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Original Article

Plant diversity in Sabkha ecosystems of arid region: spatial and environmental drivers

Diversidade de plantas em ecossistemas Sabkha da região árida: drivers espaciais e ambientais

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Abstract

This study investigated the effects of spatial and environmental factors and their interactions on plant species composition in salt marsh (Sabkha) ecosystem located in arid region (Saudi Arabia). The plant species and environmental variables were investigated in 38 sites located in three regions. A total of 15 environmental variables were measured in each site and the geographical coordinates were used to extract spatial variables (using PCNM). A total of 81plant species were reported from 38 sites. The three regions showed patterns of homogeneity of multivariate dispersions (i.e. beta diversity). The PCNM analysis extracted 18 PCNM vectors and only 3 vectors were retained after forward selection. The spatial variables (selected PCNM vectors) explained only 3.21% of the variation in species composition of plants (using variation partitioning technique). However, eight environmental variables were selected after forward selection (Lead, Copper, total organic matter, Potassium, Magnesium, pH, Zinc and Iron, F= 4.72, P<0.05) and explained 19.61% of the total variation in the species composition. In conclusion, the plant communities in Sabkhas were not spatially structured due to the low percentage of variation explained by the spatial variables (PCNM vectors). The environmental variables were corresponded to the high fraction of variation explained. On the other hand, Sabkhas in Saudi Arabia are considered a hot spot for diversity not only for plants but for other animals (birds, vertebrates and invertebrates). Therefore, immediate conservation plans should be implemented to reduce the adverse effect of urbanization, industrialization as well as other anthropogenic activities.

Keywords: spatial patterns, Sabkha, PCNM, Saudi Arabia, plant communities.

Resumo

Este estudo investigou os efeitos de fatores espaciais e ambientais e suas interações na composição de espécies vegetais no ecossistema de sapal (Sabkha) localizado na região árida (Arábia Saudita). As espécies vegetais e variáveis ambientais foram investigadas em 38 locais localizados em três regiões. Um total de 15 variáveis ambientais foi medido em cada local, e as coordenadas geográficas foram usadas para extrair as variáveis espaciais (usando PCNM). Um total de 81 espécies de plantas foi relatado em 38 locais. As três regiões mostraram padrões de homogeneidade de dispersões multivariadas (ou seja, diversidade beta). A análise PCNM extraiu 18 vetores PCNM e apenas 3 vetores foram retidos após a seleção direta. As variáveis espaciais (vetores PCNM selecionados) explicaram apenas 3,21% da variação na composição de espécies das plantas (utilizando a técnica de partição de variação). No entanto, 8 variáveis ambientais foram selecionadas após seleção direta (chumbo, cobre, matéria orgânica total, potássio, magnésio, pH, zinco e ferro, F = 4,72, P < 0,05) e explicaram 19,61% da variação total na composição de espécies. Em conclusão, as comunidades vegetais em Sabkhas não foram espacialmente estruturadas devido à baixa porcentagem de variação explicada pelas variáveis espaciais (vetores PCNM). As variáveis ambientais corresponderam à alta fração de variação explicada. Por outro lado, os Sabkhas na Arábia Saudita são considerados um *hot spot* de diversidade não apenas para plantas, mas para outros animais (aves, vertebrados e invertebrados). Portanto, planos de conservação imediatos devem ser implementados para reduzir os efeitos adversos da urbanização, industrialização e outras atividades antrópicas.

Palavras-chave: padrões espaciais, Sabkha, PCNM, Arábia Saudita, comunidades vegetais.

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1. Introduction

The diversity of habitats in Saudi Arabia has a remarkable contribution to the global biodiversity of plants in arid ecosystems [for example, see Alfarhan et al. (2002)]. This is acceptable fact as Saudi Arabia covers almost 2 million km^2 and has a unique variation in the weather from the North to the South. These habitats include the inland wetlands which are commonly known as Sabkha or Chott (Khan et al., 2008; Ozturk et al., 2010; Neffar et al., 2016; Al-Amro et al., 2018).

