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Habitat diversity and plant indicators of El-Harra Oasis, Western Desert, Egypt

Elsaied, A.
Botany Department, Faculty of Science, Al-Azhar University, Cairo, Egypt
Corresponding author: E-mail: *Baraa_elsaied@yahoo.com;* Tel.: +20 1012890605

Abstract

Habitat diversity is one of the attractive concepts in ecology that reflects the wellbeing of ecological systems. A total of 30 stands were chosen to represent habitat diversity of El-Harra Oasis. Poaceae, fababceae and astraceae were the most common families with 33 species out of 79 species belonging to 29 families. Therophytes and Hemicryptophytes were the most common life forms with 72 % of the species recorded. Chorology of all non-cultivated taxa was investigated. Species richness, Shannon and Simpson diversity indices and evenness was calculated for each stand. Eighteen soil parameters were investigated and results showed large variation among stands. Seven vegetation groups were obtained from the Two-way cluster analysis classification. Environmental parameters correlation with vegetation groups were determined using DCA and DCCA. Significant factors were detected by one way analysis of variance among the seven vegetation groups. Results showed that soil salinity indicators, soil moisture content and soil particles were the most critical factors affecting the ecological diversity in El-Harra Oasis. Indicator species of the seven habitats were halotolreants or halophytes. Managing water resources and agriculture schemes should reduce the magnitudes of salinity problem in El-Harra Oasis.

Keywords: Habitat diversity. El-Harra Oasis. Bahariya Oases. DCA. DCCA.

Introduction

Habitat diversity research is interested in measuring the structural complexity of the environment or the number of communities present in a specific geographic area (Magurran, 1988). Measuring habitat diversity has become an important component of conservation ecology since the eighties(Fuller and Langslow, 1986; Usher, 1986) and even before in the early ecological approaches (Thoreau, 1860 and Clements, 1916) and long time after (Lefcheck et al., 2015 and Sheridan *et al.*, 2017).Methods of measuring diversity and its effects on different ecosystems structure and functionality are numerous from the simple species counting to the complicated experimental work of habitat interactions (Alsterberg, 2017).

Human activities have caused serious problems to the environment including habitat homogenization for the benefit of agriculture and habitat loss due to habitat destruction. Habitat homogenization is one the reasons responsible for reducing species richness and diversity especially in the diversely rich habitats. Habitats are connected to each other not only on the species level but also on the habitat level, so one habitat that contains nitrogen fixers can facilitate nitrogen to adjacent habitats (Alsterberg, 2017). Biodiversity shift is not only affecting ecosystem on the species level but also on the level of its physical geography (Pickett and Cadenasso, 1995 and Harborne *et al.*, 2006). In a less diverse ecosystems like desert ecosystem, habitat homogenization may increase number of species by introducing new species but this should destroy the fragile desert habitats and cause habitat loss and escalate the "biome crises" problem where habitat loss rate is from eight to ten times higher than habitat protection (Hoekstra *et al.*, 2005).

Western Desert of Egypt is considered to be the most arid desert in the world (Goudie, 2002). It has the second highest temperature record after the Death Valley, California, USA (Spear, 1992) and the second lowest precipitation rate after Atacama Desert, Chile (Clarke, 2006). The Western Desert of Egypt is part of the subtropical arid deserts zone (Walter and Breckle, 1984). The annual rainfall along the Mediterranean coast of Egypt reaches 200 mm and gradually decreased to reach few millimeters in the south of Egypt (Goudie, 2002). Five main depressions and several small ones are spread over the western desert with a total area of less than 4% of Egypt's total area. According totheir locations, these depressions could be divided into two groups: northern group and southern group. Wadi Al-Natroun, Qattara Depression, Siwa Oasis and Bahariya Oases are comprising the northern group while Farafra Oasis, Dakhla Oases and Kharga Oases are comprising the southern group (Taglianti *et al*., 1999).

Bahariya depression is a closed depression 360 km southwest of Cairo with an area of about 1800 km^2 (Said, 1962). As a result of the escarpments that surround the depression, the oases is less vulnerable to the sand dune movement (Abu Al-Izz, 1971). Bahariya Oases is characterized by its mild winter and hot summer (Ayyad and Ghabour, 1986). Bahariya depression encompasses three groups of oases: 1-the main complex of the oases to the northwestern part of the depression including Al-Bawiti (the capital of Bahariya Oases), Mandisha, Al-Zabu, Al-Aguz, Al-Mamour and Al-Qasaa; 2- El-Heiz Oasis to the south of the depression; and 3- El-HarraOasis to the northeastern part of the depression (Fig. 1a).

El-Harra Oasis lies in the northeastern part of Bahariya depression. It lies between 28˚ 22ˈ N, 29˚03ˈ E and 28˚ 16ˈ N, 29˚08ˈ E.Itis one of the localities in Bahariya Oases that encompasses an iron ore (2.9 km^2) in addition to some other localities as of El-Gedida and El-Ghorabi (Elbassyony, 2000 and 2004). Few studies have been conducted on El-Harra Oasis, however most of these studies are geological studies to investigate the stratigraphy, hydrology and sedimentology of El-Harra (Khalifa *et al.,* 2002, 2003; Catuneanu*et al.,* 2006; Hamdan, 2012; Hamdan and Sawires, 2013 and Abd El Wahed, 2014). Hamdan (2012) indicated that salinity increases toward El-Harra Oasis from 433 mg/l at El Heiz to reach 586 mg/l at El Harra while transmissivity on the other side showed a decrease from 3,045 m^2/day in El-Heiz to 236 m^2/ day in El-Harra in an experiment done to calculate the lone source of water in El-Harra Oasis, Nubian sand stone aquifer system, hydraulic parameters in Bahariya Oases (Hamdan and Sawires, 2013). (Abd El Wahed, 2014) reported that the soils of the cultivated soils of El-Harra Oasis is highly contaminated with iron while the uncultivated soils is highly affected by aluminum, iron and copper. The Soils of El-Harra Sabkhas were found to contain a high concentrations of chromium, iron, led, Vanadium, arsenic and manganese (Abd El Wahed, 2014). Few studies were conducted on the vegetation of Bahariya Oasesincluding El-Harra Oasis (Abd El-Ghani, 1981; 1985; Abd El-Ghani and El-Sawaf, 2004; Abd El-Ghani and Fawzy, 2006 and El-Saied, 2012)

To the best of the author knowledge, no studies have been performed to study the habitat diversity of El-Harra Oasis. The present study aimed at investigating habitat diversity and indicator species of each habitat in El-Harra Oasis. Identifying and describing the vegetation- environment interrelationships is of great importance.

Material and Methods

A total of 30 stands were chosen to represent different habitats of El-Harra Oasis from 2015-2016. Each stand was visited two times to record required field data. Stands were subjectively chosen to represent the vegetation of different cultivated and non-cultivated habitats. GPS coordinates of these stands are shown in (Fig.1b).

Four 25 m^2 quadrates were inspected in each stand. A list of species for each quadrate was prepared and coverage (%) of each species was visually estimated. Floristic composition of the 30 stands was recorded after complete identification according to Täckholm (1974) and Boulos (1999-2009). Nomenclature was revised for accepted names using the website (http://www.theplantlist.org/). Voucher herbarium specimens were prepared and kept in the herbarium of the Department of Botany, Faculty of Science, Al-Azhar University. Different categories of life-form were identified after Raunkiaer's system of classification (Raunkiaer, 1934), as modified by Govaerts et al., (2000).Phytogeographical affinities were recorded after the system of Eig (1931).

