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**Ghanim A. Al-Abbadi & Mohamed
A. E. El-Sheikh**

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Vegetation ecology and diversity of six Kuwait Islands: factors influence on species composition and richness

Ghanim A. Al-Abbadi¹ · Mohamed A. E. El-Sheikh^{2,3}

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Abstract Kuwait lies at the Northwest corner of the Arabian Gulf, and its eastern coast comprises parallel arcs of nine islands. The present study dealt with vegetation ecology and species diversity analysis of six uninhabited islands, except Failaka, Warba, and Bubiyan islands, with varied sizes of area ranging from 0.5 to 863 km². A total of 70 species of flowering plants (60% annuals and 40% perennials), belonging to 32 families, were collected from the islands and their list is given. The main phytogeographical category was represented by Saharo-Arabian elements followed by the Irano-Turanian and Mediterranean elements. The vegetation type is essentially halophytic with widespread annuals. Six associations were identified with the application of TWINSpan, DCA, and CCA programs. They were named after the characteristic species as follows: VG I: *Polycarpon tetraphyllum*, VG II: *Zygophyllum qatarense*, VG III: *Emex spinosa*, VG IV: *Seidlitzia rosmarinus*, VG V: *Malva parviflora-Salsola imbricata*, and VG VI: *Suaeda aegyptiaca*. These associations were compared with the plant communities of Kuwait and neighboring countries of Gulf region. The soil characteristic factors alkalinity, moisture, soil texture, and

minerals showed the best correlation with the distribution of the associations. Significant differences between island area, species diversity indices, organic matter, and minerals contents of the islands were observed. Flora of these uninhabited islands with un-grazed plants constituted about 37% of the flora of the mainland of Kuwait and their valuable elements warrant prioritized conservation measures.

Keywords Arabian Gulf · Habitat diversity · Insular species richness · Island biogeography

1 Introduction

Island biogeography is a field that feeds ideas, theories, models, and tests of the same into mainstream ecology, evolutionary biology, and biogeography. Along with islands, some plants have undergone major, and often repeated migrations while showing little evolutionary change. Others have stayed, but undergone evolutionary change in a relatively short span of geological time. Yet, some others have failed to follow either of those courses, and have become extinct (Whittaker 1998).

The small islands characterized by few vegetation formations attracted attention of the scientific community owing to their distribution pattern, as they represented good experimental models, particularly their easy delimitative spatial boundaries. However, the interests were focused primarily on those environments, which sheltered a peculiar biota, with some near extinct, and endangered endemic species in the mainland (Abbadi and El-Sheikh 2002; Brown 2003). The study of these spatial changes in plant communities is central to a wide range of ecological and evolutionary topics, and thus, it has recently drawn the

✉ Mohamed A. E. El-Sheikh
 el_sheikh_eg@yahoo.co.uk

Ghanim A. Al-Abbadi
 d.gabadi@gmail.com

¹ Department of Biological Sciences, Faculty of Science, Kuwait University, P. O. Box 5969, Safat 13060, Kuwait

² College of Science, Botany and Microbiology Department, King Saud University, P. O. Box 2455, Riyadh 11451, Saudi Arabia

³ Botany Department, Faculty of Science, Damanhour University, Damanhour, Egypt

attention of Ecologists and Conservationists (for reviews, see Morlon et al. 2008). Much debate also exists over the most appropriate approach to the analysis of the factors that influence species composition, since different researchers are interested in different aspects of community analysis (Lomolino and Weiser 2001; Martinelli 2007; Laliberté 2008; Tuomisto and Ruokolainen 2008). In addition, the equilibrium theory of island biogeography (for reviews, see MacArthur and Wilson 1963, 1967) and the related concept of the metapopulation (Levins 1969, 1970) have led to the spawn of many studies of insular floras and faunas (Whittaker 1998; Morrison 2002, 2003; Panitsa et al. 2006; Dengler 2010).

Despite the fact that the vegetation of Kuwait is poor open scrubs (under-shrubs, perennial herbs, and spring ephemerals), the flora is rather small in terms of the number of species, which is about 374 (Boulos and Al-Dosari 1994). Many plant populations have become increasingly rare, while some are known only from a single locality and a few are apparently extinct especially in islands. The eastern shore of Kuwait comprises parallel nine off-shore islands in Arabian Gulf, and these islands form a significant shelter for one-third of total Kuwait flora and some of them belong to the endangered category (Abbadi and El-sheikh 2002; Al-Abbadi 2008). These changes in the vegetation structure can be attributed to many factors that influence the species composition, richness, and turnover as in the last few decades. Therefore, plant communities have spatial changes along both the mainland and the islands of Kuwait (Brown and Schocknecht 2001; Abbadi and El-Sheikh 2002; Brown 2003; El-Sheikh and El-Abbadi 2004; El-Sheikh et al. 2006, 2010, 2012).

The vegetation inventories of Arabian Gulf islands were started with Failaka island of Kuwait by Abbadi and El-Sheikh (2002) who analyzed the structure of vegetation. After that, very few articles were published on vegetation of the Kuwait islands (Al-Abbadi 2008) and Iranian islands (Akhani and Deil 2012) in the Arabian Gulf. Nevertheless, the basic aspects of the vegetation, such as identities of dominant groups, are not yet clear, since those existing work were restricted to a meager quantity and diversity of the vegetation of Gulf Islands in the semi-arid region. Thus, the present study besides testing the hypothesis that small islands have few species richness and turnover presents the floristic diversity and vegetation structure of the six islands located in the semi-arid region of Kuwait. The significant aims of the present study included: (1) providing a pioneering and comparatively extensive data on botany of these islands which seems to be interesting from the biodiversity viewpoint; (2) dealing with the species composition, life-form structure and diversity; (3) identification of the prevailing plant communities; and (4)

assessing the effect of environmental factors on species diversity and plant communities.

2 Materials and methods

2.1 Study area

Kuwait is located in NE part of Arabian Peninsula extending between 28°33' and 30°05'N–46°33' and 48°30'E, with area about 18,000 km², and includes nine off-shore islands viz., Warba, Bubiyan, Um Al-Namil, Maskan, Failaka, Auha, Kubbar, Qaruh, and Um Al-Maradim (Fig. 1). The present study concentrated only on six small islands out of the nine excluding Warba and Bubiyan due to the current military situation of the country and also as vegetation of Failaka was studied earlier by Abbadi and El-Sheikh (2002). These islands varied in size from 0.5 to 863 km² and are not populated except the presence of military men and visitors. Islands' topography is flat; and the elevation is around 2 m above sea level. In the northern islands, there are some depressions and cracks and they share a muddy surface feature due to the river sediments coming from the Euphrates River. The soil in general is sandy-to-sandy loam and shows a weak profile. Description of each island is given as follows:

1. Maskan is a small island with about 750 m² and is to the south of Bubiyan Island. Maskan Island is devoid of any vital activity and is with a lighthouse managed by Ibrahim Bu-Rashid who lived in the island along with his family to guide ships sailing in the Gulf at night. Maskan shares similar geology as Failaka having medium to coarse sand in shore with coral reefs present at few meters in depths.
2. Awah is a small island, 800 m long by 540 m wide, which corresponds to an area of about 34 ha, and is located 16 km south-east of Failaka Island, and 41 km from west of Salmiya on the mainland. Apart from a lighthouse and a small heliport, the island is uninhabited.
3. Um Al-Namil is located within Kuwait Bay, in the Arabian Gulf. It is known to be the site of several archaeological findings, mainly from the Islamic era, and the Bronze Age. The island is at shortest, 600 m away from the Kuwait mainland.
4. Kubbar is a sandy island covered with shrubs. It is located roughly 30 km off the western coast of Kuwait and 29 km off the southern coast of Failaka. The island is nearly circular, with a diameter of 370–380 m, corresponding to an area of about 11 ha. It is sandy, with low coasts and sparse vegetation. The island is inhabited by various forms of wildlife. Kubbar is

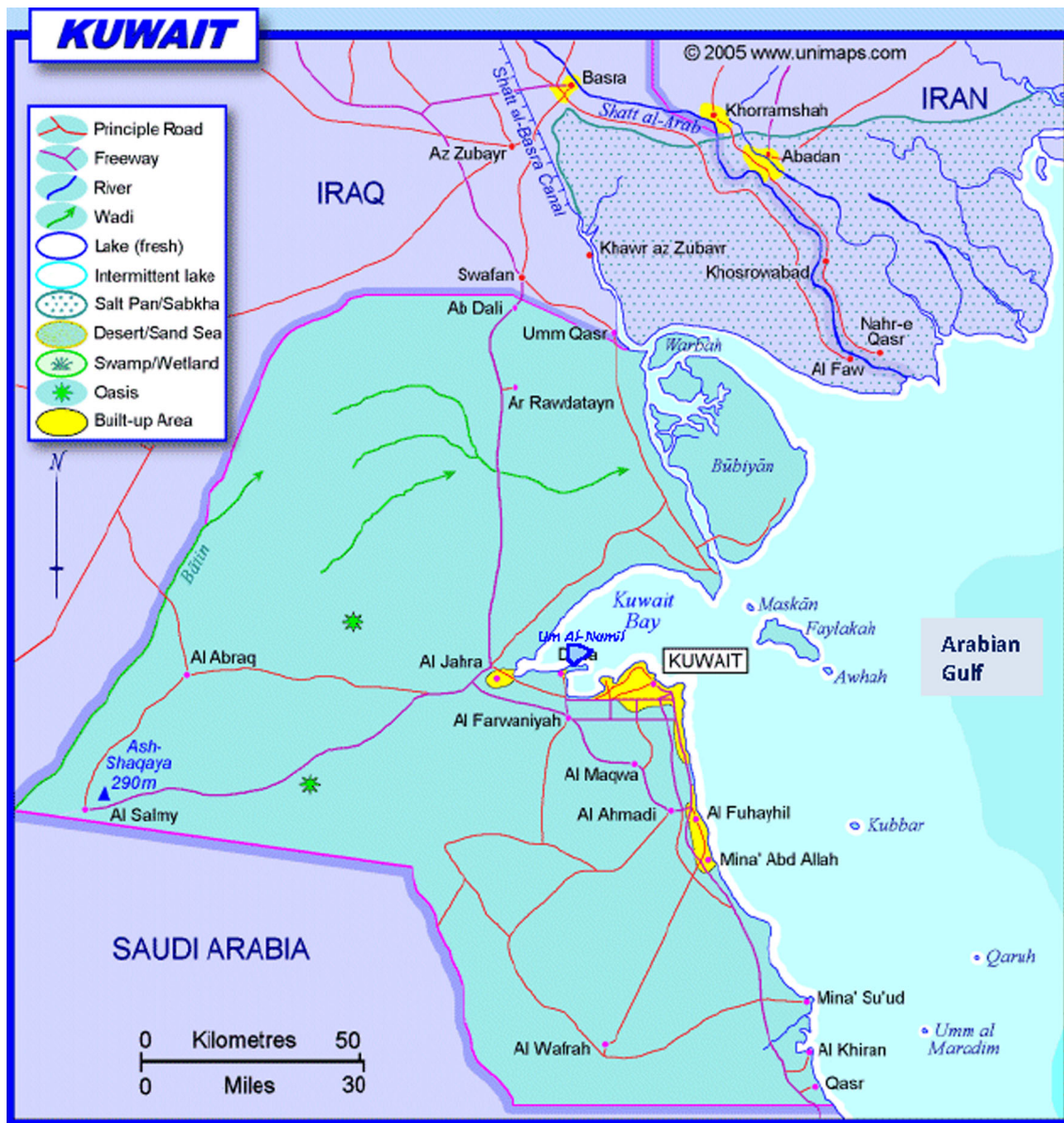


Fig. 1 Location of study area, showing the islands in the Arabian Gulf

surrounded by coral reefs and is, therefore, popular with scuba divers.

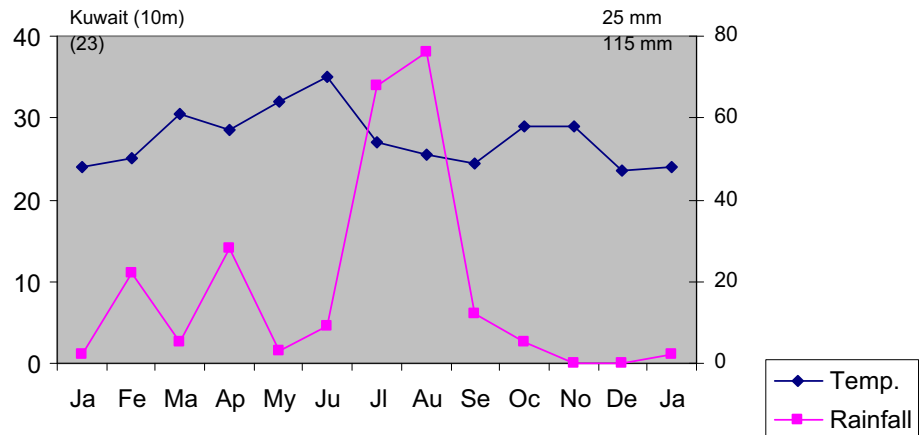
5. Qaruh is an island which received its name from the large amounts of petroleum sediments in the area (known as Qar in Arabic). It is the smallest of the nine islands, and also the furthest island from the Kuwait mainland. It is located 37.5 km away from the mainland and 17 km away from Um Al-Maradim. The island is roughly 275 m long by 175 m at its widest zone with an area of about 3.5 ha.
6. Um Al-Maradim is located between Kuwait and Saudi territorial waters. The island is 1.5 km in length and 540 m in wide with an area of about 65 ha. It is known

to have deep waters surrounding it, in which large ships can safely anchor.