Sabkha is a halomorphic or salsodic ecosystems and characterized by high salinity. Sabkhas are of great importance as a hotspot for global biodiversity and perform several necessary hydologeological and ecological functions in the ecosystem (Khan et al., 2008). In addition, they are known for their importance in refinement of the environment from the pollutants. Moreover, they contribute to the groundwater recharge in arid region as there is a severe shortage of water. The vegetation cover grows in Sabkhas can reduce the soil erosion in the coastal area and reduce the effect of flooding. Furthermore, the vegetation cover in Sabkha can serve as a shelter for several animals such as migratory birds and some reptiles and terrestrial invertebrates (Neffar et al., 2016; Chenchouni, 2017).

The natural aquatic ecosystems of Sabkha are dominated by halophytes and succulent plants species. Furthermore, only adapted perennial plant species can survive in Sabkha (Khan et al., 2008; Ozturk et al., 2010; Neffar et al., 2016; Chenchouni, 2017), for example, some species of the family Chenopodiacea such as *Atriplex* spp., *Suaeda* spp., *Salsola* spp. and *Salicornia* spp. (Brown, 2006; Neffar et al., 2016; Chenchouni, 2017). The mechanisms utilized by these plants to survive in this habitat are not fully understood but it involves maintaining the osmotic ions balance and lessen the water contents losses pathways (Rozema et al., 1985; Alvarez-Rogel et al., 2007).

An important objective of the ecological studies is to elucidate spatial patterns of diversity at large spatial scale. Therefore, there is a growing interesting to understand the spatial drivers of biodiversity of animals and plants (Gross et al., 2000; Kreft and Jetz, 2007; Jones et al., 2008; Li et al., 2011). Undoubtedly, this will facilitate understanding the effects of environmental settings and spatial processes (Yang et al., 2009; Lan et al., 2011; Li et al., 2011; Zhang et al., 2016). During the last twenty years, the metacommunity theory has been developed and the ecologists put significant efforts to determine the factors structuring the communities at large scales (Hillebrand, 2004; Ricklefs, 2004; Kreft and Jetz, 2007; Jones et al., 2008; Kier et al., 2009; Lan et al., 2011; Lan et al., 2012).

According to the available studies, there is a discrepancy on identifying the main drivers of plant biodiversity. For instance, many studies found that the floristic composition and diversity are strongly controlled by edaphic characteristics [e.g. see Hegazy et al. (1998)], topography (Tuomisto et al., 2003; Cannon and Leighton, 2004; Valencia et al., 2004; John et al., 2007, Jones et al., 2008; Lan et al., 2011). On the other hand, we should not neglect the effect of spatial drivers such as dispersal ability (Wyatt and Silman, 2004). In other words, some dispersal mechanisms, biotic interactions are responsible for a spatially-structured communities at either broad or fine scales (Lindo and Winchester, 2009; Lan et al., 2011).

Theoretically, plant diversity variability the variation may refer to two different groups of spatial structure: (1) autogenous structure that is influenced solely by one or more of environmental conditions; and (2) exogenous structure, and this a consequence of spatially-structured environmental variables (Fortin et al., 2014). Nonetheless, on the practical prospective explanation of spatially structuring communities is multifaceted because spatial structure of any plant community is a result of combined effect of different environmental and dispersal variables (Fortin et al., 2014; Yang et al., 2009)

In general, the environmental factors can influence the taxonomic composition at different levels depending on the studied environmental factors. For plant diversity, physical and chemical variables of the soil are the most important factors structuring the plant communities (Vormisto et al., 2004; John et al., 2007). In addition to this, geographical characteristics of the habitats such as altitude are known to influence the plant diversity and their communities [see Valencia et al. (2004)].

Although there is a high number of inland Sabkhas in Saudi Arabia, little effort were dedicated to investigate the environmental and spatial determinants of the plant diversity in these ecosystems [but see Al-Amro et al. (2018)]. On the other hand, there is a quite high number of studies which focused mainly on studying the geological and topographical as well as edaphic and water characteristics of Sabkhas in Saudi Arabia [e.g. Al-Harbi et al. (2006)]. However, Al-Amro et al. (2018) investigated the vegetation groups and the effect of environmental variables in several natural and man-made wetlands of Saudi Arabia. Al-Obaid et al. (2017) provided a comprehensive review about the current status wetlands in Saudi Arabia including Sabkhas with emphasis on the effect of progressive climate changes andother human activities. Giving the importance of Sabkha ecosystems and their significant role in ecological functioning and services, the biodiversity in these habitats are threatened by environmental pollution which results from intensive and continuous anthropogenic activities and urbanization. Hence, the present study can be considered as the first effort to investigate the environmental and spatial variable controlling the plant diversity in Sabkha ecosystem in arid region of Saudi Arabia.

