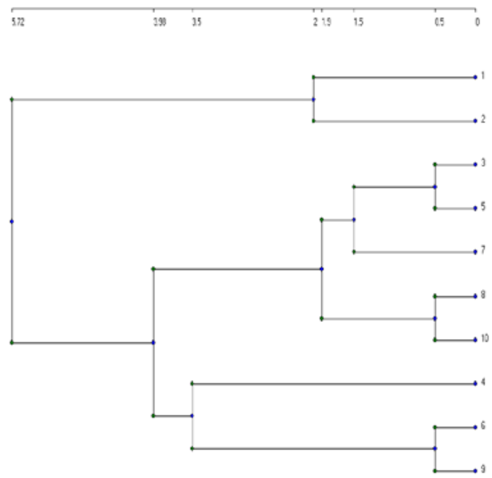
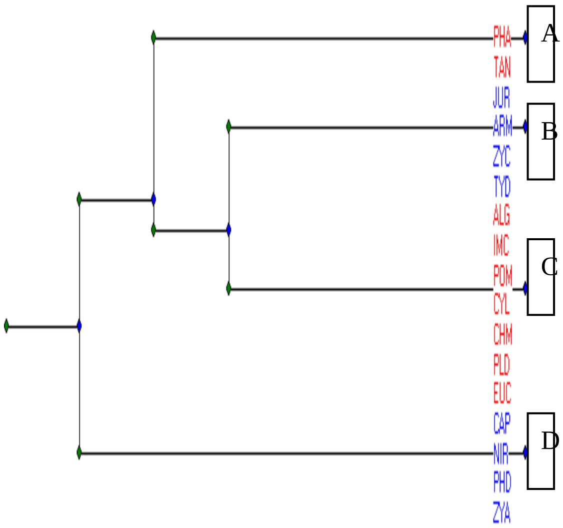


Figure2.Dendrograms showing cluster analysis of the studied stands.



Abbreviations:

PHA	*Phragmites australis*	*CAP*	*Calligonum polygonoides sub. comosum*
TAN	*Tamarix nilotica*	*ARM*	*Arthrocnemum macrostachyum*
JUR	*Juncus rigidus*	*NIR*	*Nitraria retusa*
ALG	*Alhagi graecorum*	*PHD*	*Phoenix dactylifera*
IMC	*Imperata cylindrica*	*ZYA*	*Zygophyllum album*
POM	*Polypogon monospeliensis*	*ZYC*	*Zygophyllum coccineum*
CYL	*Cyperus laevigatus*	*TYD*	*Typha domingensis*
CHM	*Chenopodium murale*	*EUC*	*Eucalyptus camaldulensis*
PLD	*Pluchea dioscoridis*		

Figure 3. TWINSPAN dendrogram of the 10 studied stands of the study area and 17 species based on their importance values. A-D are the four separated vegetation groups.

Table 4. The physical properties of soil samples collected within the study stands in Wadi El Rayan.

Location	Stand No.	Alt (m)	The saturation percentage (SP)	Texture (%)				Texture
				Coarse Sand	Fine Sand	Silt	Clay	
North East of the Lower Lake	1	-18	0.61	35.6	42.7	14.2	7.5	Loamy Sand
The Connecting channel	2	-2	0.43	39.6	46.4	9.5	4.5	Sandy
Southeast of the Lower Lake	3	-14	0.81	39.4	46.1	9.8	4.7	Sandy
Southwest of the Lower Lake	4	-3	0.08	38.8	44.5	10.4	6.3	Sandy
El Modwara (Northwest of Lower Lake)	5	-19	0.61	41.7	43.7	9.6	5.0	Sandy
Southwest of the Upper Lake	6	13	0.68	42.5	43.2	10.3	4.0	Sandy
Northwest of the Upper Lake	7	9	1.1	32.8	40.3	19.5	7.4	Loamy Sand
Southeast of the Upper Lake	8	9	1.2	35.0	42.5	16.2	6.3	Loamy Sand
Northeast of the Upper Lake	9	16	0.96	35.4	49.3	10.5	4.8	Sandy
North of the Upper Lake	10	13	20.1	44.7	47.5	5.3	2.5	Sandy

Table 5.Chemical properties of soil samples that collected within the study stands in Wadi El Rayan.