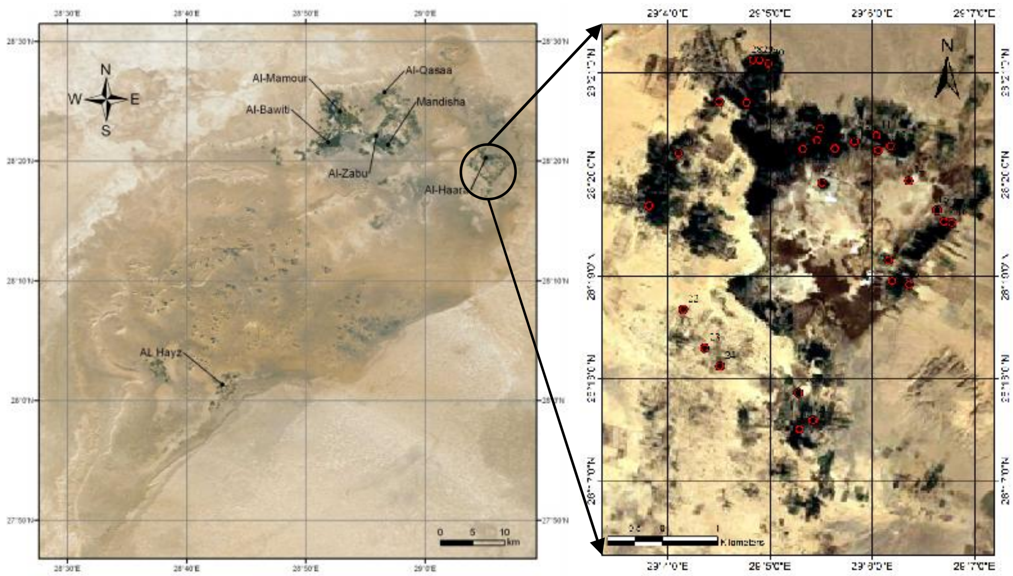


Fig. 1. Bahariya depression showing the three groups of oases (left) and the distribution of the 30 selected stands of El-Harra Oasis (right).

Species richness (S) was calculated after Whittaker (1972):

Species richness = number of species in each stand

Shannon and Simpson diversity indices were calculated after the next equations:

Shannon`s diversity index (H) = - sum (Pi*ln(Pi));
Simpson`s diversity index (D) = 1 - sum (Pi*Pi),
where Pi = importance probability in element i.

Evenness (E) was calculated for each stand after Pielou (1966)

Evenness = H / ln (Species richness).

Four soil samples were collected from each stand at a depth of 5-25 cm after removing the surface layer. Samples of each stand were pooled together to form one composite sample. Soil parameters measured in each of the 30 stands were: Mechanical analysis (%), moisture content (%), electrical conductivity (EC; mS/cm), pH, Organic matter (%), chlorides (%), Bicarbonate (%), sulfates (%), (Sodium, Potassium, Calcium, Magnesium (Cmol/kg)) in soil extract(1 soil: 2.5 water (w/v)). All Analyses took place in the Ecology lab of Botany Department, Faculty of Science, Al-Azhar University.

Data analysis was accomplished using PC-ORD ver. 5 (McCune and Mefford, 1999) to perform Data profile, Two way cluster analysis and DECORANA. CANOCO ver. 4.5 and CanoDraw ver 4.1 (DCCA; ter Braak, 1988) was used to perform DCCA. Analysis of variance (ANOVA) using SPSS ver. 23 (Santoso, 2014) was used to test the most significant soil factors affecting the classification.

Data profile was produced to evaluate both vegetation and environmental matrices for essential data manipulations. Two way cluster analysis is an agglomerative clustering method in which vegetation matrix is classified twice, one time for the rows and one more time for the columns. The Two way cluster analysis is a recommended method described by the PC-ORD software package ver. 5 to replace the two way indicator species (TWINSPAN; a divisive clustering method). McCune and Grace (2002) recommended that ecologists should minimize the use of TWINSPAN, except in some cases where the two ordered table produced by TWINSPAN is needed, because of problems dealing with several underlying gradients. Sorensen distance measure (Bray-Curtis) and flexible beta linkage method (-0.25) was used to run the analysis and in order to get the lowest chaining percentage from the analysis. Raw coverage data was used with no relativization or transformation. In the two way cluster analysis, a graphical matrix is created to help understanding the basis on which the analysis was produced and relations among individuals of the same group. Percentiles by columns was used for the graphical matrix coding.

Detrended Correspondence Analysis (DCA or DECORANA) as indirect gradient ordination technique followed by direct gradient analysis (Detrended Canonical Correspondence Analysis (DCCA)) were used to define indicator species of each habitat and identify interrelationships between vegetation and different environmental factors.

Results

Field work has resulted in recording 79 species belonging to 75 genera and 29 families including 12 cultivated species (Table 1). Poaceae (12 species), fabaceae (11 Species) and astraceae (10 species) were the prevailed families with over 40 % of the recorded species (Fig. 2). After excluding the 12 cultivated species, six life forms were identified through the 67 non-cultivated taxa. Therophytes was the most common life form with 26 species followed by hemicryptophytes with 22 species. Eight species were belonging to the Chamephytes while geophytes and phanerophytes were represented by five species each and only one parasite species was recorded (Fig. 3).

Concerning phytogeographical affinities, five species were cosmopolitan species while six species were pantropical and ten species were paleotropical (Fig. 4). Seven species were monoregional species while 23 were biregional and 16 species were pluriregionals (Table 2).Vegetation analysis showed that species richness ranged from 1 to 29 species while Evenness ranged from 0 to 0.81. Shannon diversity index for the 30 stands ranged from 0 to 2.1 while Simpson diversity index ranged from 0 to 0.81.

Soil analysis results showed great variation among the 30 stands and especially among different habitats. Mechanical analysis showed that the soil samples were sandy to loamy sand. Almost all soils of El-Harra is affected by salinity to some extent where electrical conductivity range was from 1 to 135 mS/cm. The manifestation of the salinity problem is represented also by the results of chlorides, sulfates, calcium, magnesium, sodium and potassium which showed high concentrations of these ions with a significant variation. Moisture content showed variation among different stands especially between arable lands and other stands.

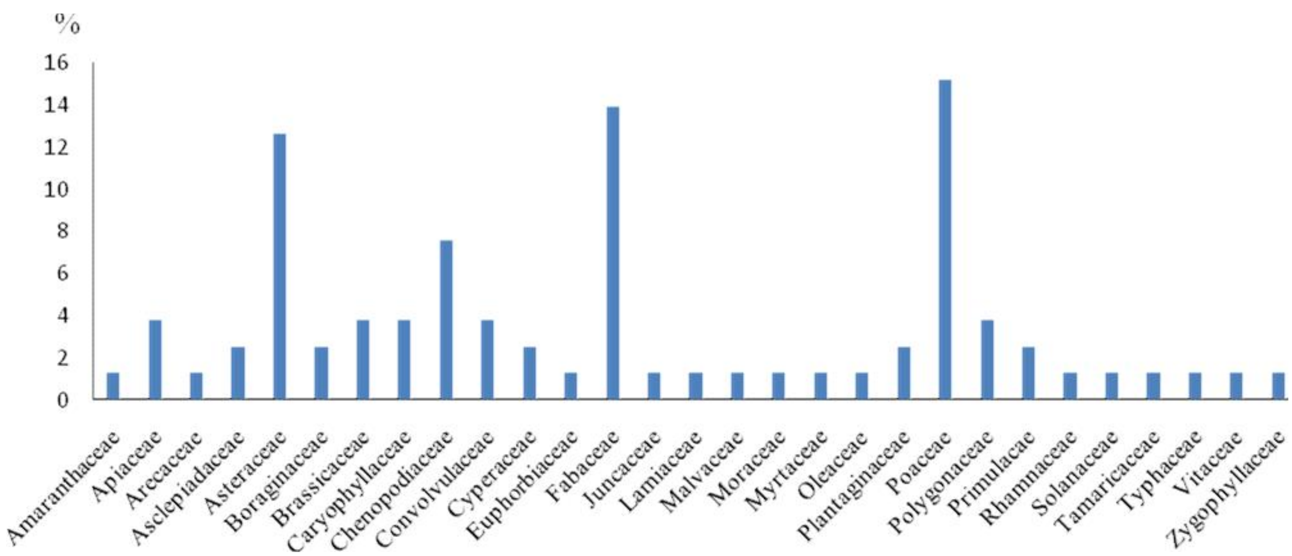
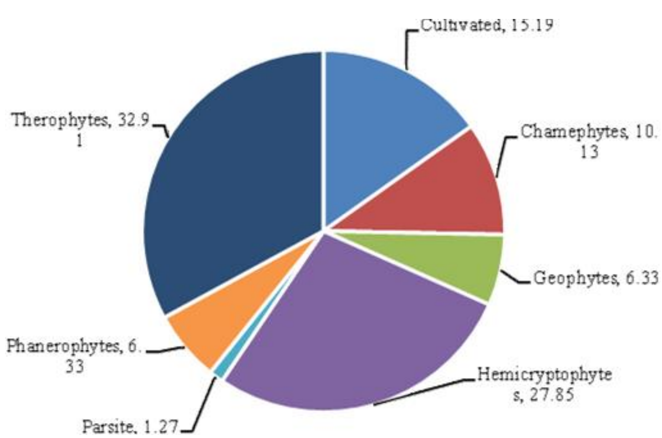


Fig. 2. Species percentage (%) for each family of the 29 recorded families out of the total number of species.