2.2 Climate

The climate is characterized by very hot, dry summers, when daytime temperature can exceed 50 °C, and cool, sometimes wet winters with −3 °C. Temperature very rarely drops below the freezing point. The mean temperature ranges between 37 and 14 °C (Fig. 2). Average seasonal precipitation in the region is 120 mm, although considerable fluctuations between 35 and 250 mm occur from 1 year to another. Rainfall is restricted to the winter

Fig. 2 Climatic diagram of Kuwait airport station after the method of Walter and Lieth (1967)



and spring months, particularly between December and March. The mean relative humidity ranges between 84 and 40%.

2.3 Vegetation samples selected

For the present study, a multi-method approach was used which combined: (1) floristic relevés along the six islands; (2) vegetation; and (3) soil analysis. To study the sequence of plant communities and the floristic turnover along ecological gradients, adequate sampling stands were selected to represent all the ecological variations along each island from the shoreline to the interior of the land, so as to represent all area of each Island. Therefore, 28 relevés were selected with an area of 30 m² to cover all physiographic variations and landform types in the six islands. Sampling was carried out during spring season when most species were expected to be growing. The vegetation parameters included listing of all plant species which were classified into their family, life forms, and chorotypes according to the field observations or as given in the Flora of Kuwait and other relevant literature (Daoud and Al-Rawi 1985; Al-Rawi 1987; Boulos and Al-Dosari 1994). In each stand, species present were recorded and their plant cover was estimated quantitatively using the line intercept method (Canfield 1941), with three parallel lines each 30 m long laid down in each relevé. The lengths of interceptions by each species in each stand were measured in centimeter, summed up, and related to the total length of lines stretched in the particular stand (in %). Such estimates were used to calculate the relative cover of each species (p_i).

2.4 Soil analysis

Three soil samples, down to 50 cm depth, were collected from each stand and mixed as one composite sample for each stand. They were air dried and passed through a 2 mm sieve to separate gravel and debris. Soil water extracts (1:5)

were prepared for the determination of electric conductivity (EC in mS cm⁻¹) and soil reaction (pH) using conductivity and pH meters. Soil texture was analyzed using the Bouyoucos hydrometer method (Bouyoucos 1962), whereby the percentage of sand, silt, and clay were calculated. Total organic matter was determined by loss-on-ignition at 550 °C for 2 h. 2.5% (v/v) glacial acetic acid was used for the extraction of Na, K, Ca, and Mg. Estimation of Na, K, and Ca was carried out by flame photometer. Atomic absorption was used for the determination of Mg, Mn, Fe, and Cu. All these procedures followed the measurement protocols outlined by Allen et al. (1989).

2.5 Data analysis

Two data matrices of species cover data were created: (1) matrix of 28 stands × 70 species cover value during the present study and (2) matrix of 28 stands × 70 species cover values × soil variables of the six islands. These matrices were subjected to a numerical classification using two-way indicator species analysis, 'TWINSPAN' (Hill 1979a). TWINSPAN produces a hierarchical classification of vegetation groups (i.e., plant communities). Plant communities were named after their dominant species. The Detrended Correspondence analysis, "DCA" (Hill 1979b), was applied to the same matrices data sets to obtain an efficient graphical representation of the ecological structure of the vegetation groups identified using TWINSPAN. To detect correlations of the derived vegetation associations with environmental data, Canonical Correspondence Analysis, 'CCA', according to Ter Braak and Smilauer (2002) was conducted with species cover, stands, and soil variables using the second matrix.

Species richness of each association was calculated as the average number of species stand⁻¹. Species turnover (β -diversity) as the ratio between the total recorded species number in a certain association and its species richness. Shannon–Wiener index $\hat{H} = -\sum_i^s p_i \log p_i$ for the

relative evenness and Simpson index $C = \sum_{i=1}^s pi^2$ for the relative concentration of dominance were calculated for each relevé on the basis of the relative cover (pi) of the i th species (Magurran 1988; Pielou 1975). Relationships between the ordination axes on one hand, and soil variables, on the other hand, were tested using Pearson's simple linear correlation coefficient (r). In addition, relationships between species diversity indices and soil variables were tested. The variation in the species diversity, stand traits, and soil variables in relation to plant community was assessed using one-way analysis of variance (SAS 1989–1996).

3 Results

3.1 Floristic diversity

In total, 70 species were recorded in the six studied islands during the study. The life-form analysis revealed that the six Kuwait islands were richer in therophytes with 42 species (60%) (Fig. 3a). The most frequent life forms are chamaephytes with 15 species (21.4%), followed by 5 hemicryptophytes (7%) and 4 phanerophytes (6%) in the 6 islands (Fig. 3a). Poaceae and Chenopodiaceae were the most dominant families in the area of present study. The results of chorological analysis are shown in Fig. 3b. The Saharo-Arabian elements were the dominant represented in the study area with 17 species, followed by Saharo-Arabian-Irano-Turanian elements (11 species) and Saharo-Arabian-Mediterranean-Irano-Turanian elements (9 species).

3.2 Vegetation composition

The cluster analysis suggested six well-separated plant associations (i.e., communities) which showed a high degree of floristic, geographic, and environmental gradient integrities at level 3 TWINSPAN. The application of DCA and CCA confirmed the separation between these communities (Table 1; Fig. 4a, b). The northern large islands were characterized by woody plants shown on the left-hand side of the negative axis AX1, and the southern small islands were dominated with ephemeral plants shown along the right-hand side of the positive part of axis AX1, whereas the first association inhabited in a very small island—Qaruh as a mono-stand—is separated along lower negative part of axis AX2 (Fig. 4b).

These associations were identified according to the dominant and co-dominant species and described as follows:

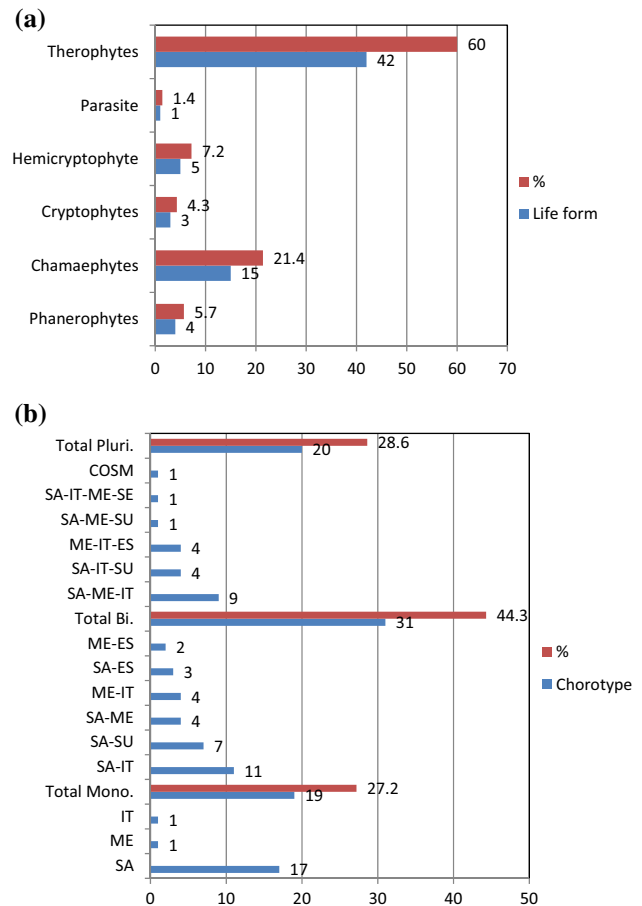


Fig. 3 The plant species percentage of **a** life form and **b** chorotypes in the six Kuwait Islands (for complete name of chorotype, see Table 1)

VG I: *Polycarpon tetraphyllum* (one relevés and one species), inhabiting on the south, far away from the mainland and the smallest island ‘Qaruh’. It is characterized by mono-species *Polycarpon tetraphyllum*. This association grows on a lower content of soil variables, i.e., very poor fertility and less stabilized soil layer, that consists of only shell particles with high content of sandy soil.