The present study investigated the environmental variables as well as the floristic diversity in 38 sites belongs to three main Sabkhas in the central of Saudi Arabia. Therefore, the objective of the study aims to investigate the spatial and environmental drivers of plant diversity in Sabkha ecosystem in arid region of Saudi Arabia.

2. Materials and Methods

2.1. Study area

A total of 38 study sites were investigated in this study during 2016 (Table 1). The 38 studied sites belongs to mainly 3 Sabkhas ecosystems as follow: 1) Al-Oshaziyah

Table 1. Geographical coordinates and altitude of the study sites in the three Sabkhas located in Saudi Arabia.

No.	Site	Acronym	Latitude (E)	Longitude (N)	Altitude (m.a.s.l.)
1	Al-Oshaziyah	Osh	26.03461	44.08133	602
2	Al-Oshaziyah	Osh	26.03386	44.08078	604
3	Al-Oshaziyah	Osh	26.03336	44.08186	603
4	Al-Oshaziyah	Osh	26.03267	44.08207	604
5	Al-Oshaziyah	Osh	26.03223	44.08223	604
6	Al-Oshaziyah	Osh	26.02514	44.08425	605
7	Al-Oshaziyah	Osh	26.02266	44.08132	610
8	Al-Oshaziyah	Osh	26.02218	44.08458	599
9	Al-Oshaziyah	Osh	26.00278	44.09166	600
10	Al-Oshaziyah	Osh	25.5848	44.10149	602
11	Al-Oshaziyah	Osh	25.58007	44.10477	604
12	Al-Oshaziyah	Osh	25.58583	44.11305	607
13	Al-Oshaziyah	Osh	26.01206	44.10331	608
14	Al-Oshaziyah	Osh	26.04046	44.09585	621
15	Al-Oshaziyah	Osh	26.04101	44.09599	621
16	Al-Oshaziyah	Osh	26.03519	44.01412	619
17	Al-Oshaziyah	Osh	26.03376	44.0939	610
18	Al-Oshaziyah	Osh	26.03169	44.09543	610
19	Al-Oshaziyah	Osh	26.02598	44.10029	604
20	Al-Oshaziyah	Osh	26.03466	44.08281	605
21	Al-Oshaziyah	Osh	26.03443	44.083	601
22	Al-Oshaziyah	Osh	26.03495	44.08136	609
23	Shaqa	Shaq	26.23091	43.48145	629
24	Shaqa	Shaq	26.23233	43.47425	629
25	Shaqa	Shaq	26.23391	43.47215	629
26	Shaqa	Shaq	26.23448	43.47543	634
27	Shaqa	Shaq	26.23485	43.48397	635
28	Shaqa	Shaq	26.23263	43.48582	625
29	Qasab	Qas	25.14282	45.32335	645
30	Qasab	Qas	25.14007	45.32598	646
31	Qasab	Qas	25.13507	45.33077	648
32	Qasab	Qas	25.13031	45.33136	669
33	Qasab	Qas	25.21091	45.195899	671
34	Qasab	Qas	25.14025	45.33300	646
35	Qasab	Qas	25.14103	45.31322	651
36	Qasab	Qas	25.16076	45.31540	644
37	Qasab	Qas	25.20314	45.22220	655
38	Qasab	Qas	25.20135	45.22130	662

(acronym Osh, 22 sites) (between 44.01 and 44.11 E and 25.58 and 26.04 N) which is located about 15km from Oniyzah (Qassim Region), 2) Shaqa (acronym Shaq, 6 sites) (between 43.48 and 43.47E and 26.3248 and 26.2309 N) which is located at the western direction of Buryidah (Qassim Region) and 3) Qasab (acronym Qas, 10 sites) which is located at the north-western direction of Riyadh of about 150 km (between 45.19 and 45.33E and 25.13 and 25.21). All the studied sites are in arid region where the temperature can reach up to 50 °C during summer and dropped to less than 10 °C during winter. The annual precipitation is very low and can be less than 200mm/year (Al-Obaid et al., 2017).