Table 1. List of species recorded in El-Harra Oasis, species were referred to their families, and life forms according to (Raunkiaer, 1934); Therophyte =Th, Hemicryptophyte = Hem, Chamaephyte= Cha, Phanerophyte= Ph, Parasite = Par, Geophyte = Geo, Helophyte = Hel. Phyto-geographical affinities according to the system of Eig (1931); COSM =Cosmopolitan, ER-SR= Euro-Siberian, IR-TR =Irano-Turanian, ME =Mediterranean, PAL= Paleotropical, PAN= Pantropical, SA-SI = Saharo-Sindian, S-Z= Sudano-Zambesian. Families are arranged alphabetically; genera and species are in alphabetical order within their respective families.

Species	Family	Chorology	Life	Abbreviation
Amaranthus viridis L.	Amaranthaceae	PAL	Th.	Ama vir
Anethumgraveolens L.	Apiaceae	Cultivated		Ane gra
Apium nodiflorum (L.) Lag.	Apiaceae	PAL	Th.	Api nod
Coriandrumsativum L.	Apiaceae	Cultivated		Cor sat
Phoenix dactylifera L.	Arecaceae	Cultivated		Pho dac
Calotropis procera (Aiton) Aiton f.	Asclepiadaceae	SA-SI	Cha.	Cal pro
Cynanchum acutum L.	Asclepiadaceae	ME+IR-TR	Ph.	Cyn acu
Ambrosia maritima L.	Asteraceae	ME	Hem.	Amb mar
Bidens pilosa L.	Asteraceae	PAN	Hem.	Bid pil
Cichorium endivia L.	Asteraceae	ME + IR-TR	Th.	Cic end
Conyza bonariensis (L.) Cronquist	Asteraceae	PAN	Cha.	Con bon
Doellia bovei (DC.) Anderb.	Asteraceae	SA-SI + S-Z	Cha.	Doe bov
Helianthus annuus L.	Asteraceae	Cultivated		Hel ann
Pluchea dioscoridis (L.) DC.	Asteraceae	SA-SI + S-Z	Cha.	Plu dio
Pseudognaohalium luteo-album (L.) Hilliard	Asteraceae	ME+SA-SI +IR-TR	Th.	Pse lut
Sonchus maritimus L.	Asteraceae	ME+IR-TR	Hem.	Son mar
Sonchus oleraceus L.	Asteraceae	COSM	Th.	Son ole
Heliotropium ovalifolium Forssk.	Boraginaceae	PAL	Th.	Hel ova
Trichodesma africana (L.) Lehm.	Boraginaceae	IR-TR + SA-SI	Hem.	Tri afr
Coronopus squamatus (Forssk.) Asch.	Brassicaceae	ME + ER-SR	Hem.	Cor squ
Eruca sativa Mill.	Brassicaceae	ME + IR-TR	Th.	Eru sat
Sisymbrium irio L.	Brassicaceae	ME+IR-TR	Th.	Sis iri
Spergularia marina (L.) Griseb.	Caryophyllaceae	ME+IR-TR+ER-SR	Hem.	Spe mar
Stellaria pallida (Dumort.) Murb.	Caryophyllaceae	ME+ER-SR	Th.	Ste pal
Vaccaria pyramidata Medik.	Caryophyllaceae	ME+IR-TR+ER-SR	Th.	Vac pyr
Arthrocnemum macrostachyum (Moric.) K.	Chenopodiaceae	ME+SA-SI	Cha.	Art mac
Beta vulgaris L.	Chenopodiaceae	ME+ IR-TR + ER-	Hem.	Bet vul
Casuarina equisetifolia L.	Chenopodiaceae	Cultivated		Cas equ
Chenopodium murale L.	Chenopodiaceae	COSM	Th.	Che mur
Kochia indica Wight.	Chenopodiaceae	IR-TR	Th.	Koc ind
Suaeda aegyptiaca (Hasselq.) Zohaary.	Chenopodiaceae	SA-SI+S-Z	Hem.	Sua aeg
Convolvulus arvensis L.	Convolvulaceae	PAL	Geo.	Con arv
Cressa cretica L.	Convolvulaceae	PAL	Hem.	Cre cre
Cuscuta campestris Yunck.	Convolvulaceae	PAN	Par.	Cus cam
Carex divisa Huds.	Cyperaceae	ME + IR-TR + ER-	Geo.	Car div
Cyperus rotundus L.	Cyperaceae	PAN	Geo.	Cyp rot
Euphorbia peplus L.	Euphorbiaceae	COSM	Th.	Eup pep
Alhagi graecorum Boiss.	Fabaceae	PAL	Hem.	Alh gra
Glycyrrhiza glabra L.	Fabaceae	ME	Ph.	Gly gla
Lathyrus aphaca L.	Fabaceae	ME + IR-TR + ER-	Th.	Lat aph
Lotus glaber Mill.	Fabaceae	ME+IR-TR+ER-SR	Hem.	Lot gla
Lotus halophilus Boiss. & Spruner	Fabaceae	ME + SA-SI	Th.	Lot hal
Medicagosativa L.	Fabaceae	Cultivated		Med sat
Melilotus indicus (L.) All.	Fabaceae	PAL	Th.	Mel ind
Sesbania sesban (L.) Merr.	Fabaceae	IR-TR+ S-Z	Ph.	Ses ses
Trifolium alexandrinum L.	Fabaceae	Cultivated		Tri ale
Trifolium resupinatum L.	Fabaceae	ME + IR-TR + ER-	Th.	Tri res
Vicia sativa L.	Fabaceae	ME	Th.	Vic sat