VG II: *Zygophyllum qatarense* (8 relevés and 46 spp.), inhabiting on the northern large island-Um Al-Namil and located at the west of Kuwait Bay. It is characterized by the common woody species, e.g., *Seidlitzia rosmarinus*, *Zygophyllum qatarense*, and *Atriplex dimorphostegia*. This island is the nearest to the mainland at low tide (600 m of the mainland). It is also notable that this island had a relative large area (863 km²) and being the largest of the six studied islands. Therefore, it is characterized by heterogeneity of habitat substrates from some dry stony ridge of shells, coral reef, and coarse sandy dunes shores to wet and soft mud surrounding the sub-tidal flat and hyper-saline mud flat depressions in the center. Moreover, this island is

Table 1 Average species cover of the six vegetation groups (associations) identified after the application of TWINSpan to the vegetation data of 28 stands in six Kuwait islands

Group no.	LF	Chorotype	I	II	III	IV	V	VI	Total
Relevé no.			1	8	9	3	5	2	Sp.
Habitat			Qaruh	Umm Al-Namil	Maskan	Awhah	Kubbar	Umm Al-Maradem	
Species number			1.0	46.0	56.0	42.0	8.0	3.0	70
Character species									
<i>Polycarpon tetraphyllum</i>	Th	ME,ES	2.0	–	3.0	2.0	–	–	3
<i>Zygophyllum qatarense</i>	Ch	SA	–	40.0	3.0	–	–	–	2
<i>Emex spinosa</i>	Th	ME,IT	–	7.3	22.7	7.0	7.0	–	4
<i>Seidlitzia rosmarinus</i>	Ch	SA,ME,IT	–	13.8	23.7	55.0	–	–	3
<i>Malva parviflora</i>	Th	ME,IT	–	60.0	4.0	32.7	38.2	4.0	5
<i>Salsola imbricata</i>	Ch	SA,SU	–	32.1	6.0	2.0	35.0	–	4
<i>Suaeda aegyptiaca</i>	Th	SA	–	–	2.0	–	40.0	60.0	3
<i>Mesembryanthemum nodiflorum</i>	Th	SA,ES	–	9.0	21.2	9.5	12.2	30.0	5
<i>Stipa capensis</i>	Th	SA,ME,IT	–	10.6	23.8	18.0	–	–	3
<i>Plantago ovata</i>	Th	SA,IT	–	31.5	25.2	3.0	–	–	3
<i>Erodium cicutarium</i>	Th	ME-IT-ES	–	15.8	9.0	6.0	–	–	3
<i>Senecio glaucus</i>	Th	SA,IT	–	7.0	2.3	7.0	–	–	3
<i>Bassia muricata</i>	Th	SA	–	4.0	3.0	2.0	–	–	3
<i>Calendula arvensis</i>	Th	SA,ME,IT	–	4.3	3.6	3.0	–	–	3
<i>Lotus halophilus</i>	Th	SA,IT	–	3.6	13.3	3.5	–	–	3
<i>Frankenia pulverulenta</i>	Th	ME,IT,ES	–	3.0	3.3	3.0	–	–	3
<i>Reichardia tingitana</i>	Th	SA,IT	–	2.3	2.8	7.0	–	–	3
<i>Plantago notata</i>	Th	SA	–	2.0	11.8	3.0	–	–	3
<i>Anabasis setifera</i>	Ch	SA,IT,SU	–	2.0	10.0	1.0	–	–	3
<i>Scrophularia deserti</i>	Ch	SA	–	2.0	7.5	4.0	–	–	3
<i>Anchusa hispida</i>	Th	SA,IT	–	1.3	1.5	1.0	–	–	3
Companion species									
<i>Trigonella stellata</i>	Th	SA,IT	–	8.3	3.7	2.0	–	–	3
<i>Plantago coronopus</i>	Th	SA,IT	–	6.0	9.8	8.0	–	–	3
<i>Chenopodium murale</i>	Th	COSM	–	4.0	2.0	1.0	–	–	3
<i>Atriplex leucoclada</i>	Ch	SA,IT,SU	–	3.5	6.0	3.0	–	–	3
<i>Helianthemum lipii</i>	Ch	SA,SU	–	3.0	6.7	7.0	–	–	3
<i>Astragalus schimperi</i>	Th	ME	–	2.7	4.0	3.0	–	–	3
<i>Spergularia diandra</i>	Th	SA,ME,IT	–	2.0	1.7	3.5	–	–	3
<i>Schismus barbatus</i>	Th	SA,ME	–	2.0	5.5	6.0	–	–	3
<i>Rostraria pumila</i>	Th	SA,ME,IT	–	1.0	1.0	1.0	–	–	3
<i>Cistanche tubulosa</i>	Pa	SA,IT,SU	–	1.5	2.0	–	2.0	–	3
<i>Stipagrostis ciliate</i>	Cr	SA	–	3.0	4.8	–	1.0	–	3
<i>Cornulaca monacantha</i>	Ch	SA	–	12.0	3.0	–	–	–	2
<i>Fagonia indica</i>	He	SA,IT	–	11.0	5.0	–	–	–	2
<i>Reseda muricata</i>	Ch	SA,ME	–	15.0	2.0	–	–	–	2
<i>Suaeda vermiculata</i>	Ch	SA,su	–	6.0	2.0	–	–	–	2
<i>Helianthemum ledifolium</i>	Th	ME,IT	–	4.0	9.0	–	–	–	2
<i>Helianthemum kahircum</i>	Ch	SA	–	3.0	20.0	–	–	–	2
<i>Launaea nudicaulis</i>	He	SA,IT,SU	–	2.0	4.0	–	–	–	2
<i>Launaea capitata</i>	Th	SA,SU	–	1.3	3.0	–	–	–	2
<i>Echinopus spinosissimus</i>	Ch	SA	–	–	2.0	1.0	–	–	2
<i>Ifloga spicata</i>	Th	SA,ES	–	–	7.3	8.0	–	–	2

