Spatial and Environmental determinants of plant diversity in Farasan Archipelago, Saudi Arabia

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Abstract: The present study aimed at investigating the effects of spatial and environmental factors on plant species richness in Farasan Archipelago, Saudi Aarbia. The principal coordinates of neighbor matrices (PCNM) technique was used to identify the spatial variables (PCNM vectors). The PCNM produced 9 eigenvectors and only two vectors were positive and significant based on the forward selection procedures. Similar forward selection technique, based on the two stopping criteria, was also employed to determine the most important environmental variables controlling the plant species richness. Among the 13 environmental variables investigated, only 6 variables were retained after forward selection that controlling species richness in Farasan Archipelago. These selected parameters, arranged according to their importance, were altitude, electrical conductivity (EC), calcium (Ca), sodium (Na), calcium carbonate ($CaCO_3$) and organic matter (OM). The variation partitioning technique was employed to examine the relative importance of environmental and spatial factors to the plant species richness. The selected environmental parameters (altitude, EC, Ca, Na, $CaCO_3$ and OM explained 26.3% of the total variance in species richness. However, the two selected spatial variables (PCNM vectors) explained only 4.2% of the richness variation. On the other hand, the spatially-structured environmental variables (shared fraction) explained 5.6 % of the total variance in plant species richness. The present study revealed that the environmental variables (altitude and soil chemistry) are the most important factors regulating the species richness in Farasan Archipelago. However, the spatial variables showed to be less important in shaping the diversity patterns of plants in Farasan Archipelago.
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1. Introduction

There is a growing interest among the ecologists to study the spatial patterns of diversity at broad-scale (Gross et al., 2000; Kreft and Jetz, 2007; Jones et al., 2008; Li et al., 2011). This effort in community ecology and biogeography is necessary for better understanding of the influence of environmental (niche processes) and spatial factors (neutral processes) and on diversity (Yang et al., 2009; Zhang et al., 2010; Lan et al., 2011; Li et al., 2011). In the last decades, several ecologists have showed significant interest to explore the species diversity at large spatial scales (Ricklefs, 2004, Kreft and Jetz, 2007; Jones et al., 2008; Kier et al., 2009; Lan et al., 2011; Lan et al., 2012). Thus, it added valuable information to the modern of community ecology and advanced biogeography (Hillebrand, 2004).

The findings from various studies on the environmental drivers of plant diversity are inconsistent. For example, several studies suggested that floristic composition and abundances strongly influenced by the variation in soil properties (Hegazy, 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). In contrast, there is a long-standing debate on at which level floristic composition respond to environmental variables compared to other processes (e.g. dispersal limitation and biotic factors, Hubbell, 2001; Wyatt and Silman, 2004). Several factors which affect plant distributions may create spatially-structured communities. For instance, Dispersal, biotic interactions, and gap dynamics are likely to produce spatial structure most evident at relatively fine scales, whereas topographic variation may produce structure at different scales depending on underlying geomorphology (Lindo and Winchester, 2009; Lan et al., 2011). Hence, it is suggested that dispersal and biotic factor are expected to generate spatial structure especially at fine scales.

Theoretically, variation in the plant diversity can indicate two types of spatial structure: (1) autogenous structure which is independent and not affected by any environmental variation; and (2) exogenous structure, which is a result of spatially-structured environmental variables (Fortin and Dale, 2005). Practically, however, the justification of spatial structuring is complex as the spatial patterns in plant community is a cumulative of various environmental and dispersal factors. (Fortin et al., 2006; Yang et al., 2009)

The variation partitioning technique (Borcard et al., 1992; Anderson and Cribble, 1998) is ecologically important and has been applied intensively in recent ecological research (e.g. Jones et al., 2008 and Li et al., 2011, Al-Shami et al., 2013). The reported total variation explained in plant species in most of available studies ranged from 20 to 72% in temperate forests (Borcard et al., 1992; Gilbert and Lechowicz, 2004; Cottenie, 2005; Svenning and Skov, 2005; Corney et al., 2006), and from 16 to 86% in tropical forests (Duivenvoorden, 1995; Balvanera et al., 2002; Dalle et al., 2002; Arbeláez and Duivenvoorden, 2004; Svenning et al., 2004). However, in alpine meadow communities, Li et al. (2011) reported total explained variance of 40% in which spatially structured environment explained 17.6%, pure spatial factors explained 18.0% and pure environmental factors explained as low as 4.4% at the scale of quadrats.