2.2. Floristic data

Surveying the plant species in the Sabkhas was determined using 5m × 5m m stands during the Spring of 2016 with three replicates in each site. The presence/absence of vascular plants were reported. Thereafter, the plant species were identified using the available taxonomical keys of Chaudhary (2000) and Collenette (1999).

2.3. Environmental data

At each location three soil samples were collected randomly at depth of 50 cm from each location using plastic scoop. The samples were sieved through 2 mm sieve and transferred to the laboratory in polyethylene labelled bags. A total of 15 environmental variables were measured from the soil samples namely; Sodium, Calcium, Potassium, Phosphorus, Magnesium, Manganese, Iron, Copper, Zinc, Lead, Chrome, Cadmium, pH, Total Nitrogen and Total organic matter. Physical and chemical analysis of the soil variables were conducted following the standard methods and tools of Allen (1989) and APHA (2000). Descriptive statistics of the investigated variables are presented in Table 2.

2.4. Spatial variables

The latitude and longitude as well as the altitude (m.a.s.l.) were instantly recorded in the studied sites. The geographical coordinates and altitude of the studied sites are summarized in Table 1. The spatial vectors were extracted from the longitude and latitude using principal coordinates of neighbor matrices (PCNM). This technique is widely applied in spatial ecology to determine the spatial variability of species diversity and distribution scale. The PCNM vectors represent the spatial variables (Diniz-Filho and Bini, 2005; Borcard and Legendre, 2002).

2.5. Statistical analysis

All statistical analyses were carried out using R program 2.14.1 (R Development Core Team, 2018). We conducted the the canonical analysis of principal coordinates according to discriminant analysis (CAP) was applied to investigate the variation in the species richness and taxonomic composition in the three Sabkhas ecosystems. The test was conducted out through the function *CAPdiscrim* of *BiodiversityR* package. Multivariate homogeneity of groups dispersions (variances) [PERMDISP; Anderson (2006)] was applied to determine the multivariate dispersions in plant communities within each Sabkha (i.e. beta diversity across a set of sites in a Sabkha) The function *betadisper* of *vegan* package in R program was used to calculate the average the distance of centroids based on Sorenson dissimilarity measure as it is recommended for presence/absence data.

Using the function of *pcnm* in the *PCNM* package of R, PCNM spatial variables were produced. Then, both environmental variables and spatial variables (PCNM vectors) were subjected to forward selection to determine the main environmental and spatial variables structuring the plant taxonomic composition in Sabkhas. The forward selection of the function *forward.sel* in *Packfor* package was applied taken into the account two stopping criteria

Table 2. Physical and chemical properties (mean±SD) of the soil in three Sabkhas and the one-way ANOVA results (significance level=0.05). Significant values are in bold.

	Al-Oshaziyah (Osh)	Shaqa (Shaq)	Qasab (Qas)	F-value	P-value
Sodium (ppm)	5739.06±1570.41	5545.28±1679.56	4239.49±2095.68	2.630	0.086
Calcium (ppm)	42556.98±22047.35	54206.83±14274.93	31858.83±29983.69	1.742	0.190
Potassium (ppm)	15388.15±11068.47	21873.55±8657.58	11912.15±12686.17	1.484	0.241
Phosphorus (ppm)	83.32±161.66	70.29±9.19	18.39±23.03	0.924	0.406
Magnesium (ppm)	45416.06±27721.75	77437.23±6536.83	42853.73±39551.71	3.156	**0.050**
Manganese (ppm)	108.50±181.25	1.59±0.52	5.22±6.42	2.573	0.091
Iron (ppm)	6065.61±3146.24	8457.60±2286.87	7882.27±11881.27	0.460	0.635
Copper (ppm)	81.76±137.33	47.42±29.89	53.18±45.59	0.371	0.693
Zinc (ppm)	30.72±17.31	34.58±10.15	48.91±41.79	1.782	0.183
Lead (ppm)	34.23±101.45	5.04±4.71	3.69±4.48	0.676	0.515
Chrome (ppm)	31.57±30.27	49.47±44.85	41.04±43.75	0.656	0.525
Cadmium (ppm)	1.51±1.79	2.29±2.33	0.64±0.41	1.954	0.157
pH	7.36±0.33	7.51±0.44	7.52±0.33	0.946	0.398
Total Nitrogen	13.51±2.71	14.76±1.78	13.94±3.91	0.427	0.656
Total organic matter (%)	3.51±1.75	1.86±0.70	9.89±1.73	64.907	**0.000**