Juncus rigidus Desf.	Juncaceae	ME+IR-TR+SA-SI	Hem.	Jun rig
Mentha longifolia (L.) Huds.	Lamiaceae	ME+IR-TR+ER-SR	Hem.	Men lon
Malva parviflora L.	Malvaceae	ME+IR-TR	Th.	Mal par
Ficus carica L.	Moraceae	Cultivated		Fic car
Eucalyptus camaldulensis Dehnh.	Myrtaceae	Cultivated		Euc cam
Olea europaea L.	Oleaceae	Cultivated		Ole eur
Plantago lagopus L.	Plantaginaceae	ME	Th.	Pla lag
Plantago major L.	Plantaginaceae	ME + IR-TR + ER-	Th.	Pla maj
Avena fatua L.	Poaceae	COSM	Th.	Ave fat
Bromus diandrus Roth.	Poaceae	ME+IR-TR+S-Z	Th.	Bro dia
Cynodon dactylon (L.) Pers.	Poaceae	PAN	Geo.	Cyn dac
Desmostachya bipinnata (L.) Stapf	Poaceae	SA-SI + S-Z	Hem.	Des bip
Digitaria ciliaris (Retz.) Koeler	Poaceae	S-Z + PAN	Hem.	Dig cil
Imperata cylindrica (L.) Raeusch.	Poaceae	ME+S-Z	Hem.	Imp cyl
Lolium perenne L.	Poaceae	ME+IR-TR+ER-SR	Hem.	Lol per
Phragmites australis (Cav.) Trin. ex Steud.	Poaceae	PAL	Geo.	Phr aus
Polypogon monspeliensis (L.) Desf.	Poaceae	COSM	Th.	Pol mon
Sorghum halepense (L.) Pers.	Poaceae	PAL	Cha.	Sor hal
Sporobolus spicatus (Vahl) Kunth	Poaceae	ME + SA-SI + S-Z	Hem.	Spo spi
Triticum aestivum L.	Poaceae	Cultivated		Tri aes
Calligonum polygonoides L.	Polygonaceae	IR-TR + SA-SI	Cha.	Cal pol
Emex spinosa (L.) Campd.	Polygonaceae	ME	Th.	Eme spi
Polygonum equisetiforme Sm.	Polygonaceae	ME+ IR-TR	Hem.	Pol equ
Anagallis arvensis L.	Primulacae	ME+IR-TR+ER-SR	Th.	Ana arv
Samolus valerandi L.	Primulacae	PAL	Hem.	Sam val
Ziziphus spina-christi (L.) Desf.	Rhamnaceae	SA-SI + S-Z	Ph.	Ziz spi
Solanum nigrum L.	Solanaceae	ME+IR-TR+ER-SR	Hem.	Sol nig
Tamarix nilotica (Ehrenb.) Bunge.	Tamaricaceae	SA-SI+S-Z	Ph.	Tam nil
Typha domingensis (Pers.) Poir. ex Steud.	Typhaceae	PAN	Hem.	Typ dom
Vitis venifera	Vitaceae	Cultivated		Vit ven
Zygophyllum coccineum L.	Zygophyllaceae	SA-SI+S-Z	Cha.	Zyg coc



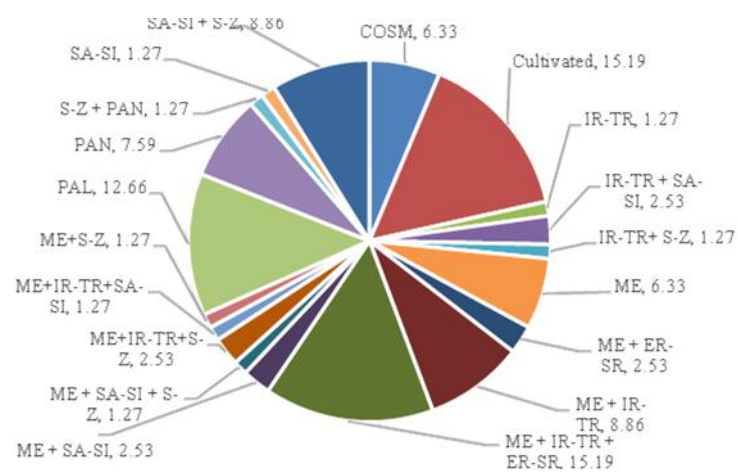


Fig. 3.Life forms of El-Harra recorded species.

Fig. 4.Phytogeographical affinities of El-Harra recorded species.

Table 2. Number of species belonging to the main floristic categories and their percentages (%). Phytogeographical affinities according to the system of Eig (1934); COSM =Cosmopolitan, ER-SR= Euro-Siberian, IR-TR =Irano-Turanian, ME =Mediterranean, PAL= Paleotropical, PAN = Pantropical, SA-SI = Saharo-Sindian, S-Z= Sudano-Zambesian.

Chorology	Number of	Percentage (%)
COSM	5	6.33
PAL	10	12.66
PAN	6	7.59
Cultivated	12	15.19
Monoregional species		
IR-TR	1	1.27
ME	5	6.33
SA-SI	1	1.27
Total	7	10.45
Biregional species		
IR-TR + SA-SI	2	2.53
IR-TR+ S-Z	1	1.27
ME + ER-SR	2	2.53
ME + IR-TR	7	8.86
ME + S-Z	1	1.27
S-Z + PAN	1	1.27
SA-SI + S-Z	7	8.86
ME + SA-SI	2	2.53
Total	23	34.33
Pluriregional species		
ME + IR-TR + ER-SR	12	15.19
ME + SA-SI + S-Z	1	1.27
ME + IR-TR + S-Z	2	2.53
ME + IR-TR + SA-SI	1	1.27
Total	16	23.88

Two-way cluster analysis

The hierarchal classification showed 5.70 chaining percentage for the stands and 6.61 for species classification. Stands were classified into two groups at the first level of classification where arable lands (21 stands) were separated from other natural habitats (9 stands). On the second level, each group was divided into two more groups. Results of the third level was adopted to identify different ecological groups. Seven groups were produced where arable lands were divided into four groups (1-4) while natural habitats were divided into three groups (5-7) (Fig. 5). Group members and indicator species of each group are listed in (Table 3).

DECORANA (Indirect gradient analysis)

Results of DECORANA showed the separation of the two major groups along the first two axes (Fig. 6). Stands tended to cluster in the same manner to the results obtained from the two-way cluster analysis. Environmental factors were plotted over the DECORANA scatter plot to produce a joint plot (biplot) in order to understand the interrelationships between different groups and different environmental factors. Results showed that DCA Axis 1 was positively correlated with almost all salinity indicators in addition to fine sand while diversity indices and coarse sand showed negative correlation with Axis 1. DCA axis 2 was negatively correlated with Calcium. Other environmental factors were in a correlation with axis 1 and 2 with less than 0.3. Pearson Correlation of all significant environmental factors are listed in (Table 4).

DCCA (Direct gradient analysis)

Detrended canonical correspondence analysis was used as a direct gradient analysis to explore the correlations between different groups and different environmental parameters and as a confirmatory test for the results obtained from the indirect gradient analysis of the DCA. Data was plotted along the first two axes of DCCA and results showed the separation of the environmental groups into two groups (Fig. 7). First group included all salinity indicators and fine sand while the second group included all diversity indices in addition to soil moisture content and coarse sand. The first group was correlated with groups 5, 6 and 7 while the second group was correlated with groups 1, 2, 3 and 4. Correlations between significant environmental factors and DCCA axes are listed in (Table 4).

Analysis of Variance (ANOVA)

A comparison between ecological groups for each environmental factor was achieved using one way ANOVA. Results showed that EC, calcium, sodium, species richness, Shannon index and fine sand were the highest significant factors with *P*-value lower than 0.01 followed by Simpson index, gravel, potassium, chlorides, sulfates and soil moisture content with *P*-value lower than 0.05 and higher than 0.01, other 11 factors showed non-significant differences between groups (Table 5).

A comparison between the two groups of habitats showed that only nine parameters out of the 23 environmental parameters were non-significant. EC, calcium, sodium, potassium, species richness, Shannon index and Simpson index, chlorides, bicarbonates, sulfates showed a highly significant differences between the two groups (P-value < 0.01) followed by Evenness, magnesium and fine sand (P-value < 0.05 and > 0.01) (Table 6). Significant soil parameters ranges according to different classification schemes among different habitats are listed in (Table 7)

Table 3. Ecological groups derived from the Two-way cluster analysis for the 30 stands of El-Harra Oasis. Members of each group and the characteristic species of it are listed. For species abbreviations see Table 1.