Location	Stand No.	pH	T.D. S ppm	EC ds/m	%	%	%	Cations (meq/l)				Anions(meq/l)		
					Organic matter	Organic carbon	$CaCO_3$	Ca^{++}	Mg^{++}	Na^{+}	K+	HCO_3-	Cl^-	SO_4^{--}
Northeast of the Lower Lake	1	8.50	4928	7.70	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
The Connecting Channel	2	8.11	9664	15.10	0.43	0.24	6.7	37.1	53.3	99.1	5.5	2.01	122.0	70.99
Southeast of the lower lake	3	8.15	11904	18.60	0.81	0.46	7.16	50.1	35.8	140.0	8.1	2.11	205.0	26.89
Southwest of the lower lake	4	8.12	3974.4	6.21	0.08	0.046	6.60	26.1	8.5	22.2	3.20	1.33	42.1	16.57
El Modwara (Northwest of Lower Lake)	5	8.11	3840	6.0	0.61	0.35	5.05	19.3	9.7	25.1	2.9	1.0	33.1	22.9
Southwest of the Upper Lake	6	8.05	8192	12.8	0.68	0.39	3.81	35.2	38.4	78.2	4.2	3.0	100.0	53.0
Northwest of the Upper Lake	7	8.0	40320	63.0	1.1	0.63	7.16	115.0	107.0	590.0	6.8	4.01	700.0	114.8
Southeast of the Upper Lake	8	8.49	10496	16.4	1.2	0.69	28.6	55.0	37.8	110.0	5.2	3.02	180.0	24.98
Northeast of the Upper Lake	9	8.02	3763.2	5.88	0.96	0.55	22.7	20.0	3.6	25.2	3.2	2.11	43.1	6.79
North of the Upper Lake	10	7.89	15040	23.5	0.2	0.11	8.6	57.8	25.1	199.2	2.8	2.9	244.2	37.8

Table 6. Mean values of chemical analysis of soil for different plant species within the study stands in Wadi El Rayan.

Species Name	pH	T.D.S ppm	EC ds/m	% Organic matter	% Organic carbon	% $CaCO_3$	Cations (meq/l) Ca++	Mg++	Na+	K+	Anions (meq/l) HCO_3-	Cl-	SO_4--
Phragmites australis	8.14	11135.29	17.40	0.65	0.37	14.12	43.08	33.09	131.23	4.12	2.29	167.74	41.49
Tamarix nilotica	8.14	11212.16	17.52	0.67	0.38	13.43	43.78	33.36	132.11	4.52	2.27	171.47	40.03
Juncus rigidus	8.19	8483.84	13.26	0.73	0.42	20.32	38.04	23.86	88.94	3.74	2.45	122.50	29.64
Alhagi graecorum	8.17	6636.80	10.37	0.67	0.38	17.78	28.63	27.43	58.65	4.05	2.08	77.58	39.10
Imperata cylindrica	8.31	7296.00	11.40	0.52	0.30	22.30	29.65	33.85	65.60	4.41	1.61	83.60	48.30
Polypogon monospeliensis	8.5	4928	7.7	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
Cyperus laevigatus	8.5	4928	7.7	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
Chenopodium murale	8.5	4928	7.7	0.61	0.35	37.9	22.2	14.4	32.1	3.31	1.2	45.2	25.61
Pluchea dioscoridis	8.31	7296.00	11.40	0.52	0.30	22.30	29.65	33.85	65.60	4.41	1.61	83.60	48.30
Calligonum polygonoides	8.12	3974.4	6.21	0.08	0.046	6.6	26.1	8.5	22.2	3.2	1.33	42.1	16.57
Arthrocnemum macrostachyum	8	40320	63	1.1	0.63	7.16	115	107	590	6.8	4.01	700	114.8
Nitrari aretusa	8.12	3974.4	6.21	0.08	0.046	6.6	26.1	8.5	22.2	3.2	1.33	42.1	16.57
Phoenix dactylifera	8.06	5309.87	8.30	0.57	0.33	11.04	27.10	16.83	41.87	3.53	2.15	61.73	25.45
Zygophyllum album	8.12	3974.4	6.21	0.08	0.046	6.6	26.1	8.5	22.2	3.2	1.33	42.1	16.57
Zygophyllum coccineum	8	40320	63	1.1	0.63	7.16	115	107	590	6.8	4.01	700	114.8
Typha domingensis	7.89	15040	23.5	0.2	0.11	8.6	57.8	25.1	199.2	2.8	2.9	244.2	37.8
Eucalyptus camaldulensis	8.02	3763.2	5.88	0.96	0.55	22.7	20	3.6	25.2	3.2	2.11	43.1	6.79