In general, the degree in which environmental conditions influence the species composition varied according to identity of measured variables. However, soil chemistry always shows to be the key factor controlling the plant diversity (Vormisto et al., 2004; John et al., 2007). On the other hand, geographical factors (altitude) were proven to affect the floristic composition (Harms et al., 2001; Balvanera et al., 2002; Dalle et al., 2002; Cannon and Leighton, 2004; Valencia et al., 2004).

Although the spatial ecological studies on plant communities have been carried out in several tropical and temperate areas which help in better understanding of diversity drivers in plant communities, no attempt was made to investigate the importance of spatial and environmental factors on plant communities in the Arabian Peninsula. Most of previous studies from this region were in the form of biodiversity surveys (e.g. Alwelaie et al., 1993; Alfarhan et al., 2002) with limited information on the effect of environmental factors (but see Mutairi et al., 2012). Considering the ecological importance of this area, biodiversity is highly threatened by development and intensive anthropogenic activities. Furthermore, the comprehensive knowledge on plant diversity patterns and their drivers are incomplete that may result in profound loss of biodiversity and poor conservation efforts.

In the view of limited information available on the drivers of plant diversity in this region, this study was conducted in 20 islands of Farasan Archipelago in the Red Sea (Saudi Arabia) to explore the response of plant species richness to spatial and environmental variables at large scale area. Thus, principle coordinate neighbor matrix (PCNM) was used to elucidate the spatial variables based on geographical coordinates followed by forward selection and variation partitioning techniques to determine the relative importance of spatial and environmental variables.

2. Materials and Methods

2.1. Study area

Farasan archipelago (Figure 1) situated in the southern part of Red Sea (16^0 20\` -$17^0$ 20\` N, 41^0 24\`- $42^0$ 26\` E). It is far about 40 km from the Jizan coast (mainland) and attains a width of approximately 120 km in SE to NW direction. In this area, the Sea is very shallow (approximately100 meters in depth) and has a width of about 360 km between Jizan coast and the corresponding coast in Eritrea (Alfarhan, 2002).

The islands range in size from very small, a few m^2, to the very large island of Farsan Al-Kabir about 381 km^2 (Table 1). The shore may rise gently to be followed by salt marshes and sandy plains, or be marked by small cliffs emerging from the coralline plateau and covered by coral rubble, and some islands feature a rugged structure of hillocks and outcrops. Some islands for example Zifaf and Sasu islands are being hilly. Large boulders, gravels and small stones are found in the steep runnels of these islands.

Unfortunately, there are no climatic records available for Farasan Islands. The climate at Jizan city (42 km from Farsan Islands) is hot and humid with a maximum daily temperature in the range of 35–40°C during July. The overriding influence on the islands received temperature is the high year-round humidity, mitigated by winds. The mean annual rainfall is about 70 mm in Jizan. As in most arid regions, the condensation of dew is very important for the growth of vegetation on these islands (Osborne, 2000).

Figure 1: The islands of Farasan archipelago in the Reds Sea, Saudi Arabia (Source: Ministry of Defense, KSA).

Table 1: Location and area of the islands in the Farasan Archipelago.

Isalnd	Area (Km²)	Coordinates
Farsan Alkabr	319.527	16 53'N 41 46'E
Sajid	126.871	16 51'N 41 55'E
Zufaf	25.527	16 43'N 41 38'E
Dumsuk	9.820	16 33'N 42 03'E
Manzar Abu Shawk	6.590	16 50'N 42 02'E
Dushak	3.601	16 39'N 41 52'E
Kayyirah	4.351	16 48'N 41 45'E
Manzar Sajid	3.604	16 47'N 42 00'E
Ad Dissan	31.576	16 54'N 41 42'E
Shura	2.887	16 48'N 41 59'E
Abu Shawk Umm Hawk	8.224	16 57'N 41 55'E
Abkar	1.821	16 37'N 41 55'E
Aslubah	1.416	16 35'N 41 59'E
Sulayn	1.158	16 44'N 42 13'E
South Reefs	0.411	16 42'N 42 15'E
At Targ	2.570	16 55'N 41 43'E
Al Hindiyah	0.505	16 34'N 42 14'E
Safrah	0.141	16 57'N 41 45'E
Rayyak Al Kabir	0.171	16 54'N 41 44'E
North Reefs	0.081	16 44'N 42 13'E

Table 2: Physical properties (mean±SD) of the soil in islands of the Farasan Archipelago.