Table 1 continued

Group no.	LF	Chorotype	I	II	III	IV	V	VI	Total
Relevé no.			1	8	9	3	5	2	Sp.
Habitat			Qaruh	Umm Al-Namil	Maskan	Awhah	Kubbar	Umm Al-Maradem	
Species number			1.0	46.0	56.0	42.0	8.0	3.0	70
<i>Medicago laciniata</i>	Th	SA,IT	–	–	8.1	5.5	–	–	2
<i>Aizoon canariense</i>	Th	SA,ME,IT	–	–	4.0	4.0	–	–	2
<i>Erodium laciniatum</i>	Th	SA,ME,IT	–	–	3.3	8.0	–	–	2
<i>Anthemis deserti</i>	Th	ME,IT,ES	–	–	1.0	1.0	–	–	2
<i>Filago pyramidata</i>	Th	ME,IT	–	–	1.0	2.0	–	–	2
<i>Silene Arabica</i>	Th	SA	–	–	1.0	2.0	–	–	2
<i>Paronychia Arabica</i>	Th	SA	–	–	1.0	2.0	–	–	2
<i>Atriplex dimorphostegia</i>	Th	SA,IT	–	25.0	–	–	–	–	1
<i>Asphodelus tenuifolius</i>	Cr	SA,ME,SU	–	7.8	–	–	–	–	1
<i>Astragalus haurarensis</i>	Th	SA	–	3.0	–	–	–	–	1
<i>Lycium shawii</i>	Ph	IT	–	3.0	–	–	–	–	1
<i>Cakile Arabica</i>	Th	ME,ES	–	2.5	–	–	–	–	1
<i>Nitraria retusa</i>	Ph	SA,SU	–	1.7	–	–	–	–	1
<i>Astragalus spinosus</i>	Ch	SA,IT	–	1.0	–	–	–	–	1
<i>Hordeum murinum</i>	Th	SA,ME	–	1.0	–	–	–	–	1
<i>Picris babylonica</i>	Th	SA,ES	–	–	3.0	–	–	–	1
<i>Asphodelus viscidulus</i>	Cr	SA	–	–	2.0	–	–	–	1
<i>Moltkiopsis ciliata</i>	Ch	SA,ME,IT	–	–	2.0	–	–	–	1
<i>Haplophyllum teberculatum</i>	He	SA,IT	–	–	1.0	–	–	–	1
<i>Aronsohnia factoroviskyi</i>	Th	SA,ME	–	–	1.0	–	–	–	1
<i>Citrullus colocynthis</i>	He	SA	–	–	1.0	–	–	–	1
<i>Plantago psammophila</i>	Th	SA	–	–	1.0	–	–	–	1
<i>Cutandia dichotoma</i>	Th	ME,IT,ES	–	–	–	17.0	–	–	1
<i>Gypsophila capillaries</i>	Th	SA	–	–	–	1.0	–	–	1
<i>Polycarpha repens</i>	He	SA,SU	–	–	–	2.0	–	–	1
<i>Prosopis farcta</i>	Ph	SA	–	–	–	1.0	–	–	1
<i>Tamarix aphylla</i>	Ph	SA,ME	–	–	–	1.0	–	–	1
<i>Halocnemum strobilaceum</i>	Ch	SA,IT,ME,SE	–	–	–	–	3.0	–	1

The vegetation groups are named follows: VG I: *Polycarpon tetraphyllum*, VG II: *Zygophyllum qatarense*, VG III: *Emex spinosa*, VG IV: *Sedlitzia rosmarinus*, VG V: *Malva parviflora-Salsola imbricata*, and VG VI: *Suaeda aegyptiaca*. LF life form, Th therophytes, Ch chamaephytes, Pa parasite, Cr cryptophytes, He Hemicryptophytes, and Ph phanerophytes, SA Saharo-Arabian, IT Irano-Turanian, ME Mediterranean, ES Euro-Siberian, SU Sudanian, and COSM Cosmopolitan

characterized by high content of clay or mud due to the proximity of effluents of Euphrates River.

VG III: *Emex spinosa* (9 relevés and 56 species), inhabits the Maskan Island that located at the north east of Kuwait Bay and characterized by species *Emex spinosa*, *Mesembryanthemum nodiflorum*, *Plantago ovate*, *Helianthemum ledifolium*, and *Anabasis setifera*. This island having medium to coarse sand in shore with coral reefs presents at few meters in depths and had a lower human impacts or devoid of any vital activity.

VG IV: *Seidlitzia rosmarinus* (3 relevés and 42 species), inhabiting small southern island ‘Awhah’ and characterized by ephemeral and halophytic species, e.g., *Emex*

spinosa, *Malva parviflora*, *Plantago ovate*, *Seidlitzia rosmarinus*, and *Cutandia diccotima*. The edaphic substrate is characterized by high values of moisture, organic matter, and mineral contents.

VG V: *Malva parviflora-Salsola imbricata* (5 relevés and 8 species), inhabits the small southern island ‘Kubbar’ that is characterized by halophytes *Suaeda aegyptiaca*, *Malva parviflora*, and *Salsola imbricata*. Kubbar Island has saline soil with high moisture, organic matter, silt, and lower of pH content.

VG VI: *Suaeda aegyptiaca* (2 relevés and 3 species), inhabits the small southern island ‘Umm Al-Maradim’ that characterized by halophytes, such as *Mesembryanthemum*