(adj- R^2 and P value of 0.05) as suggested by Blanchet et al. (2008).

The variation partitioning techniques were carried out using the function varpart in vegan package (Oksanen et al., 2022). Therefore, the variation in the plant species composition was partitioned into: a) pure environmental variation (variation explained mainly by environmental variables); b) spatially-structured environmental variation (variation shared by spatial and environmental variables); c) pure spatial variation (variation explained exclusively by spatial variables); and d) unexplained (residual) variation as explained previously by Legendre and Legendre (1998).

3. Results

3.1. Plants diversity in Sabkhas

A total of 81 plant species were identified from the three Sabkhas. Figure 1 exhibits the CAP first two axes (F-value=2.879, P=0.003) with the variation in species composition among the three Sabkhas. Figure 2 depicts the average distance to the centroids (i.e. beta diversity) of plant species in each Sabkha ecosystem. The two Sabkhas of Al-Oshaziyah and Qasab had the highest mean of distance (i.e. beta diversity) of values of 0.548 and0.549, respectively.

3.2. Spatial patterns of plant diversity

According to the PCNM analysis, 18 spatial vectors (variables) were resulted (positive). However, after running the forward selection procedures (using two stopping criteria), only 3 spatial vectors were retained (PCNM 1 (adj-R^2=0.061, F=4.841, P=0.001), PCNM 2 (adj-R^2=0.039, F=4.017, P=0.001) and (PCNM 3 (adj-R^2=0.026, F=3.773, P=0.001). The selected PCNM vectors were arranged according to their importance and showed the relationship with plant taxonomic composition. There was a significant relationships based on the regression models of species composition and the selected spatial variables (i.e. vectors) was significant (F= 3.227, P=0.001). The three selected PCNM spatial axes are illustrated in Figure 3.

Despite those 15 environmental variables at the start were examined, the forward selection retained only 8 variables (F= 4.72, P<0.05) which are structuring the plant communities in Sabkha ecosystems (Table 3). These variables were arranged to their importance in the forward selection model as follow; Lead, Copper, Total organic matter, Potassium, Magnesium, pH, Zinc and Iron. The adj-R^2, F-value and P-value are presented in Table 3.

The variation partitioning procedures were applied to understand the contribution of environmental and spatial variables (retained after forward selection procedures) to the variation in the plant species composition in Sabkhas (Table 4). The environmental variables tended to explain the highest amount of variation in plant species diversity and accounted for 19.61% (F=7.35, P<0.001). However, the spatial variables explained only 3.21% of the variation in

Table 3. Results of forward selection of environmental variables with plant species composition in Sabkha ecosystems in Saudi Arabia.

	Variable	adj-R^2	F-value	P-Value
1	Lead	0.127	2.451	0.027
2	Copper	0.065	2.288	0.022
3	Total organic matter	0.057	1.233	0.050
4	Potassium	0.045	1.395	0.036
5	Magnesium	0.044	1.420	0.030
6	pH	0.032	1.456	0.028
7	Zinc	0.018	2.469	0.026
8	Iron	0.014	1.418	0.035