Island	Clay (%)	Sand (%)	Silt (%)	pH	EC
Farsan Alkabr	12.501.87±	72.17±7.33	15.33±6.95	21.50±32.58	28.00±5.22
Sajid	17.25±9.85	54.125±32.09	29±24.54	8.25±0.46	10.125±8.25
Zufaf	7.29±3.02	79.71±7.76	12.21±6.02	8.43±0.65	18.36±10.70
Dumsuk	9.00±3.06	73.12±18.16	19.06±19.00	7.82±0.53	4.47±13.98
Manzar Abu Shawk	8.00±3.70	81.88±7.95	10.25±6.36	7.63±0.52	0.00±0.00
Dushak	10.50±5.33	76.61±13.90	12.67±11.54	8.61±0.61	11.50±10.84
Kayyirah	7.10±6.15	64.70±31.00	28.20±27.30	9.00±0.00	10.80±10.74
Manzar Sajid	10.06±4.26	67.29±17.71	22.06±16.96	11.41±6.30	51.53±31.82
Ad Dissan	11.50±3.46	64.63±3.46	24.63±5.55	46.00±4.90	29.25±3.01
Shura	13.71±2.06	77.00±4.76	9.29±4.07	1.57±1.13	37.14±31.97
Abu Shawk Umm Hawk	9.30±4.00	73.50±11.93	16.20±9.93	2.10±2.81	36.40±32.44
Abkar	10.06±4.26	67.29±17.71	22.06±16.96	11.41±6.30	51.53±31.82
Aslubah	11.50±3.46	64.63±3.46	24.63±5.55	46.00±4.90	29.25±3.01
Sulayn	13.71±2.06	77.004.76±	9.29±4.07	1.57±1.13	37.14±31.97
South Reefs	9.30±4.00	73.50±11.93	16.20±9.93	2.10±2.81	36.40±32.44
At Targ	5.18±2.79	85.73±5.46	7.73±3.47	4.00±1.18	27.18±7.97
Al Hindiyah	4.00±1.69	87.93±7.08	8.07±6.22	2.93±0.80	19.93±4.18
Safrah	16.00±5.05	26.00±8.34	61.60±4.10	2.20±0.45	15.80±2.86
Rayyak Al Kabir	13.00±1.29	72.29±5.15	14.71±4.42	26.57±3.26	16.86±1.95
North Reefs	10.34±7.64	64.17±30.55	25.52±27.06	8.24±9.01	47.66±31.08

2.2. Floristic data

The plant species were surveyed in the 20 islands based on relevés which were distributed randomly. The relevé size was about 10 × 10 m. Plants inside the border of the relevé were counted in. Furthermore, plants rooted outside the border but with branches extending over the sides of the relevé were also included in the sample. Relevés were quite far from each other and covered the entire site. The number of relevés was depending on island area.

In each relevé, presence/absence of all vascular plant species was recorded. Introduced species that were naturalized on the islands were included in the survey. The nomenclature and identification of plants followed Chaudhary (2000) and Collenette (1999).

2.3. Environmental data

Three soil cores per relevé were randomly collected at profiles 0-30 cm and pooled together to form one composite sample. These samples were brought to the laboratory immediately after collection, air dried, thoroughly mixed, passed through 2 mm sieve and packed in polyethylene bags for further physical and chemical analysis. Soil texture (the proportions of sand, silt and clay) were determined by the hydrometer method where by the percentage of sand, silt and clay were calculated. Soil–water extracts (1:5) were prepared for the estimation of electrical conductivity (EC) and soil reaction (pH) using YSI conductivity meter (model 35) and a digital pH meter (model 5995). Organic matter and the total $CaCO_3$ percentages were also estimated. Meanwhile, sodium, potassium and calcium were estimated by flame photometry. Chloride, carbonate, bicarbonate were measured. The physical and chemical properties of the soil in the Archipelago islands are shown in Table 2 and 3, respectively.