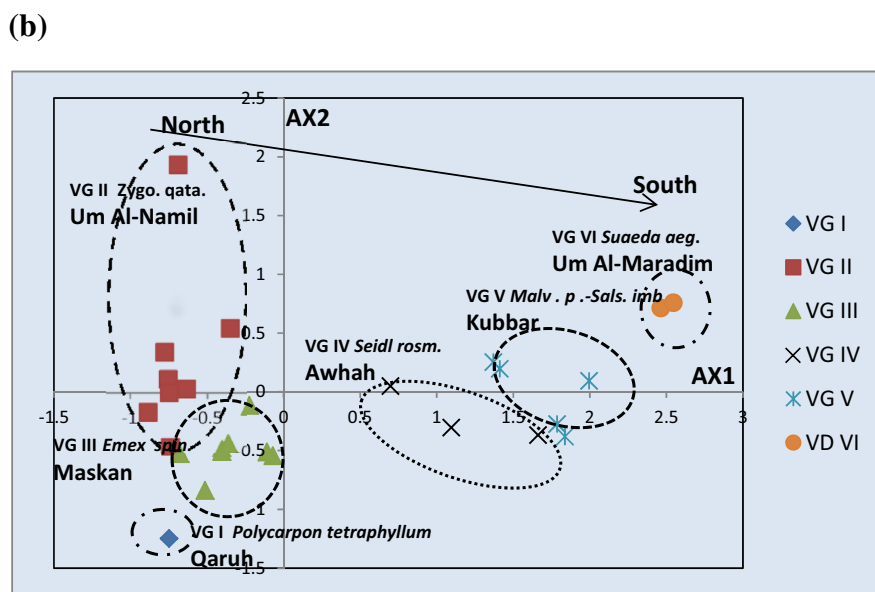
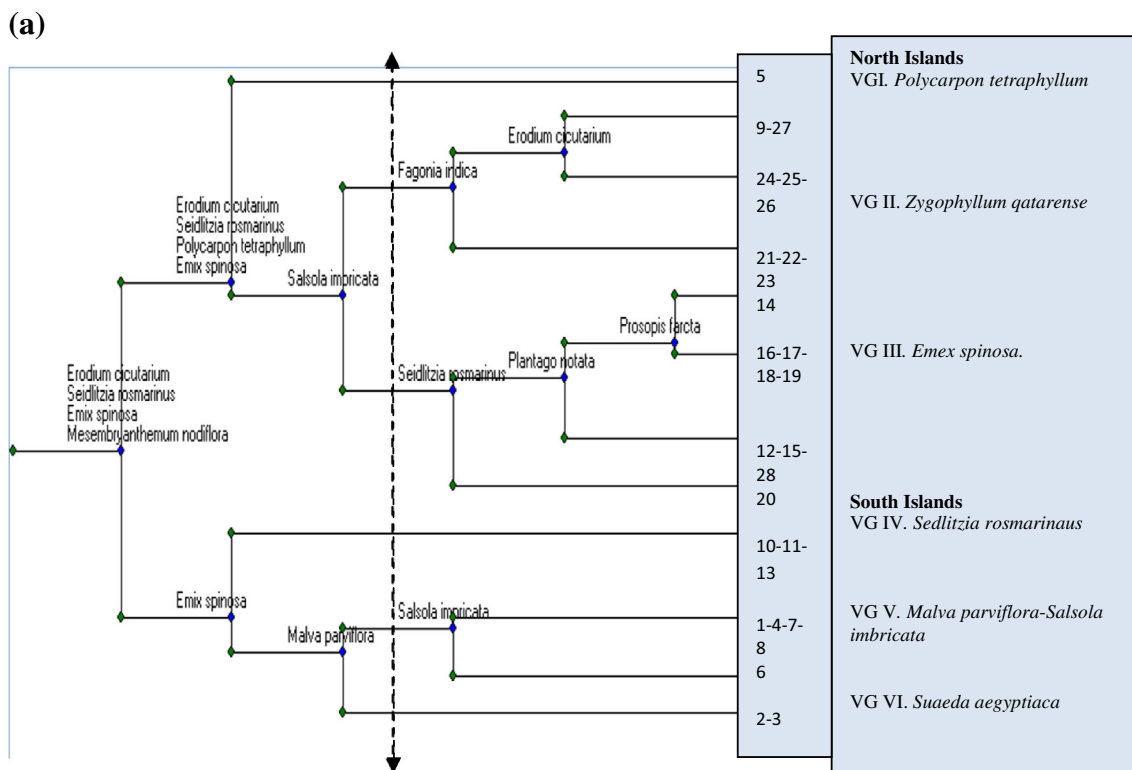


Fig. 4 Classification of the 28 stands by TWINSpan (a) and their ordination by DCA program (b) on the six Kuwait islands

nodiflorum and *Malva parviflora*. This island is characterized by higher values of salinity contents.

3.3 Relationships between plant associations and environmental variables

Correlation coefficients between the environmental factors and DCA and CCA axes (Table 2; Fig. 5a) indicated that

the separation of relevés along the first axis was positively influenced by species turnover, relative species dominance, salinity, moisture, organic matter, silt, and mineral contents, and negatively by island area, species number, cover, richness, evenness, relative species evenness, pH, and sand contents. On the other hand, the separation of the relevés along the second axis was correlated positively with Ca and negatively with pH.

Table 2 Inter-set correlations of the environmental variables with axes CCA of the six Kuwait islands

Variable	AX1	AX2	AX3	AX4
Island area m ²	−0.6408***	0.3107	0.3627	0.1996
Species number	−0.6792***	−0.1468	0.1220	−0.0178
Species cover 100/100 m	−0.6623***	−0.1874	0.1026	0.0318
Species richness sp. stand ^{−1}	−0.6955***	−0.1369	0.1126	−0.0314
Species turnover	0.6424***	0.0536	0.1844	0.0675
Species Evenness	−0.4457*	−0.1174	0.4162	−0.1390
Shannon H'	−0.8112***	−0.1768	0.1342	−0.0932
Simpson C	0.7842***	0.1629	−0.1863	0.1128
pH	−0.6433***	−0.4220*	0.1277	−0.3614
EC μ mhos cm ^{−3}	0.5713**	0.3107	0.1543	0.0454
Moisture %	0.6543***	0.0934	−0.3116	−0.0513
Organic matter %	0.5801**	0.2026	−0.1008	0.1980
Sand %	−0.3808*	−0.1749	0.3114	0.3489
Silt %	0.6379***	0.2792	−0.3092	0.0195
Clay %	0.1690	0.0852	−0.2536	−0.4827
Na mg 100 g ^{−1}	0.5797**	0.0996	0.1731	0.0929
K mg 100 g ^{−1}	0.5300**	0.0753	0.0637	0.1030
Ca mg 100 g ^{−1}	0.4633*	0.6518***	0.2136	−0.0535
Mg mg 100 g ^{−1}	0.5524**	0.3536	0.0795	0.0594
Fe mg 100 g ^{−1}	0.2709	−0.2301	−0.4499	0.0465
Mn mg 100 g ^{−1}	0.3120	−0.2471	−0.4102	−0.0295
Cu mg 100 g ^{−1}	0.6865***	−0.3039	−0.1342	−0.3627

Significant *r* values are bold and coded as follows: * $p \leq 0.05$, ** $p \leq 0.01$, and *** $p \leq 0.001$

The woody shrubs species (*Lycium shawii*, *Nitraria retusa*, *Salsola imbricata*, and *Zygophyllum qatarense*) of the association VG II that inhabits northern large island 'Um Al-Namil' were correlated with island area and species number, and the psammophytic herbaceous species (*Stipa capensis*, *Stipagrostis ciliata*, and *Launaea nudicaulis*) that belonged to the association VG III which inhabits 'Maskan' island were correlated with sand, species richness, evenness, total plant cover, and pH along the negative part of axis one (Fig. 5b). On the other hand, the halophytic species (*Suaeda aegyptiaca*, *Mesembryanthemum nodiflorum*, and *Halocnemum strobiliaceum*) of the associations IV, V, and IV which inhabit that the small southern islands were correlated with Simpson dominance, moisture, organic matter, salinity, and mineral contents of the positive axis one (Fig. 5b).

From data presented in Table 3, it was inferred that the island area correlated positively with species number, richness, evenness, and relative evenness and negatively with Cu. Species number, richness, and relative evenness were positively correlated with pH and negatively correlated with moisture, organic matter, and Cu. On the other hand, relative dominance was correlated positively with moisture, organic matter, and Cu and negatively with pH.

Species turnover correlated positively with moisture and silt.