Groups	Stands	Characteristic species
Group 1	1, 3, 7 and 21 (four members)	Pol mon; Ana arv; lot gla and Son mar
Group 2	2, 4, 6, 9, 11 and 29 (six members)	Lol per; Ste pal and Che mur
Group 3	5,12, 17, 24, 26, 27, 28 and 30 (eight members)	Imp cyl; Cyn dac and Cyn acu
Group 4	8,10 and 18 (three members)	Eup pep and Tri res
Group 5	13,16, 22 and 23 (four members)	Tam nil and Imp cyl
Group 6	14, 15 and 20 (three members)	Art mac and Tam nil
Group 7	19 and 25 (two members)	Des bip

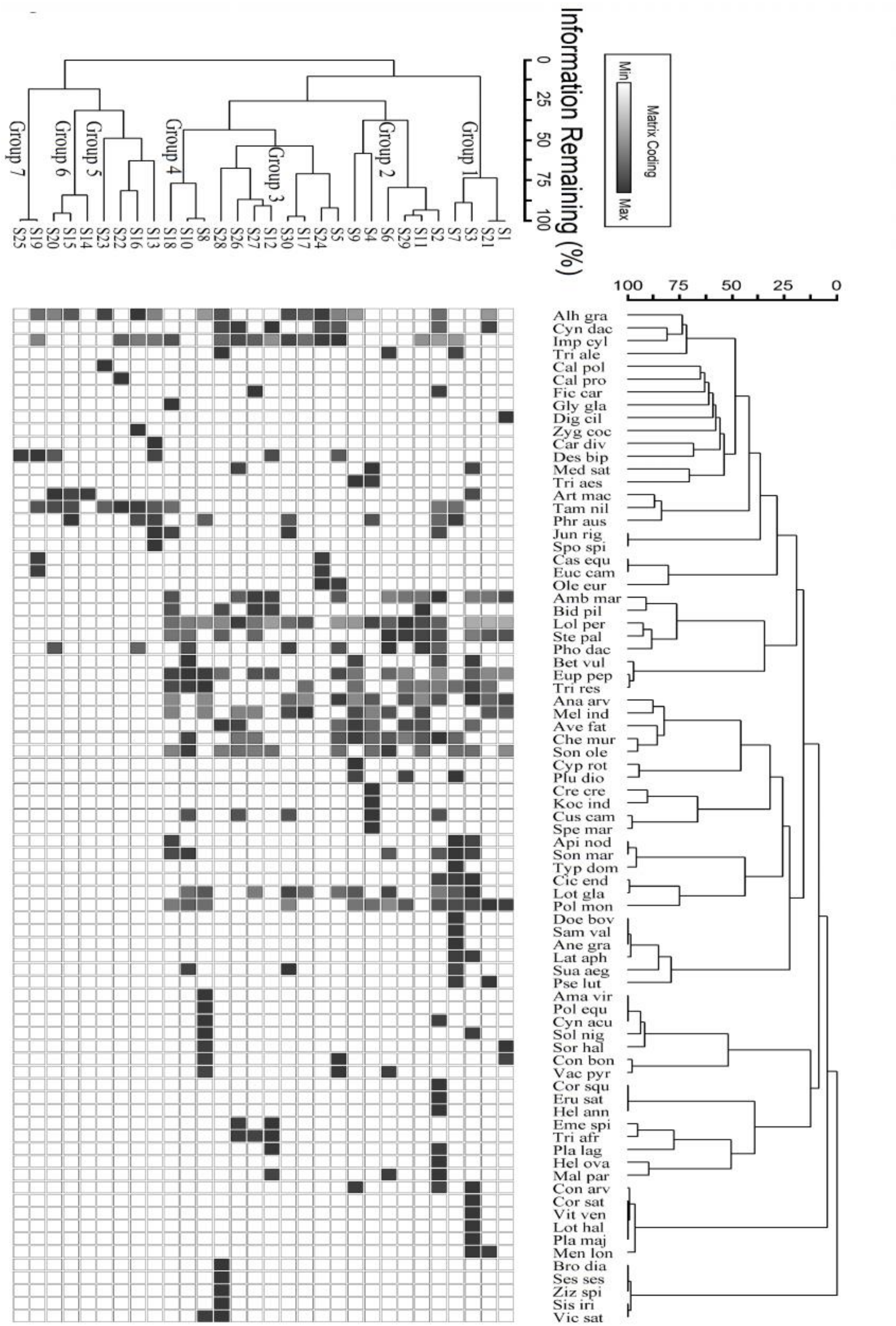


Fig. 5. Two-way cluster analysis dendrogram (Using Sorensen and Flexible beta of -0.25) showing the analysis of both the 79 recorded species and the 30 studied stands. Ecological groups (1-7) are presented on the hierarchal classification of the stands. Species presence and coverage (%) on each stand are plotted as a colored square ranged from the white (stand where the species is absent) to the black (stand where a species has its highest coverage %). Intensity of the black color reflects a species coverage % in relation to other stands.

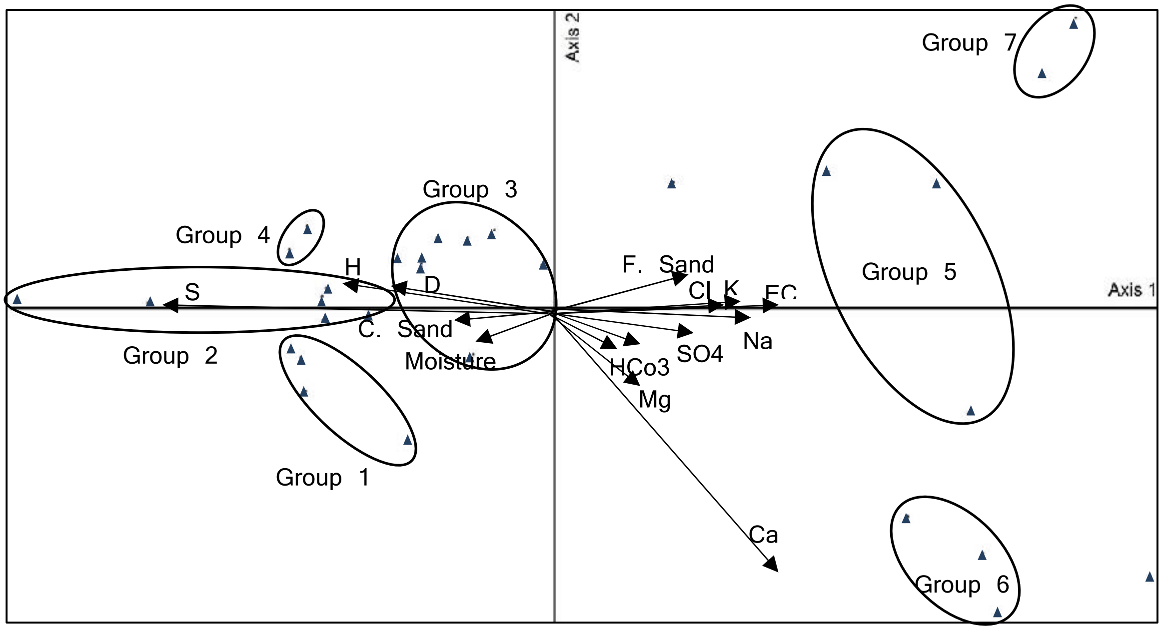


Fig. 6. DCA ordination joint plot (Indirect gradient analysis) showing the ecological groups and environmental factors correlated with each group