2.4. Spatial variables

The latitude and longitude of each relevé were recorded in the field using GARMIN GPS map 276. The spatial variables were obtained using principal coordinates of neighbor matrices (PCNM). PCNM is commonly technique applied in community ecology to detect the spatial patterns in ecological data for a large scale studies (Borcard and Legendre, 2002). Thus, the produced PCNM axes (eigenvectors) are spatial variables that capture, at broad and fine scales the spatial pattern of the site (Diniz-Filho and Bini, 2005; Borcard and Legendre, 2002). Moran's I criteria (Moran, 1950) were applied to determine the spatial autocorrelation and to select the positive PCNM vectors.

2.5. Statistical analysis

The plant richness was expressed as the total number of species at each relevé. Firstly, environmental variables were subjected to the forward selection procedures based on two stopping criteria: 1) 0.05 significance level, and 2) adjusted-R^2 (adj-R^2) of the final model (Blanchet et al., 2008). At this stage, the key environmental variables structuring plant species richness in Farasan Archipelago were determined. Similar forward selection procedures were applied on the produced PCNM (only the positive and significant based on Moran criteria). The correlation between selected PCNM vectors and the selected environmental variables was conducted using Pearson correlation (at $P<0.05$). The multiple regression technique was employed to determine the effect of spatial variables (PCNM vectors) to species richness of plants in Farasan Archipelago. The relative importance of environmental and spatial variables (PCNM vectors) on plant species richness was examined using variation partitioning techniques. The total variation in the species richness in Farasan Archipelago was partitioned into: a) pure environmental variation (variation explained solely 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 elaborated earlier by Legendre and Legendre (1998). All statistical analyses were carried out using R 2.15.1 program and packages; *spdep*, *ade4*, *AEM*, *PCNM*, *vegan* 1.13-1 and *packfor*.

Table 3: Chemical properties (mean±SD) of the soil in islands of the Farasan Archipelago.

Island	Calcium (ppm)	Magnesium (ppm)	Sodium (ppm)	Potassium (ppm)	Carbonate (ppm)	Bicarbonate (ppm)	Chloride (ppm)	Calcium Carbonate (%)	Organic Matter (%)
Farsan Alkabr	1965.17±122.89	2079.83±575.39	620.17±88.62	26.17±5.27	4.28±1.29	244.72±33.45	513.50±438.85	74.35±13.35	0.90±0.30
Sajid	849.125±479.72	405.625±241.91	285.5±259.56	41±41.70	7.7±12.32	194.9375±32.43	268±105.36	52.075±33.23	0.975±0.33
Zufaf	1399.21±532.12	2272.79±566.76	314.14±145.17	21.14±9.69	17.89±16.72	160.74±26.92	276.93±205.93	45.92±14.41	0.74±0.36
Dumsuk	236.00±490.05	331.46±859.31	95.06±74.59	21.06±13.43	43.02±10.67	178.86±40.65	224.06±183.91	103.08±67.69	0.58±0.52
Manzar Abu Shawk	54.70±49.09	61.34±16.23	74.63±22.44	25.63±12.81	46.35±7.79	164.55±53.26	187.00±52.14	120.16±67.77	0.68±0.45
Dushak	1065.28±276.32	98.67±23.07	270.33±138.78	9.33±3.18	5.59±2.39	297.53±125.23	561.00±310.50	65.07±19.72	0.52±0.48
Kayyirah	1177.92±940.31	926.05±939.64	195.30±152.07	29.30±33.79	4.49±2.97	291.31±51.58	315.80±258.51	84.90±8.20	0.72±0.63
Manzar Sajid	3826.12±254.09	1704.41±104.89	84.12±40.52	5.47±3.84	169.00±66.09	4381.55±570.11	347.53±216.36	14.47±30.58	0.25±0.25
Ad Dissan	67.96±0.00	1095.27±150.98	294.00±0.00	3.63±0.74	157.75±20.94	788.90±330.42	140.00±12.93	0.79±0.56	0.36±0.25
Shura	85.74±3.59	137.29±11.95	12.43±1.62	3.00±0.00	152.50±0.00	354.50±0.00	173.00±0.00	0.29±0.16	0.26±0.15
Abu Shawk Umm Hawk	149.33±203.72	289.60±475.58	13.90±3.11	3.00±0.00	149.45±9.64	549.45±616.49	173.20±0.63	0.70±0.21	0.27±0.27
Abkar	3826.12±2983.77	1704.41±1630.59	84.12±40.52	5.47±3.84	169.00±66.09	4381.55±3767.29	347.53±216.36	14.47±30.58	0.25±0.25
Aslubah	2187.00±0.00	7558.88±1408.11	294.00±0.00	3.63±0.74	157.75±20.94	13713.00±5179.10	140.00±12.93	0.79±0.56	0.36±0.25
Sulayn	85.74±3.59	137.29±11.95	12.43±1.62	3.00±0.00	152.50±0.00	354.50±0.00	173.00±0.00	0.29±0.16	0.26±0.15
South Reefs	149.33±203.72	289.60±475.58	13.90±3.11	3.00±0.00	149.45±9.64	549.45±616.49	173.20±0.63	0.70±0.21	0.27±0.27
At Targ	348.36±70.01	690.73±53.63	16.27±2.69	0.00±0.00	167.80±0.00	1375.18±96.84	507.36±102.85	0.12±0.14	0.29±0.29
Al Hindiyah	243.40±96.53	450.00±68.53	20.40±4.98	6.73±0.80	191.15±44.16	616.09±54.28	808.67±46.29	0.19±0.15	0.38±0.35
Safrah	145.00±0.00	398.00±0.00	119.00±21.05	22.00±0.00	220.08±129.95	709.00±0.00	229.40±30.09	1.50±0.32	0.26±0.27
Rayyak Al Kabir	1414.86±122.53	4169.00±481.34	166.57±22.11	5.57±2.51	228.80±0.00	7976.00±0.00	183.00±0.00	1.00±0.00	0.64±0.92
North Reefs	721.40±725.26	1405.10±1391.58	90.65±116.50	14.07±24.68	154.76±88.37	1740.07±2197.43	294.93±192.83	8.43±18.67	0.36±0.34