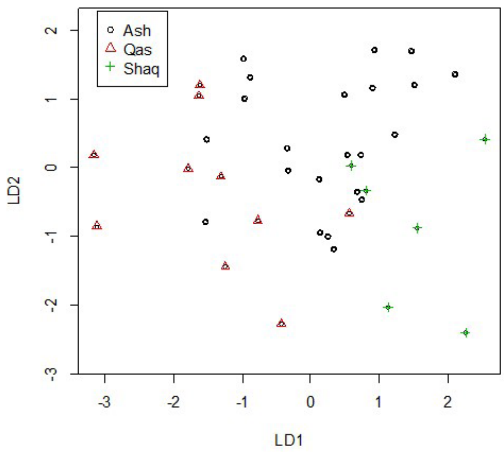

Figure 1. The first two axes of canonical analysis of principal coordinates based on discriminant analysis (CAP) of plant species composition in the three Sabkha ecosystems. Ash: Al-Oshaziyah; Qas: Qasab; Shaq: Shaqa. F-value= 2.879 and P-value=0.003 of the CAP model.

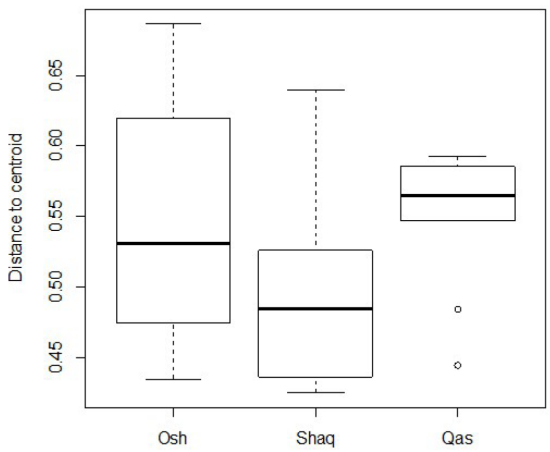

Figure 2. Average distance to the centroid (homogeneity of multivariate dispersions, beta diversity) of plant species compostion in the three Sabkha ecosystems. Ash: Al-Oshaziyah; Qas: Qasab; Shaq: Shaqa. n=38. ANOVA: F-value= 1.835 and P-value=0.025.