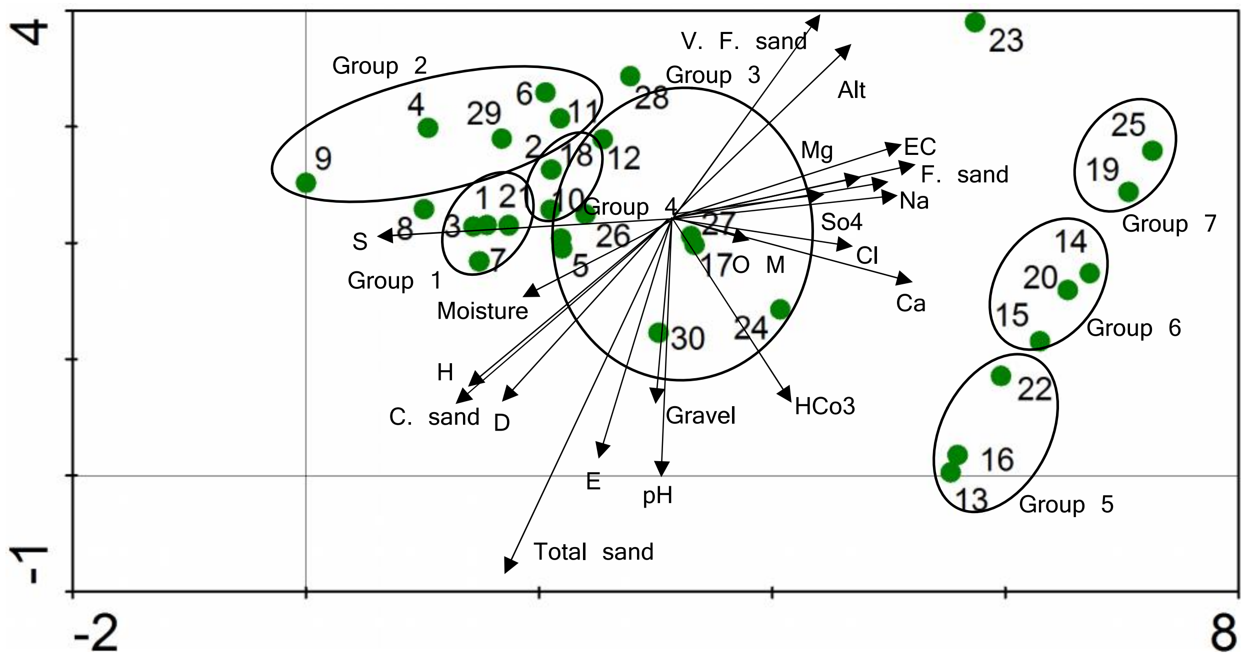


Fig. 7. DCCA ordination joint plot (Direct gradient analysis) showing the ecological groups and environmental factors correlated with each group.

Table 4. Pearson Correlation of the significant environmental factors affecting species distribution along the first two axes of both DCA and DCCA. Correlations above 0.3 or below -0.3 are only listed.

Environmental parameters	DCA 1	DCA 2	DCCA 1	DCCA 2
Species richness	-0.75		-0.7507	0.3026
Electrical conductivity	0.59		0.5973	
Calcium	0.59	-0.63	0.6502	-0.3731
Shannon Index	-0.55		-0.4393	
Sodium	0.55		0.5733	
Potassium	0.54		0.5683	
Chlorides	0.52		0.4854	
Simpson Index	-0.49		-0.329	
Sulfates	0.46		0.469	
Fine sand	0.46		0.5369	
Coarse sand	-0.37		-0.4515	
Bicarbonates	0.37		0.4092	-0.4346
Magnesium	0.36	-0.32	0.3866	
Moisture content	-0.32		-0.3441	
Total sand				-0.3867
pH				-0.3997
Clay				0.3049
Alt			0.3558	

Table 5. ANOVA results of different environmental factors for the seven ecological groups including Mean ± Standard error of each parameter. Significance (*) is at *P* value < 0.05

Parameters	G1	G2	G3	G4	G5	G6	G7	F	*P*-value
	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE	Mean ± SE		
Bicarbonates (%)	1.33 ± 0.27	1.16 ± 0.22	0.98 ± 0.17	1.44 ± 0.40	3.91 ± 2.09	4.55 ± 2.31	1.16 ± 0.17	2.14	0.086
Chlorides (%)	4.49 ± 1.86	11.4 ± 5.60	1.26 ± 0.44	2.04 ± 0.88	56.6 ± 24.3	104. ± 64.8	161. ± 160.	3.04	0.024*
Sulfates (%)	17.1 ± 4.41	19.6 ± 6.11	22.1 ± 5.90	27.6 ± 10.6	97.7 ± 44.2	717. ± 559.	512. ± 467.	2.58	0.046*
Organic matter (%)	0.99 ± 0.35	0.92 ± 0.19	1.53 ± 0.25	1.60 ± 0.40	1.56 ± 0.14	0.83 ± 0.17	1.64 ± 0.39	1.51	0.218
pH	8.12 ± 0.16	8.13 ± 0.20	8.25 ± 0.13	8.48 ± 0.27	8.31 ± 0.69	8.71 ± 0.25	8.45 ± 0.34	0.40	0.872
EC (mS/cm)	2.25 ± 0.27	3.58 ± 0.85	2.54 ± 0.53	3.11 ± 1.13	15.5 ± 3.29	55.5 ± 22.5	69.1 ± 60.8	5.00	0.002*
Calcium (Cmol/kg)	4.82 ± 2.84	4.04 ± 1.12	2.36 ± 0.67	1.88 ± 0.77	15.4 ± 5.03	66.7 ± 8.00	10.4 ± 7.82	41.9	000*
Magnesium (Cmol/kg)	4.82 ± 1.02	7.26 ± 0.90	7.20 ± 2.09	3.88 ± 0.39	15.9 ± 5.33	385. ± 308.	101. ± 94.8	2.51	0.051
Sodium (Cmol/kg)	3.63 ± 1.03	1.92 ± 0.58	1.54 ± 0.52	4.18 ± 1.68	32.2 ± 5.36	210. ± 94.8	228. ± 206.	5.16	0.001*
Potassium (Cmol/kg)	9.67 ± 1.84	19.2 ± 9.10	15.3 ± 4.49	21.1 ± 11.1	94.8 ± 31.7	164. ± 111.	352. ± 316.	3.27	0.017*
Moisture content (%)	21.0 ± 9.65	6.66 ± 2.90	2.87 ± 1.38	8.03 ± 1.40	1.94 ± 1.01	6.03 ± 3.50	0.25 ± 0.04	2.72	0.038*
Gravel (%)	3.93 ± 0.76	1.79 ± 0.43	2.91 ± 0.44	2.73 ± 0.63	1.32 ± 1.32	5.12 ± 0.06	3.00 ± 0.00	2.94	0.027*
Coarse sand (%)	75.8 ± 1.91	64.1 ± 7.84	51.2 ± 7.53	75.6 ± 3.05	39.2 ± 15.7	74.7 ± 4.50	43.3 ± 0.32	2.51	0.051
Fine sand (%)	7.09 ± 1.75	11.5 ± 2.89	16.9 ± 3.38	4.87 ± 0.75	25.6 ± 3.86	8.23 ± 2.60	23.8 ± 1.60	4.56	0.003*
Very fine sand (%)	7.70 ± 2.98	17.2 ± 5.17	20.3 ± 4.11	12.8 ± 4.30	26.3 ± 11.7	8.58 ± 1.62	22.2 ± 2.43	1.16	0.361
Sand (%)	94.3 ± 0.81	94.7 ± 1.05	91.1 ± 1.33	95.9 ± 1.46	92.5 ± 3.58	96.5 ± 0.83	92.2 ± 4.50	1.19	0.344
Silt (%)	2.49 ± 0.56	2.16 ± 0.75	3.70 ± 0.41	2.16 ± 1.25	5.22 ± 2.37	1.77 ± 0.19	2.37 ± 1.71	1.22	0.331
Clay (%)	3.18 ± 0.30	3.13 ± 1.02	5.16 ± 1.29	1.86 ± 0.23	2.26 ± 1.24	1.65 ± 0.67	5.39 ± 2.78	1.29	0.299
Altitude (m)	124. ± 6.19	120. ± 3.64	128. ± 3.02	121. ± 6.11	128. ± 5.78	122. ± 6.83	131. ± 4.5	0.64	0.695
Species richness (S)	16.7 ± 3.14	15.6 ± 2.76	11.5 ± 1.22	15.3 ± 1.20	5 ± 1.22	3.33 ± 1.20	3.5 ± 2.5	6.01	0.000*
Evenness (E)	0.52 ± 0.07	0.44 ± 0.06	0.67 ± 0.03	0.61 ± 0.06	0.45 ± 0.09	0.42 ± 0.23	0.20 ± 0.20	2.36	0.063
Shannon Index (H)	1.48 ± 0.31	1.19 ± 0.18	1.61 ± 0.10	1.66 ± 0.14	0.75 ± 0.26	0.62 ± 0.33	0.37 ± 0.37	4.46	0.003*
Simpson Index (D)	0.61 ± 0.10	0.53 ± 0.09	0.70 ± 0.02	0.73 ± 0.04	0.37 ± 0.13	0.36 ± 0.19	0.17 ± 0.17	3.33	0.016*