3.4 Characteristics of plant associations with edaphic values

Significant differences between species diversity indices, Ca, and organic matter contents of all the six associations were noted (Table 4). The *Polycarpon tetraphyllum* association—VG I—inhabits that the smallest 'Qaruh' island was characterized by higher values of sand content and lower values of island area, species number, cover and all species diversity indices, soil salinity, moisture, organic matter, silt, clay, and mineral contents 'i.e., poor soil' (Table 4), while the *Salsola imbricata* association—VG II—which inhabits larger northern island 'Um Al-Namil' was characterized by high values of island area, species number, cover and species richness, and lower values of Cu content. The *Malva parviflora-Salsola imbricata* association—VG V—which inhabits small southern island 'Kubar' was characterized by higher values of moisture, organic matter, silt, alkalinity, K, and Cu, whereas—VG VI—*Suaeda aegyptiaca* that inhabits small southern island 'Umm Al-Maradim' was characterized by higher values of

Table 3 Simple linear correlation (r values) between the environmental variables and diversity indices

Variable	Island area	Sp. number	Sp. cover	Sp. richness	Sp. turnover	Sp. evenness	Shannon H'	Simpson C
Island area m ²	1							
Sp. number	0.540**	1						
Cover m100 m ⁻¹	0.506**	0.805**	1					
Sp. richness	0.557**	0.985**	0.774**	1				
Sp. turnover	0.141	-0.118	0.160	-0.173	1			
Sp. evenness	0.509**	0.428*	0.442*	0.436*	0.042	1		
Shannon H'	0.571**	0.699**	0.678**	0.736**	-0.247	0.626**	1	
Simpson C	-0.335	-0.590**	-0.533**	-0.642**	0.524**	-0.531**	-0.849**	1
pH	0.320	0.553**	0.510**	0.570**	-0.316	0.318	0.744**	-0.631**
EC μ hos cm ⁻³	-0.180	-0.329	-0.205	-0.315	0.281	0.123	-0.430*	0.143
Moisture %	-0.339	-0.433*	-0.149	-0.417*	0.413*	-0.200	-0.449*	0.400*
Organic matter %	-0.242	-0.406*	-0.230	-0.400*	0.366	-0.102	-0.545**	0.400*
Sand %	0.083	0.225	-0.026	0.190	-0.378	-0.032	0.092	-0.120
Silt %	-0.281	-0.378	-0.169	-0.370	0.445*	-0.184	-0.450*	0.345
Clay %	0.060	-0.081	0.145	-0.035	0.257	0.163	0.156	-0.049
Na mg 100 g ⁻¹	-0.250	-0.330	-0.201	-0.321	0.260	0.102	-0.451*	0.141
K mg 100 g ⁻¹	-0.282	-0.279	-0.151	-0.261	0.206	0.097	-0.402*	0.072
Ca mg 100 g ⁻¹	0.040	-0.263	-0.204	-0.254	0.340	0.122	-0.338	0.224
Mg mg 100 g ⁻¹	-0.184	-0.322	-0.214	-0.309	0.246	0.099	-0.427*	0.135
Fe mg 100 g ⁻¹	-0.295	-0.082	-0.054	-0.071	-0.006	-0.496**	-0.246	0.333
Mn mg 100 g ⁻¹	-0.270	-0.114	-0.026	-0.087	-0.022	-0.324	-0.184	0.187
Cu mg 100 g ⁻¹	-0.647**	-0.513**	-0.410*	-0.542**	0.293	-0.299	-0.622**	0.547**

The significant levels of the r values are bold and coded as follows: * $p \leq 0.05$, ** $p \leq 0.01$, and *** $p \leq 0.001$

absence in habitat variations. Positively one or both of these mechanisms of the area-habitat relationship might have influenced the vegetation in the Kuwait islands.

The *Zygophyllum qatarense* (VG II) inhabits on the northern relatively large island-Um Al-Namil which is dominated by widely spread common woody perennials, shrubs, sub-shrubs, and salt tolerant chamaephytes intermingled with many grasses. This Island is characterized by high species number, dense plant cover and species richness may be due to the large area of the Island that posses a heterogeneity of habitat substrates, high contents of clay, or mud, and it is the nearest island to the mainland. These indicate that the short distance (600 m from mainland) and anemochorous dispersal of majority of the recorded species facilitate recurrent colonization and corroborates with the 'rescue effect' of Brown and Kodric-Brown (1977). Therefore, rescue effects and/or intra-island dispersal could be the common factors that resulted in the absence of isolation in the present study (King 1988; Butaye et al. 2001). This present study also showed that the relationship between the numbers of species is strongly related to size of island area similar to that reported for the Borollos lake islands in Egypt (Khedr and Lovett-Doust 2000). Furthermore, the observed species-area relationships in this present study corroborate with the habitat and microhabitat

diversity hypothesis (Conner and McCoy 1979; Kelly et al. 1989; Kohn and Walsh 1994; van der Maarel 1997), and agree with the findings of Dengler (2010) and Triantis and Sfenthourakis (2012), since larger the island the larger is the number of habitats and microhabitat diversity.

The psammophytic herbaceous species, belonging to the association *Emex spinosa* (VG III), inhabited Maskan Island are correlated with sand, species richness, evenness, total plant cover, and pH. The species richness is related to the absence of human impacts in this Island.

The associations VG IV: *Seidlitzia rosmarinus*, VG V: *Malva parviflora-Salsola imbricata*, and VG VI: *Suaeda aegyptiaca* that inhabit the relative small southern three islands Awhah, Kubbar, and Um Al-Maradim, respectively, are dominated by halophytic plants and characterized by low species richness, higher values of salinity, moisture, organic matter, silt, minerals contents, and alkaline content. Thus, there were considerable variations between vegetation associations in edaphic variables, which are the most important gradients for correlating with the distribution of wetland vegetation (Halwagy et al. 1982; Haase 1990; de Leeuw et al. 1991; Shaltout et al. 1995; Rey Benayas et al. 1999; Khedr and Lovett-Doust 2000), and consequently, the zonation pattern of vegetation in Kuwait islands shows an interesting edaphic factor gradients.

Table 4 Mean is shown in the first line and \pm standard deviation in the second line of six vegetation groups after TWINSpan classification in six Kuwait islands as follows: VG I: *Polycarpon**tetraphyllum*, VG II: *Zygophyllum qatarense*, VG III: *Emex spinosa*, VG IV: *Sedlitzia rosmarinaus*, VG V: *Malva parviflora-Salsola imbricata*, and VG VI: *Suaeda aegyptiaca*