3. Results

3.1. Diversity of plants in Farasan Archipelago

A total of 191 vascular species were encountered in the study area belonging to 129 genera and 53 families (Appendix 1). Dicotyledons were the most dominant comprised 79.8% of the total (153 species in 45 families), while the monocotyledons were represented by 38 species and 8 families.

3.2. Spatial patterns of plant species richness in Farasan Archipelago

The PCNM analysis yielded 9 spatial variables (vectors) but forward selection, based on two stopping criteria, retained only two spatial variables (PCNM 1 (adj-R^2=0.052, F=3.326, *P*=0.001) and PCNM 2 (adj-R^2=0.044, F=3.017, *P*=0.001). The selected PCNM vectors were arranged according to their importance and showed the association with plant species richness. The regression model of species richness versus with retained spatial variables was significant (F= 3.074, *P*=0.005).

Although 13 environmental parameters initially examined, the forward selection retained only six variables (F= 3.056, $P<0.05$) which are controlling the plant species richness in Farasan Archipelago (Table 4). These selected parameters, arranged according to their importance were; altitude, electrical conductivity (EC), calcium (Ca), sodium (Na), calcium carbonate (CaCO3) and organic matter (OM). Thus, they are the key factors controlling the species richness in Farasan Archipelago were the altitude (Adj-R^2=0.122, F=10.12, *P*=0.001) followed by EC (Adj-R^2=0.024, F=3.22, *P*=0.012) and calcium (Adj-R^2=0.021, F=2.94, *P*=0.014). However, other selected factors including sodium, carbonate and organic matter showed weak yet significant effect on plant species richness in Farasan Archipelago (Table 4).

As shown in Table 5, most of the selected environmental parameters presented significant correlation coefficients (Pearson correlation test at $P<0.05$) with the produced spatial variables (PCNM vectors). The PCNM 1 represented the broad-scale variation and was positively correlated with altitude (r=0.544, $P<0.01$), Ca (r=0.264, $P<0.05$), Na (r=0.203, $P<0.05$) and OM (r=0.425, $P<0.01$). However, PCNM 1 was negatively correlated with EC (r=-0.366, $P<0.01$). While PCNM 2 represented intermediate- to small- scale variation and was correlated positively with altitude (r=0.425, $P<0.01$), Na (r=0.420, $P<0.01$), $CaCO_3$ (r=0.255, $P<0.05$) and OM (r=0.309, $P<0.05$) .