Table 6. ANOVA results of different environmental factors for the two major groups including Mean ± Standard error of each parameter. Significance (*) is at *P* value < 0.05

Parameters	G1 (1-4)	G2 (5-7)	F	Sig.
	Mean ± SE	Mean ± SE		
Bicarbonates (%)	1.16 ± 0.11	3.51 ± 1.17	9.224	.005*
Chlorides (%)	4.90 ± 1.81	95.8 ± 37.0	14.540	.001*
Sulfates (%)	21.2 ± 3.16	396. ± 205.	8.174	.008*
Organic matter (%)	1.26 ± 0.14	1.34 ± 0.16	.086	.771
pH	8.22 ± 0.08	8.47 ± 0.30	1.092	.305
EC (mS/cm)	2.86 ± 0.35	40.8 ± 14.6	16.431	.000*
Calcium (Cmol/kg)	3.24 ± 0.67	31.4 ± 9.46	21.073	.000*
Magnesium	6.29 ± 0.87	158. ± 107.	4.878	.036*
Sodium (Cmol/kg)	2.42 ± 0.43	135. ± 54.8	14.379	.001*
Potassium (Cmol/kg)	16.1 ± 3.34	175. ± 72.3	11.702	.002*
Moisture content (%)	8.15 ± 2.38	2.93 ± 1.35	1.903	.179
Gravel (%)	2.76 ± 0.29	2.96 ± 0.79	.084	.774
Coarse sand (%)	63.1 ± 4.19	52.0 ± 8.69	1.690	.204
Fine sand (%)	11.7 ± 1.80	19.4 ± 3.31	4.746	.038*
Very fine sand (%)	15.9 ± 2.40	19.5 ± 5.58	.482	.493
Sand (%)	93.4 ± 0.73	93.8 ± 1.80	.048	.828
Silt (%)	2.81 ± 0.34	3.43 ± 1.16	.468	.500
Clay (%)	3.73 ± 0.61	2.75 ± 0.87	.802	.378
Altitude (m)	124. ± 2.08	127. ± 3.40	.513	.480
Species richness (S)	14.2 ± 1.13	4.11 ± 0.78	30.835	.000*
Evenness (E)	0.57 ± 0.03	0.38 ± 0.09	5.346	.028*
Shannon Index (H)	1.47 ± 0.09	0.62 ± 0.16	22.569	.000*
Simpson Index (D)	0.64 ± 0.03	0.32 ± 0.08	15.686	.000*

Table 7. Significant soil parameters ranges according to different classification schemes among different groups (G1-7). For coarse sand (C.S), fine sand (F.S), very fine sand (V.F.S), sodium, potassium, calcium, magnesium and chlorides 1=very low; 2 = low; 3= moderate; 4= high 5= very high (Metson, 1961; Hazelton and Murphy, 2007; Horneck *et al.*, 2011). For electrical conductivity (EC) 1= non-saline; 2= slightly saline; 3= moderately saline; 4= highly saline; 5= extremely saline (Richards, 1954). For organic matter (OM) 1= extremely low; 2= low; 3= moderate (Emerson, 1991 and Charman and Roper, 2007). For pH, 3= neutral; 4= slightly alkaline; 5= moderately alkaline; 6= strongly alkaline (Horneck *et al.*, 2011). For species abbreviations see Table 1.

Groups	Agro habitats (G 1-4)	Natural habitats (G 5-7)	G1	G2	G3	G4	G5	G6	G7
Indicator species			Pol mon Anaarv	Lol per Ste pal	Imp cyl Cyn dac	Eup pep Tri res	Tam nil Phr aus	Art mac	Des bip
EC	1-3	4-5	1-2	1-3	1-3	1-3	4-5	5	4-5
Na	1-3	5	1-3	1-3	1-3	1-3	5	5	5
Ca	1	1-3	1	1	1	1	1-2	3	1
Mg	1-3	1-5	1-2	2	1-3	2	1-3	3-5	3-5
K	3-5	5	3-4	3-5	3-5	3-5	5	5	5
Cl	3-5	4-5	5	3-5	3-5	3-5	5	4-5	4-5
OM	1-3	1-3	1-2	1-3	1-3	2-3	2-3	1-2	2-3
pH	3-6	3-6	5	3-6	4-6	4-6	3-6	4-6	4-6
C.S	3-5	2-5	5	4-5	4-5	4-5	2-5	5	4-5
F.S	1-3	1-3	1-2	1-2	1-3	1	1-3	1-2	2
V. F. S	1-3	1-5	1-2	1-3	1-3	1-2	1-5	1-2	2

Discussion

The present work aimed to shed the light on habitat diversity and the prevailing plant communities in El-Harra Oasis. Vegetation structure and several environmental factors, in 30 stands representing different habitats, have been investigated in order to get an impression about the ecological situation in El-Harra Oasis.

Soil properties

Soils of El-Harra Oasis could be classified according to different soil parameters into different groups. Results showed that salinity is a very important factor that affect most of El-Harra Oasis soils. One of the attention-grabbing features that characterizes El-Harra Oasis is the presence of a large salt affected area located in the center of Harra Oasis map and in the middle of the arable lands (Fig. 1). This feature is a manifestation of the salinity problem where most of the oasis soils are drained towards this low altitude salt marsh. Salinity is a major problem in the soils of the Egyptian Oases and around the world (Abd ElGhani, 2000; Elsaied, 2012; Elsaied *et al.*, 2015; Satir and Berberoglu, 2016; Gorji *et al.*, 2017 and Niñerola *et al.*, 2017). According to the salinity classification levels of Richards (1954) soils of El-Harra Oasis are ranged from non-saline soils to the extremely saline soils with only eight non-saline stands and five extremely saline soils. Horneck *et al.* (2011) has categorized soil chlorides into five categories from very low to excessive. Soils of El-Harra Oasis ranged from very low to the excessive chloride content. Metson (1961) has classified levels of exchangeable cations (Na^{+}, K^{+}, Ca^{++} and Mg^{++}) into five classes from the very low to the very high. Soils of the study area ranged from very low to very high sodium and magnesium content while very low to moderate calcium content and moderate to very high potassium content.

Horneck *et al.* (2011) has classified pH ranges into six classes from strongly acidic to strongly alkaline. Soils of El-Harra Oasis ranged from neutral to strongly alkaline. These results are in accordance with other studies on Bahariya Oases (Metwally, 1981; Kaddora, 1991 and Elsaied, 2012). Soil pH is one of the most decisive factors affecting nutrients and chemical species availability to plant roots. Brady (1984) and Peverill *et al.* (1999) have used pH to determine nutrients deficiencies and toxicity. Hazelton and Murphy (2007) reported that most of elements availability is reduced at strongly acidic and strongly alkaline soils.

McKenzie *et al.* (2004) stated that clay particles are physically and chemically active in contrary to sand particles, the less active particles, due to the high surface area of the clays and this has a very large effect on soil properties. Hazelton and Murphy (2007) classified soil particles into five levels from the very low to the very high content. Soils of El-Harra Oasis showed significant variations among different soil particles. The lowest content of soil particles was for gravel followed by clay and silt content while sand had the highest share among different soil particles with over 80 % of all soil samples which indicate the poor quality of El-Harra Oasis soils.

Emerson (1991) and Charman and Roper (2007) grouped soil organic matter content into six ranks from extremely low in the severely eroded degraded soils to very high in the highly stable good structured soils. Soils of study area ranged from the extremely low level to the moderate level which indicate once more the poor quality of El-Harra Oasis soils.

Habitat diversity

Results of the present study highlighted the ecological diversity of El-Harra Oasis. The 30 studied stands were found to represent two major groups of habitats (agro habitats vs. natural habitats) including seven different habitats, each with unique indicator species and environmental conditions. Different habitats were named after their characteristic species.

Agro-habitats(Groups 1-4)

This group of habitats is characterized by the presence of many halo-tolerant species as indicator species as *Lolium perenne*, *Lotus glaber*, *Sonchus maritimus*, *Alhagi graecorum* and *Cynodon dactylon.* Soils of this group is non-saline to moderately saline with alkaline reaction and very low to moderate organic matter in addition to relatively higher clay content in relation to the second group of habitats. A higher species richness and diversity indices in relation to the other group of the natural habitats is indicating the more favorable conditions for of the species of El-Harra Oasis.