3.2.2. Ordination

There was a successive decrease in the Eigenvalues of the first three CCA axes. These Eigenvalues were somewhat higher for the DCA axes (Tables 7 and 8), which indicates that the important explanatory stand variables were not measured and included in the analysis or some of the variations were not explained by environmental variables (Franklin & Merlin, 1992; McDonald *et al.*, 1996).

However, The DCA analysis revealed information about the range of variation among the stands at the two lakes (Table 7 and Figure 4). Results showed that the first gradient is the longest, explaining about 36.8 % of the total species variability, whereas the second and higher axes explain much lower. Also, the first axis was very well correlated with the environmental data (r=1), and the correlation for the other axis was considerably lower. This suggests that the whole data set was governed by a single dominant gradient. The number of axis scores calculated for a species–environmental variable bi-plot was restricted in a DCA, by one or two defaults.

The first axis was negatively correlated with the altitude (Alt) and soil contents (fine sand and clay), with the increasing concentration of (K+, Mg++ and organic matter), positively correlated with (Na+, Cl^- , total dissolved salts with electrical conductivity), and with the increasing concentration of (SO_4^{--}, Ca++, and HCO_3^-), with the increasing concentration of $CaCO_3$ and pH gradient.

The positions of arrows for environmental variables suggest that there was a group of variables that were mutually highly positive correlated (Alt, $CaCO_3$, pH, clay and fine soil) and negative correlated with (Cl^-, K^+, Ca^{++} and organic matter) with the total dissolved salts and electrical conductivity. A closer inspection of the correlation matrix in the CANOCO Log View showed that the variables were indeed correlated, but in some cases the correlation is not very strong. The correlation matrix also confirmed that the correlation of all measured variables with the second axis was rather weak (Figure 4).

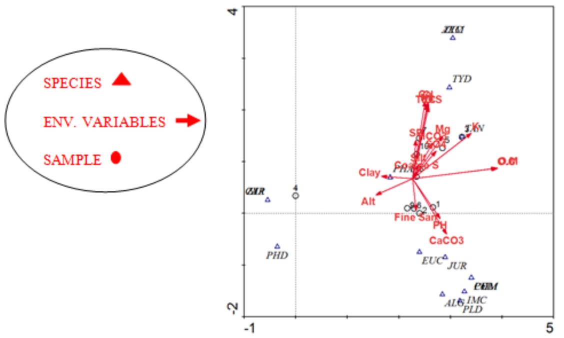
This pattern also appeared in the summary (Table 8), where the first axis explained more than the second, third and fourth axes do together. Comparing this summary with that from the DCA, it is noticed that the percentage variance explained by the first axis was the same as that explained by the first axis in the unconstrained DCA (36.8), where the species environment correlation was only slightly higher. The first axis of CCA was very similar (both for the species and for the sample scores) to the first axis of DCA (Figures 4and 5). However, the second axis was different: The CCA showed a remarkable arch effect – the quadratic dependence of the second axis on the first one.

Table7. Environmental parameters used in the DCA and their Eigenvalues.