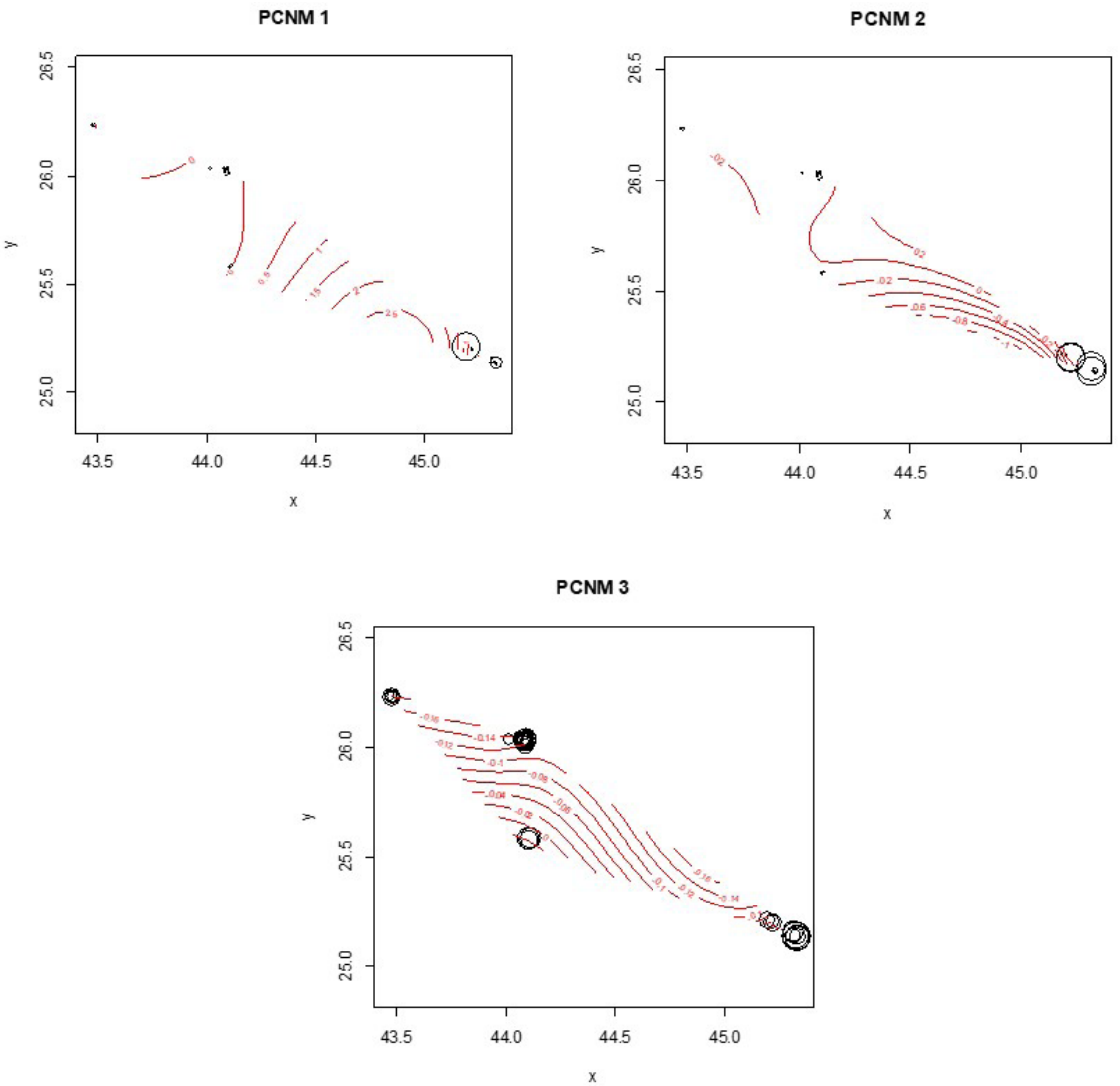

Figure 3. Ordination of the selected and signficant vectors of principal coordinates of neighbour matrices (PCNM) at large spatial scale in Saudi Arabia. The X and Y axes are latitude and longitude of the 38 sites, respectively. Three PCNM axes (spatial vectors) retained after forward selection procedures. Plotting the PCNM axes were performed using the function *ordisurf* of *vegan* package in R program 2.14.1.

Table 4. Partitioning of variation in plant diversity in Sabkhas in Saudi Arabia. The amount of unexplained variance is 72.31% (permutation=999).

	Variance explained %	F-value	Significance
a	19.61	7.35	*P*<0.001
b	3.21	5.39	*P*<0.001
c	4.87	nd	nd
Total explained variation (a+b+c)	27.69	4.88	*P*<0.001

a: Pure environmental parameters. b: Pure spatial variables. c: Shared fraction of variation between spatial and environmental variables. nd: Not detected.

the plant diversity in Sabkhas (F=5.39, P<0.001). The shared fraction (environmental and spatial variables) explained 4.87 of the total variation. The amount of residual variation (unexplained) in the plant species diversity in Sabkhas was 72.31%.

4. Discussion

In the present study, the Sabkhas in Saudi Arabia harbour remarkable diversity in plant species with a total of 81 plant species reported from 38 study sites. According to Al-Amro et al. (2018), the wetlands of Saudi Arabia are considered important and unique habitats for several organisms such as plants, birds, invertebrates, vertebrates and microbes. Furthermore, these wetlands have a vital role in the water cycle and removing the pollutants from the environment (Al-Obaid et al., 2017; Al-Amro et al., 2018). The present study can be considered as the first effort to investigate the contribution of spatial and environmental variables to the plant community structure in Sabkha ecosystem.

The techniques to extract the spatial variables and determine their contribution to organisms diversity have interesting topic in most recent ecological studies. For example Al-Mutairi and Al-Shami (2014) have investigated the effect of spatial and soil variables on plant diversity in selected islands of Farasan Archipelago in Saudi Arabia. Jones et al. (2008) determined the drivers of variation in plant species composition especially spatial and environmental drivers of pteridophytes in tropical forests of Costa Rica. In the same context, Lan et al. (2011) studied the spatial patterns of trees community (13 dominant species) in tropical forests of China.