The variation partitioning technique on the two components; spatial and environment factors was applied to explain the variation in the plant species richness of Farasan Archipelago (Table 6). Fraction “a” is the amount of variation solely explained by the environmental variables. Meanwhile, fraction “b” is the amount of variation in species richness explained merely by the spatial variables (PCNM vectors). The shared fraction between “a” and “b” is “c” which explained the variation in species richness by the spatially-structured environmental variables (Table 6). In this study, the highest amount of variation in plant species richness was explained by pure environmental variables and accounted for 26.3% (F=5.89, $P<0.001$). However, the variation explained exclusively by spatial variables was as low as 4.2% (F=6.36, $P<0.001$). Interestingly, the shared fraction “c” explained 5.6% of the total variation in species richness in Farasan Archipelago (Table 6). The unexplained variance in the species richness in Farasan Archipelago was 63.9%.

Table 4: Forward selection results of environmental parameters with plant species richness in Farasan Archipelago.

Parameter	R^2	Cumulative R^2	Adj-R^2	F-value	Significance
Altitude	0.132	0.132	0.122	10.12	0.001**
Electrical Conductivity (EC)	0.058	0.190	0.024	3.22	0.012*
Calcium	0.041	0.231	0.021	2.94	0.014*
Sodium	0.033	0.264	0.018	2.62	0.020*
Calcium Carbonate	0.026	0.29	0.014	2.29	0.022**
Organic Matter	0.019	0.309	0.011	1.99	0.034*

*$P<0.05$; **$P<0.01$

Table 5: Correlation coefficients (Pearson) between selected spatial filters (PCNM vectors 1 and 2) and retained environmental parameters. Both PCNM vectors and environmental parameters are arranged according to their importance in the forward selection procedures.

Parameter	**PCNM 1**	**PCNM 2**
Altitude	**0.544****	**0.425****
Electrical Conductivity (EC)	**-0.366***	0.085
Calcium	**0.246***	0.131
Sodium	**0.203***	**0.420****
Calcium Carbonate	0.153	**0.255***
Organic Matter	**0.425****	**0.309***

*$P<0.05$; **$P<0.01$

Table 6: Partitioning of the variation in plant diversity in Farasan Archipelago. The amount of unexplained variance is 63.9 % (permutation=999).

	Variance explained %	F-value	Significance
a	26.3	5.89	*P*<0.001
b	4.2	6.36	*P*<0.001
c	5.6	nd	nd
Total explained variation (a+b+c)	36.1	4.91	*P*<0.001

a=pure environmental parameters, **b**= pure spatial variables, **c**=shared fraction of variation between spatial and environmental variables, **nd**= not detected.

4. Discussion

4.1. Spatial and environmental constraints

In the present study, islands of Farasan Archipelago supported high diversity of plants as 191 species were reported. Unfortunately, there are few studies which dedicated to examine the relationships between environmental variables and plant diversity in this region. In our previous report (Mutairi et al., 2012), we found that plant diversity varied among the different habitats in Farasan Archipelago with pronounced effects of environmental conditions. This study can be considered as the first report investigating the underlying effects of both spatial and environmental factors on the plant diversity in these islands.

Basically, detangling the spatial and environmental drivers of biodiversity is of growing interest in both temperate and tropical ecosystems. For example, Jones et al. (2008) studied the variation in plant community composition in relation to environmental and spatial variables in Costa Rican tropical rain forest pteridophytes. Lan et al. (2011) investigated the spatial patterns in the distributions of the 13 dominant tree species in a tropical rain-forest plot in China in relation to topographic factors. They found that topographic factors including mean elevation, convexity, slope and aspect explained the highest fraction of variation in the species distribution.

It was found that only two PCNM vectors were selected after the forward selection procedures. It indicates fine-scales of the spatial variation in Farasan Archipelago. Although a total of 13 environmental variables predicted to influence the plant diversity in Farasan Archipleago, the forward selection retained only 6 parameters; altitude, electrical conductivity (EC), calcium (Ca), sodium (Na), calcium carbonate ($CaCO_3$) and organic matter (OM). The altitude showed to be the key factor controlling the plant species richness. Similarly, Bartha et al. (1995) and Karst et al. (2005) and found that topographic variables are important factors shaping the plant communities at large scales. Similar findings were also reported from a tropical rain-forest plot in China by Lan et al. (2011). Several researchers considered the altitudinal variability is the key factor structuring the plant communities (for example see Zhao et al., 2005). The islands of Farasan Archipelago showed obvious variation in the altitude creating a variety of habitats which would support high species diversity (AL Mutairi et al., 2011). It is accepted fact that increase of habitats number often results in higher diversity of plant species (Mutairi, 2012).