Axes	1	2	3	4
Eigenvalues	0.756	0.25	0.099	0.02
Lengths of gradient	3.224	1.478	1.402	0.841
Species-environment correlations	1	1	1	1
of species data	36.8	49	53.8	54.8
of species-environment relation	28.7	43.5	0	0
The saturation percentage (SP)	0.0633	0.291	-0.1671	0.3675
Coarse S	0.0333	0.0572	-0.3723	-0.3823
Fine San	-0.0168	-0.2297	-0.2635	0.1383
Silt	0.0482	0.1123	0.4083	0.1891
Clay	-0.1756	-0.0325	0.3047	0.2017
PH	0.1121	-0.2511	-0.1829	-0.2658
EC	0.1754	0.5593	0.4979	0.3654
O.M	0.499	0.2137	0.4848	0.3654
$CaCO_3$	0.1318	-0.3548	-0.211	0.089
Ca	0.161	0.5932	0.4958	0.0906
Mg	0.2234	0.3657	0.3026	0.2062
Na	0.1689	0.5712	0.5148	0.3373
K	0.3882	0.4296	0.4114	0.0226
HCO_3	0.1553	0.2945	0.2447	0.3962
Cl	0.1775	0.5926	0.5381	-0.2252
SO_4	0.1667	0.2415	0.1335	0.1818
Altitude	-0.2286	-0.1794	-0.0585	0.3902

Table8. Environmental parameters used in the CCA and their Eigen values.

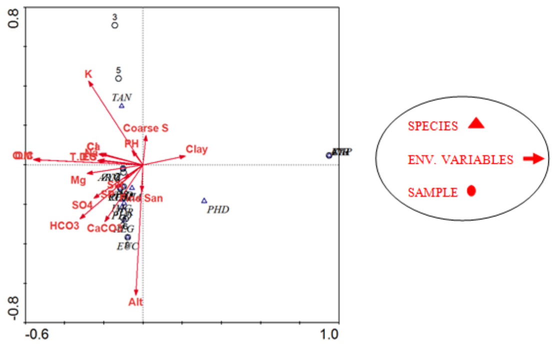
Axes	1	2	3	4
Eigenvalues	0.756	0.421	0.251	0.213
Species-environment correlations	1	1	1	1
of species-environment relation	36.8	57.3	69.5	79.9
The saturation percentage (SP)	-0.1404	-0.117	0.4948	0.8326
Coarse S	0.016	0.1498	-0.0919	0.7283
Fine San	-0.0061	-0.1349	-0.2887	0.5317
Silt	-0.0951	-0.0685	0.2729	-0.7654
Clay	0.2161	0.0451	0.0172	-0.7096
PH	-0.0557	0.0719	-0.4951	-0.1779
EC	-0.2312	0.0214	0.8418	-0.3918
O.M	-0.5586	0.0272	0.0966	-0.5516
$CaCO_3$	-0.1941	-0.2875	-0.3408	-0.0102
Ca	-0.2148	0.0581	0.848	-0.3053
Mg	-0.2848	-0.0435	0.6292	-0.5363
Na	-0.2242	0.0255	0.8548	-0.3825
K	-0.2772	0.4249	0.1586	-0.484
HCO_3	-0.3214	-0.2736	0.6972	-0.1547
Cl	-0.2264	0.0559	0.8486	-0.378
SO_4	-0.2508	-0.1699	0.6065	-0.4855
Altitude	-0.0358	-0.6612	0.438	0.1003



Abbreviations:

PHA	*Phragmitesaustralis*	*CAP*	*Calligonumpolygonoidessub .comosum*
TAN	*Tamarixnilotica*	*ARM*	*Arthrocnemummacrostachyum*
JUR	*Juncusrigidus*	*NIR*	*Nitrariaretusa*
ALG	*Alhagigraecorum*	*PHD*	*Phoenix dactylifera*
IMC	*Imperatacylindrica*	*ZYA*	*Zygophyllum album*
POM	*Polypogonmonospeliensis*	*ZYC*	*Zygophyllumcoccineum*
CYL	*Cyperuslaevigatus*	*TYD*	*Typhadomingensis*
CHM	*Chenopodiummurale*	*EUC*	*Eucalyptus camaldulensis*
PLD	*Plucheadioscoridis*		

Figure 4. The samples, species and environmental (circles, triangle and arrow, respectively) triplot of the DCA of the whole data set.