VG Island	VG I Qaro	VG II Um Al-Namil	VG III Miskan	VG IV Uoha	VG V Kubbar	VG VI Um Al-Mardem	Total mean	F value
Island area m ²	4.00 0.00	80.13 27.93	58.11 14.17	34.00 0.00	32.60 29.58	65.00 0.00	55.82 28.75	4.89***
Sp. number	1.00 0.00	19.00 9.40	16.89 9.01	7.33 1.15	2.80 1.30	2.50 0.71	12.36 9.95	4.80***
Sp. cover m100 m ⁻¹	2.00 0.00	172.38 55.28	145.33 58.90	115.67 15.95	73.40 29.85	85.50 6.36	127.64 62.82	4.40**
Sp. richness sp. stand ⁻¹	0.00 0.00	3.38 1.60	3.22 1.56	1.00 0.00	0.20 0.45	0.00 0.00	2.14 1.90	6.81***
Sp. Turnover	1.00 0.00	5.50 0.53	5.33 0.71	5.33 0.58	7.40 1.52	8.00 1.41	5.75 1.69	14.624
Sp. evenness	0.00 0.00	0.88 0.35	1.00 0.00	0.67 0.58	0.60 0.55	0.90 0.00	0.82 0.39	2.19
Shannon H'	0.00 0.00	0.88 0.35	1.00 0.00	0.67 0.58	0.00 0.00	0.00 0.00	0.64 0.49	13.95***
Simpson C	0.00 0.00	0.13 0.35	0.00 0.00	0.33 0.58	0.80 0.45	1.00 0.00	0.29 0.46	6.34***
pH	9.00 0.00	9.01 0.32	9.35 0.17	9.06 0.59	8.44 0.19	8.49 0.34	8.99 0.43	7.49***
EC μ mhos cm ⁻³	90.00 0.00	323.25 598.69	238.00 215.39	373.33 169.21	2102.00 3017.05	2800.00 1131.37	787.43 1525.23	2.40
Moisture %	2.00 0.00	3.94 2.57	5.11 4.17	9.10 4.94	11.86 7.91	9.90 0.71	6.64 5.31	2.51
Organic matter %	2.00 0.00	2.63 0.67	2.26 1.18	2.43 1.46	5.34 3.10	4.85 0.07	3.11 1.91	3.25*
Sand %	96.00 0.00	91.21 4.18	89.12 5.12	86.90 2.00	87.30 4.88	87.90 4.24	89.31 4.59	1.12
Silt %	1.00 0.00	1.96 1.46	1.86 0.94	3.13 1.40	4.70 3.32	4.20 2.12	2.67 2.05	2.29
Clay %	3.00 0.00	6.83 2.88	9.02 4.23	9.97 1.40	8.00 1.67	7.90 2.12	8.02 3.21	1.14
Na mg 100 g ⁻¹	5.00 0.00	7.56 5.15	17.78 20.55	25.33 10.02	178.70 253.92	190.75 7.42	56.30 123.33	2.50
K mg 100 g ⁻¹	3.00 0.00	5.13 2.83	7.33 5.94	10.00 2.65	43.20 62.57	34.75 9.55	15.20 28.79	1.72
Ca mg 100 g ⁻¹	10.00 0.00	30.88 51.72	13.83 5.18	18.17 6.05	54.20 58.94	146.50 135.06	35.71 55.61	2.78*
Mg mg 100 g ⁻¹	1.00 0.00	3.44 5.70	2.06 0.81	3.67 1.76	16.90 22.60	19.00 0.71	6.45 11.29	2.24
Fe mg 100 g ⁻¹	2.00 0.00	67.88 97.79	137.17 154.17	521.83 881.79	112.60 204.53	8.25 1.77	140.16 305.27	1.19
Mn mg 100 g ⁻¹	0.00 0.00	0.75 0.53	2.50 1.95	6.17 9.81	1.90 1.95	0.75 0.35	2.07 3.41	1.35
Cu mg 100 g ⁻¹	7.00 0.00	3.85 0.59	5.90 1.58	6.73 1.76	8.06 1.35	7.45 0.92	5.94 1.94	7.78***

The maximum and minimum values are with bold letter

The significant levels of the *F* values are coded as follows: * $p \leq 0.05$, ** $p \leq 0.01$, and *** $p \leq 0.001$

The CCA and correlation analyses evidence the significance of size of island area, and edaphic and community variables in the determination of floristic structure and diversity of the islands of Kuwait. The species richness and evenness which characterize shrubby and psammophytic life-form associations on the large North Islands were positively correlated with island area and soil pH 'alkalinity', and negatively correlated with moisture, organic matter, and Cu content. Ghazanfar (2006) reported that this positive relationship between species richness and pH 'alkalinity' was due to high species numbers at either end of the gradient (sand formation and marshy habitat, respectively), and therefore, species richness increased mainly in the elevated parts of the large Islands, where salinity was lower (Halwagy and Halwagy 1974a, b, 1977; Abbad and El-Sheikh 2002; El-Sheikh and El-Abbad 2004; El-Sheikh et al. 2006). The halophytic growth form was positively correlated with relative concentration of species dominance, whereas the relation of the concentration of species dominance with moisture and organic matter in most cases of plant cover is accounted for by one or two dominant halophytic species (e.g., *Mesembryanthemum nodiflora*, *Suaeda aegyptiaca*, *Zygophyllum qatarense*, etc.) that can make the best use of available resources similar to earlier reports (Buckley 1985; Khedr and Lovett-Doust 2000; Abbad and El-Sheikh 2002). The important features of saline/or alkaline vegetation are: (1) impoverished in the species number; (2) majority of present species show C4 photorespiration pathway which adapt and survive in these high temperatures, intense light, and moisture conditions; (3) most of this vegetation is composed of mono-specific stands with two or three species; and (4) the majority of the species are obligate halophytes, but salt tolerant and salt secreting species, such as that of *Sporobolus*, *Aleuropus*, *Limonium*, and *Tamarix*, are also present. These interrelationships may have important implications for conservation and management of the floristic diversity.

The total of 138 species reported from the 6 islands of the present study and that from an earlier study of Failaka Island together constitute about 37% of the total number of vascular plants listed in the flora of Kuwait (Boulos and Al-Dosari 1994). *Limonium carnosum* is the unique species for Failaka Island, because it is not recorded on the mainland of Kuwait and *Convolvulus cephalopodus*, *Bupleurum semicompositum* and *Erodium bryoniifolium* are recorded in these islands but only in one locality on the mainland (Daoud and Al-Rawi 1985; Al-Rawi 1987). As these islands are uninhabited, human impact is low and vegetation cover is higher than that of the mainland. Thus, these islands warrant redesignation as natural reserve for wildlife.

5 Conclusions

- The vegetation type of Kuwait Islands is halophytic with widespread grass and annuals. The species diversity of these islands is related to the size of the island and edaphic gradients.
- The non-fertile smallest island 'Qaruh' is characterized by mono-species '*Polycarpon tetraphyllum*' association (VG I) on mono-site.
- The northern large islands are dominated by *Zygophyllum qatarense* (VG II) on the northern relatively large island-Um Al-Namil and *Emex spinosa* (VG III) on Maskan Island. These Islands are dominated by widely spread woody species with high species diversity due to the large area of islands, presence of many psammophytic and annual species in rainy season, and higher habitat heterogeneity (e.g., depressions, rocks, and cracks) and provides mosaic patchy habitats for different species.
- Whereas *Seidlitzia rosmarinus* (VG IV), *Malva parviflora-Salsola imbricata* (VG V), and *Suaeda aegyptiaca* (VG VI) inhabit the small southern three islands Awhah, Kubbar and Um Al-Maradim, respectively. The halophytic plants dominate these humid Islands and are adapted to the saline and humid habitats with lower diversity due to the salinity stress.

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