Here, it was found that only 3 PCNM vectors were retained after performing forward selection techniques. On the other hand, forward selection retained only 8 environmental variables out of studied 15 physical and chemical variables studied. These selected 8 variables have shown to significantly affect the plant species composition in Sabkhas ecosystem. This finding does not agree with some relevant studies which reported strong influence of topographic variables on plant communities (Bartha et al., 1995; Karst et al., 2005; Zhao et al., 2005; Lan et al., 2011). However, Chenchouni (2017) have found that edaphic profile would be of great importance in shaping plant communities in Sabkha ecosystem. It is acceptable fact that in saline environments, soil variables would have strong controller of plant community structure as these parameters are corresponding to the plant survival rates, reducing the fecundity and general fitness to the environment (Ribeiro et al., 2015; Ozturk et al., 2010; Wang and Li, 2016; Chenchouni, 2017) .

In this study, it was found that the selected 8 variables (from forward selection) explained 19.61% of the total variation in the plant species composition. This percentage is lower compared to the findings of Jones et al. (2008) where the environmental variables explained about 25.80% of tropical floristic variation. However, Li et al. (2011) found that the environmental variables explained as low as of 4.4% of variation in the plant diversity of alpine meadow communities. However, in Farasan Archipelago in Saudi Arabia, Al-Mutairi and Al-Shami (2014) reported that variation in the plant diversity was strongly explained by soil variables (26.3%).

According to Jones et al. (2008), the 20 environmental variables of soil (especially chemical variables) are strong drivers of plant diversity. Out of the studied variables, pH, Ca, Mg, C and N were the key variables controlling the floristic diversity variation. This was also in the line with previous findings. For example, Zhang et al. (2010) reported that approximately 40% of variation in plant diversity was explained by the soil variables. Hence, soil physical and chemical properties have been widely reported in the literature for their strong influence in shaping the plant communities either at small or large spatial scales [e.g. Li et al. (2011), Lan et al. (2011), Lan et al. (2012), Al-Mutairi and Al-Shami (2014)]. Wang et al. (2007) suggested that the soil organic matter as well as contents of nitrogen and phosphorus are the main variables shaping plant communities in alpine meadows. In this study, we have found that pH was among the strong drivers of plant diversity in Sabkha. This is in agreement of related reports such as Karst et al. (2005) who found the pH as a main factor that explains variation in the floristic diversity.

On the other hand, the spatial variables (PCNM vectors) explained only 3.21% of variation in the species composition of plants in Sabkha. This indicates that the plant communities in Sabkha are not strongly spatially structured. This percentage of variation explained by spatial variables is somewhat comparable to other studies from China tropical forests [5%, Lan et al. (2011)] and Farasan Archipelago [4.2%, Al-Mutairi and Al-Shami (2014)]. But it was lower compared to what have been reported by Jones et al. (2008) and Li et al. (2011) where the percentages were 15.9 and 18%, respectively. In this study, both environmental and spatial variables altogether explained almost 23% of the variation in the plant species composition. This amount of variation explained is still comparable to other studies findings such as Jones et al. (2008) (32%) and Lan et al. (2011) (36.1%).

This inconsistency in the amount of variation explained by spatial variables may indicate the possible differences in the disperse abilities, as well as the biotic relationships between plant species (Lindo and Winchester, 2009; Lan et al., 2011; Lan et al., 2012). The "spatially structured environmental parameters (shared fraction) were accounted for 4.87% (in this study) may influence the amount of variation explained by "pure spatial" variables.

In conclusion, the natural wetlands (specifically Sabkhas) support high diversity of plants as well as other organisms (such as birds, vertebrates and invertebrates). The plant diversity (composition) is environmentally structured. At large scale the spatial variables have weak role in structuring the plant communities in Sabkha ecosystems. This is probably due to effect of exotic variables such as anthropogenic activities and other biological factors such as dispersion and biotic interactions. To draw a general conclusion about spatial patterns of plant species in Sabkha ecosystems, further comparative investigations should be carried out at larger spatial scale. On the other hand, the wetlands in Saudi Arabia should be conserved immediately as they represent unique natural ecosystems with vital role in maintaining the ecological and biological balance.

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