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PLD	*Plucheadioscoridis*		

Figure 5.The samples, species and environmental (circles, triangle and arrow, respectively) triplot of the CCA of the whole data set.

4. Discussion

The present study examined the environmental correlates of species distribution at different geomorphologic locations of Wadi El Rayan Protected Area along the coast of the two lakes. Both DCA and CCA assessed the soil-vegetation relationships: CCA analysis showed the relative positions of species and sites along the most important ecological gradients. Both ordination techniques clearly indicated that soil pH, electric conductivity (salinity), $CaCO_3$, organic matter, and relative concentrations of cations (Ca++, Mg++, Na+ and K+) were the most important parameters for the distribution of the vegetation pattern in the area.

The organic matter, considered as a key factor affecting the soil fertility of some desert ecosystems in Egypt (Sharaf El Din and Shaltout, 1985; Abd El-Ghani, 1998, 2000) and soils of arid lands have a low level of organic matter, are slightly acid to alkaline in reaction (pH) at the surface (Dregne, 1976). The soil chemistry affects the plant species composition through salinity levels (Sharma and Shankar, 1991; Kumar, 1996; Abbadi and El Sheikh, 2002), pH, calcium and organic carbon (Abd El-Ghani, 1998).The present study showed that Wadi El Rayan is characterized by a variety of soil types (based on their physical and chemical attributes), which is in accordance to its varying nutrient status (Amin, 1998). Literature reported, on average, a higher species richness in the area of Wadi El Rayan than the the one recorded in the present study (60 species: Abdou, 2002; 38 species: EEAA, 2003; 27 species: Azzazi, 2009; 13 species: Saleh *et al*., 1984). The lower number of the recorded species here is due to our confined scope towards wetlands and desert ecosystems; while others have also included species from the springs' oases and the cultivated lands. Furthermore, the human pressures may play a role in the distribution of the species (e.g., overgrazing, land encroachment, reduction in water levels due to decreased water collected in the lakes and tourism).Conservation of the vegetation in Wadi El Rayan requires stopping the severe human impacts that lead to the elimination of certain plant populations and, hence, the modification of the complex plant communities into simple fragile once. However, water supply is of great importance as it determines the Wadi El Rayan's future and its vegetation cover.

The ecosystems investigated in the present study are relatively simple, in which the survived species with stand stress environmental conditions, as Wadi El Rayan is located at the Sahara eco-region of the Palearctic eco-zone, the world's largest hot desert. However, the desert ecosystem of Wadi El Rayan consists of arid vegetation (xerophytic and halophytic plants) with a sparse plant cover except in wetlands ecosystem at the shoreline of the lakes which are characterized by some hydrophytic and halophytic plants.