In the present study, only 6 environmental variables were retained after forward selection procedures and explained 26.3 % of the total variance in the plant diversity in Farasan Archipelago. This is in agreement with findings of Jones et al. (2008) who reported that environmental variables explained 25.8% of the variation in tropical floristic diversity. Lan et al. (2011) found that topographic factors explained the highest amount of variation (26%) in the dominant tree species diversity. Interestingly, Li et al. (2011) reported that environmental factors were weak (4.4%) to explain variation in the diversity of alpine meadow communities.

The current findings revealed that soil properties had a substantial influence on the plant species richness. In their study on floristic diversity in tropical pteridophytes forest, Jones et al. (2008) studied the influence of 20 environmental variables representing the soil chemistry, soil type and tropography and found that the soil chemistry parameters were the most important descriptors of floristic diversity. In details, soil pH, soil concentrations of Ca, Mg, C and N, and slope angle and relative topographic position showed to be the factors controlling the variation in floristic variation (Demerdashi, 1996; Khedr et al., 2000). This is also in agreement with earlier findings of Zhang et al. (2010) who found that more than 40 % of variation in the plant diversity was explained by soil properties. Typically, soil concentrations of Ca and Mg contents have been reported in the literature as key factors explaining the variation in plant diversity at different spatial scales (Tuomisto et al. 2003a; Costa et al. 2005; Poulsen et al. 2006). Wang et al. (2007) reported that the soil organic matter, nitrogen and phosphorus were the most important factors controlling the diversity of plants in the alpine meadows. Although Karst et al. (2005) found that soil pH as a major factor would explain variation in the floristic diversity; it was difficult to detect this study. Yet, this is not the general pattern as other studies also found no profound effect of pH on floristic diversity (e.g. Jones et al., 2008; Wang et al., 2007; Li et al., 2011).

The results of variation partitioning in this study revealed that the explained variance by both spatial variables and key environmental conditions was 36.1%. This amount of variation was in agreement with study of Jones et al. (2008) as the explained variance in the model of spatial and environmental variables was 32%. Similarly, Lan et al. (2011) reported 36% of variance explained by both spatial and environmental factors in dominant tree species of a tropical seasonal rain forest in China. A slightly higher amount of explained variance of the spatial-enviromental model on the plant diversity was reported in the alpine meadow communities (Li et al., 2011).

On the other hand, less variation in species richness was explained by spatial variables (PCNM vectors) as the amount of variation explained in this study was as low as 4.2 %. This amount of variation is somewhat similar to what has been reported from a tropical Chinese forest of 5% (Lan et al., 2011). Yet, Jones et al. (2008) reported higher percentage of explained variation by spatial variables (15.9%). In similar context, Li et al. (2011) found that alpine meadow communities were highly structured by spatial factors as the amount of variation explained was as high as 18%. Several studies found that spatial variables explained more variation compared to environment variables (see Lan et al., 2011), but these studies did not involve soil chemistry profile (Borcard et al., 1992; Svenning et al., 2004) or their study site was disturbed landscapes (Dalle et al., 2002). Meanwhile, the results of Svenning and Skov (2005) gave an exception even their data were derived from coarse-scale maps rather than actual soil sampling.

This discrepancy in the amount of variation explained by spatial factors may reflect the differences in the dispersal, biotic interactions as they have the ability to create spatial patterns in the plant diversity (Lindo and Winchester, 2009; Lan et al., 2011).

Although the fraction of variation explained exclusively by spatial variables has often been principally considered as a dispersal effects and limitations (e.g. Gilbert and Lechowicz 2004; Cottenie 2005; Karst et al. 2005), it was not applicable in our study. Similar conclusion was drawn by Jones et al. (2008). It was suggested that probably due to spatially-structured environmental variables which is the ‘shared fraction’ and explained 5.6% of the total variation in plant richness in Farasan Archipelago.

In conclusion, it was found that, at large scale, the plant diversity is mainly controlled by altitude and soil chemistry. The spatial variables had weak capability to regulate the floristic diversity in Farasan Archipelago. This may due to less variability in geographical location and distance among the investigated islands. Furthermore, absence of spatial patterns in diversity may reflect the alterations in the dispersal ability and biotic interactions of plant species. Further comparative studies involving larger scale of the islands and mainland are needed to explore the actual effect of spatial variation on floristic diversity in the Arabian Peninsula. Thus, it will help to draw a general conclusion about the spatial patterns of plant composition in this region.

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