Group 1: Polypogon monseplensis

Indicator species of this group are *Polypogon monesplensis, Anagalis arvensis,* followed by *Lotus glaber* and *Sonchus maritimus.* This group has the highest species richness in relation to other groups. Soils of this habitat are non-saline to slightly saline and have the lowest pH, electrical conductivity, potassium, sulfates and very fine sand content. On the other side it has the highest moisture and coarse sand content in relation to other habitats. Callaway and Zedler (1997) stated that *Polypogon monseplensis* can tolerate wide range of salinity. Atia *et al.* (2010)reported that *Polypogon monspeliensis* can maintain its growth even at salinity levels of 300 mm NaCl. *Anagallis arvensis* was also recorded in many saline habitats with a range that can reach 10 mS/cm (Abusaief *et al*., 2013). Frondoni and Iberita (2002) and Koul and Chehma (2015) has reported *Sonchus maritimus* as a salt tolerant species.

Group 2: *Lolium perenne - Stellaria pallid*

Indicator species of this group are *Lolium perenne* and *Stellaria pallid* followed by *Chenopodium murale.* This group has the second highest species richness after the first group. Soils of this group are non-saline to moderately saline with high coarse sand content. *L.perenne and C. murale* are salt tolerant species that could protect themselves against different toxicity (Holm *et al*., 1997 andGuertin, 2003). Hu *et al.* (2012) attributed the response of *L.perenne* against salinity stress to an antioxidant gene that maintain the biological process on the molecular level.

Group 3: *Imperatacylindrica*

Indicator species of this group are *Imperata cylindrica* followed by *Cynodon dactylon* and *Alhagi graecorum.* This group has the highest evenness among the seven habitats with relatively high species richness and diversity. Soils of this group are non-saline to moderately saline. The lowest sand, sodium, bicarbonates and chlorides content and relatively high organic matter in relation to other habitats was recorded in this group. *I.cylindrica* is a wide spread aggressive species that can grow in a wide range of habitats. It dominates abandoned lands in Bahariya Oases and the boundaries of arable lands (Elsaied, 2012). *I.cylindrica* can produce allelopathic phenolic compounds to suppress the growth of associated species (Eissa, 2007). Trautwig *et al.* (2017) reported that the presence of *I.cylindrica* is affecting soil productivity may be due to the allelopathic effect on the soil micro flora. *Alhagi graecorum* is another very common nitrogen fixative species in Bahariya Oases and it may form pure communities or can be associated with *T. nilotica* and *D. bipinnata* (Zahran, 1998 and Zahran and Willis, 2009).

Group 4: *Euphorbia peplus -Trifolium resupinatum*

Indicator species of this group are *Euphorbia peplus* and *Trifolium resupinatum.* This group has the highest diversity indices records and relatively high evenness and species richness. Soils of this group are non-saline to moderately saline. The lowest calcium, magnesium and fine sand content was recorded in this group. *E. peplus* was reported by many authors to have therapeutic effect and its secondary metabolites can work as anti skin cancer (Ramsay *et al.* (2011); Hua *et al.* (2017) and lishmanicidal (Amin *et al*., 2017). Ates and Tekeli (2007) reported the salinity tolerance of *T. resupinatum.*

Natural habitats(Groups 5-7)

This group of habitats is characterized by the presence of halophytes and highly salt tolerant species that can tolerate extreme conditions as of *Arthrocnemum macrostachyum*, *Tamarix nilotica*, *Phragmites australis*. Soils of this group of habitats are highly to extremely saline with alkaline reaction and low to moderate organic matter. Low species richness and diversity indicates the extreme unfavorable conditions of this group of habitats.

Group 5: Tamarix nilotica – Phragmites australis

Tamarix nilotica, *Phragmites australis* and *Imperata cylindrica* are the indicator species of this group. This group has relatively low species richness and diversity. Soils of this group have the lowest gravel and coarse sand content and the highest fine sand, very fine sand, and silt content with highly to extremely saline conditions. *Tamarix nilotica* is very common in Bahariya Oases sand dunes and salt marshes with sand deposits and it represents the climax of the salt marshes habitat in the Oases (Zahran and willis, 2009). It is a wide ecological amplitude species that can adapt to various habitats (Kassas and Girgis, 1970).*Phragmites australis* is another wide ecological amplitude species that can grow in different moisture and salinity conditions. Under the less wet conditions *Tamarix nilotica* and *Imperata cylindrica* are most common associated species with *Phragmites australis* (Zahran and Willis, 2009).Several studies have investigated the ability of *P. australis* to remove heavey metals and salinity (Wathugala *et al.*, 1987 and Yeh *et al.*, 2009)

Group 6: Arthrocnemum macrostachyum

Arthrocnemum macrostachyum and *Tamarix nilotica*, are the indicator species of this group. It has the lowest species richness and relatively low species diversity. This group has the lowest clay, silt and organic matter content and the highest gravel and sand content in relation to other habitats. McKenzie *et al.* (2004) reported the positive correlation between clay and organic matter. Soils of this group are extremely saline with the highest sulfates, calcium and magnesium content. Soils in this group are strongly alkaline and has the highest bicarbonates content in relation to other groups. *A.macrostachyum* is a very common species in Bahariya Oases salt marshes and forms many pure communities and can be associates with some species as *Tamarix nilotica* and *Phragmites australis* (Elsaied, 2012).El-Bana and Al-Mathani (2009) recorded *T.nilotica* to grow at the highest salinity record in their study at the level of 45 mS/cm where in the present study it was recorded at the level of 100 mS/cm.

Group 7: Desmostachya bipinnata

Desmostachya bipinnata is the indicator species of this group. This group has the lowest species diversity and the second lowest species richness after the *Arthrocnemum* group. Soils of this group have the highest clay and organic matter content in contrary to the previous group which confirms again the correlation between soil texture and organic matter. The lowest moisture content was recorded in this group with extremely saline conditions where the highest electrical conductivity, chlorides, sodium and potassium content was recorded in this group. *D.bipinnata* a common species in Bahariya Oases especially on sand accumulations around salt marshes (Elsaied, 2012). Zahran and Willis (2009) reported that *D.bipinnata*is a rigid grass that is extensively grazed and can grow widely and form communities in extreme conditions but flourish only when salinity is low. Adnan *et al.* (2016) reported *D.bipinnata* as a fodder crop that can manage photosynthesis and oxidative stress under moderate saline conditions. In the present study *D.bipinnata* was recorded as an indicator species in two stands where one of them has the highest salinity record in the whole study with 130 mS/cm.

Conclusion

The present work showed that soil salinity is the major determinative factor in habitat diversity in El-Harra Oasis followed by soil water content and soil texture. The combination of the all three groups of factors are affecting species distribution and habitat recognition and consequently species richness, diversity and productivity. All vegetation groups were under salinity stress where average salinity level of all groups ranged from slightly saline to extremely saline. The identified groups showed that salinity should not be only dealt with as a problem caused by the increase of sodium chloride only but magnesium, potassium and sulfates can also represent a serious problem. Almost all indicator species of El-Harra Oasis are halotolerantes or halophytes which necessitates the better usage of these species as untraditional crops for this harsh environment. The management of water resources is inimitable to sustain both natural and agro ecosystems of El-Harra Oasis. Habitat conversion in El-Harra Oasis is accelerated by wasting more water and consequently the expansion of salt marshes and salt affected soil are inevitable. Monitoring the situation on the ground using traditional and remote sensing techniques is very essential to help in decreasing the rate of habitat loss in El-Harra Oasis. New reclaimed lands should adopt salt tolerant plantations such as *Phoenix dactylifera*, *Olea europea* and *Medicago sativa* instead of planting glycophytes. A good drainage system, appropriate irrigation timing and correct manure application could restrain the escalation of the salinity problem and should maintain a reasonable soil quality and higher crop production.

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