Our results are in accordance with those of Amin (1998), who identified three major ecosystems in Wadi El-Rayan area: desert, lake and spring ecosystems. However, the spring ecosystem was not recognized in the area of the current study. Each of these ecosystems has its own habitat features that support the growth of variant plant communities, mainly hydrophytes, reed swamps, halophytes, and xerophytes. In the present study, the wetlands are represented by species *P. australis*, *T. nilotica*, *J. rigidus*, *T. domingensis*, *C. laevigatus*, *C. marale*, *P. monspeliensis*, *P. dioscoridis*, *E. camaldulensis* and *I. cylindrica*; while the desert is represented by *T. nilotica*, *A. graecorum*, *C. polygonoides sub. comosum*, *N. retusa*, *Z. album*, *Z. coccineum*, *A. macrostachyum* and *P. dactylifera*. The study area is dominated by two species: *P. australis* and *T. nilotica*. The latter is the most widely distributed plant in Wadi El Rayan and can be considered as the most successful species in the study area as it grows at a variety of ecosystems and habitats (e.g., desert areas, edges of wetlands and salt marshes). Other 15 species were recorded in a very limited abundance (see Table 1), amongst them are *T. domingensis* (which has a very limited distributional range in the study area to the northern edge of the Upper Lake) and *E. camaldulensis* an exotic (non-native to the area) species represented with very limited distribution (northeast edges of the Upper Lake) and typically grows along river banks and in alluvial valleys) (El-Hadidi and Boulos, 1989). Amin (1998) demonstrates the adaptation of different plant species in Wadi El Rayan to environmental stresses (extreme drought and salinity conditions), via (a) having a shedded green cortex (*Z. album* and *Z. coccineum*); (b) defoliation (*N. retusa*); (c) salt removal by secretion (*T. nilotica*); and (d) the ability to phytogenic mounds controlled mainly by the life-form of the species (*C. polygonoides*, *N. retusa*, *Z. album*, *Z. coccineum* and *T. nilotica*). Simpson (1932) reported that *T. domingensis* is more sensitive to salt than *P. australis* as the latter grows well in the Lake Mariut area, while the former is present only where the Lake receives fresh water from the Mahmudiya Canal. *A. graecorum* was a widely distributed species (Kassas, 1952) and was considered as a groundwater-indicating plant (Girgis, 1972). However, the dominant species *P. australis* was the most adaptive and suitable plant species for the quality of the water in Wadi El Rayan (EEAA, 2003).

A high variability of the recorded plants' growth forms was noticed, including shrubs with photosynthetic stems (e.g. *C. polygonoides*), succulent xerohalophytic semi-shrubs (e.g. *Z. album*), virgate and thorny trees and shrubs (e.g. *N. retusa*). The results of the present study are in accordance with the results of Beeftink (1977) and Zahran (1982) that the life-form chamaephytes and geophytes are able to withstand water logging, high salinity levels and a wide range of temperature variability. Also a high percentage of hemicryptophytes and therophytes in sandy dune habitats could be related to their ability to resist drought, sand accumulation and grazing (Danin and Orshan, 1990; Danin, 1996).

Chorological analysis of the floristic data showed that the Saharo-Arabian chorotype (33 %), Irano-Turanian (24 %) and Mediterranean (22 %) formed the major components of the floristic structure along the study area. Abd El-Ghani and Amer (2003) reported that the plants of the Saharo-Arabian species are good indicators for the quality of desert environmental conditions, while the Mediterranean species are more related to the mesic environment. In arid and semi-arid regions, seasonal variations may lead to differential physiological responses in the plants inhabiting such environments, including adaptations to high temperature, drought, and salt stresses (Joyce *et al*., 1984; Murakeozy *et al*., 2003; Kusaka *et al*., 2005).Wickens (1977) and Boulos (1997) reported that the Saharo-Arabian region is characterized by few endemic species and genera, and the absence of endemic families.

Zahran and Willis (2009) reported that, in the extreme environmental conditions of arid lands, the interactions between its different components are of high significance, so that small changes in one component of the ecosystem can lead to substantial variations in others, creating distinct micro-habitats. In arid lands, the inter-relationships between soils, vegetation and atmosphere are so interconnected that they can hardly be considered, ecologically, as separate entities. However, extreme arid conditions, notably high salinity and high aridity, act as filters to species that are able to adapt in the hyper-arid environment.

5. Conclusion

In Wadi El Rayan, as hyper-arid environment, the wild plants have adapted to survive extreme climate conditions and soil factors, where both ordination techniques clearly indicated that soil pH, electric conductivity (salinity), $CaCO_3$, organic matter, and relative concentrations of cations were the most important parameters for the distribution of the vegetation pattern in the area. Considerations of the exploitation and conservation of wild plants must take ecological principles into account. Sustainable management of the floral biodiversity in Wadi El Rayan requires the termination of the severe human impacts that lead to eliminating certain plant populations and, hence, the modification of the complex plant communities into simple fragile once.

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