

Influences of Island Characteristics on Plant Community Structure of Farasan Archipelago, Saudi Arabia: Island Biogeography and Nested Pattern

Khalid Al Mutairi¹, Mashhor Mansor¹, Magdy El-Bana^{2,3,*},
Saud L. Al-Rowaily² and Asyraf Mansor¹

¹*School of Biological Sciences, Universiti Sains Malaysia, Penang,*

²*Department of Plant Production, College of Agricultural & Food Sciences,
King Saud University, Riyadh,*

³*Department of Biological Sciences, Faculty of Education at El-Arish,
Suez Canal University, El-Arish,*

¹*Malaysia*

²*Saudi Arabia*

³*Egypt*

1. Introduction

Biogeographers have long been fascinated by the factors influencing numbers of species on islands. The increase in species number with area is one of the oldest known ecological patterns, first documented by Watson and deCandolle in the mid-nineteenth century (Rosenzweig, 1995). Island biogeographers lacked a cohesive body of theory, until island biogeography equilibrium theory (MacArthur & Wilson, 1967) attempted to explain variation in species richness between islands of different area and isolation. The theory predicts that species richness decreases with decreasing island area and increasing isolation as these two variables influence immigration and extinction (Rosenzweig, 1995). Numerous studies have examined and argued the stability of these relationships on different island groups and for different taxonomic categories.

However, the equilibrium theory should be expanded to include other aspects of insularity other than area and isolation in order to fully understand the mechanisms of island biogeography (Whittaker, 2000). In addition to area, distance, and elevation, numerous other variables have been examined as potential predictors of insular species richness, such as habitat diversity (Rafe et al., 1985; Kohn & Walsh, 1994), rainfall (Heatwole, 1991), soil type (Johnson & Simberloff, 1974), energy (Wright, 1983) and disturbance (El-Bana, 2009).

Although classical island biogeographical theory has been questioned (Gilbert, 1980; Whittaker, 2000) and a call for a new paradigm of island biogeography has been issued

* Corresponding Author

(Lomolino, 2000a), area and distance still play primary roles in alternative theories (Heaney, 2000; Lomolino, 2000b). In general island area, and to a lesser degree isolation, can hardly be disputed as important determinants of insular species richness.

Area might influence species richness directly in two ways: larger islands present larger targets for dispersing individuals and they generally support larger populations. Thus, island area may influence species richness by its effect on colonization rates or on the outcomes of several mechanisms that determine vulnerability to extinction (MacArthur & Wilson, 1967). Area might also influence species richness indirectly via its correlation with other factors that affect diversity directly. Among the most plausible of such potentially confounding variables is habitat diversity, which is often presumed to increase in direct relation to island area (Kohn & Walsh, 1994). The negative correlation between island isolation (distance from either the mainland and/or the large islands) and species richness, although not as strong, is also well documented. Since species differ in the maximum distance over which they can disperse, islands that are near the mainland will potentially receive propagules from more species than will distant islands (Rosenzweig, 1995).

During the last decade, ecologists and biogeographers have devoted increasing attention to the pattern of nested species assemblages in insular habitats. Nestedness occurs where assemblages in depauperate sites are comprised of species that constitute subsets of species that occur in successively richer sites. In nested biotas, common species tend to occur in all sites while rare species tend to occur only in the richest sites. This pattern indicates a high level of non-random organization of assemblages and has important implications for conservation (Patterson & Atmar, 1986; Patterson, 1990; Patterson & Brown 1991; Fleishman et al., 2007). Nestedness has been interpreted as a measure of biogeographic order in the distribution of species (Atmar & Patterson, 1993). This pattern indicates a high level of non-random organization of assemblages and has important implications for maintaining or maximizing species diversity in ecosystems threatened by anthropogenic effects (Maron et al., 2004; Fleishman et al., 2007).

Diverse biotic and abiotic processes are believed to generate nested distributions, including selective extinction (Atmar & Patterson 1993; Wright et al., 1998), differential colonization (Kadmon, 1995), nested habitats (Wright et al., 1998; Honnay et al., 1999), and differential environmental tolerances among species (Fleishman et al., 2007). Differences in environmental tolerances among species may interact with nested habitats to produce nestedness. According to this hypothesis, species-rich sites are those that contain the greatest habitat heterogeneity and/or have environmental conditions tolerable to the largest number of species (Cook, 1995; Honnay et al., 1999). Differential nestedness among groups of species (e.g., taxonomic groups or guilds) that vary in sensitivity to a particular environmental variable may determine how that variable contributes to the general pattern of species nestedness.

Nestedness has important implications for conservation, when species assemblages on an archipelago or habitat fragments show nestedness, it is more efficient to protect large islands or fragments than smaller islands or fragments (Patterson, 1987). Others have suggested that the management of colonization processes might also be important for the long-term maintenance of diversity (Lomolino, 1994; Cook, 1995).

On the arid archipelagoes, environmental features such as salinity, aridity, habitat diversity, elevation and human disturbance may interact with life history characteristics of plant species in determining local extinctions or colonization. The islands and archipelagos of Red Sea attracted less attention about their pattern of vegetation distribution and dynamics, compared to the Mediterranean Sea (Panitsa & Tzanoudakis, 1998, 2001; Panitsa et al., 2006; Médail & Vidal, 1998; Khedr & Lovett-Doust, 2000; Bergmeier & Dimopoulos, 2003; El-Bana, 2009).

Here we explore the patterns exhibited by plant species richness and nestedness on 20 islands of the Farasan archipelago in the Red Sea (Saudi Arabia) to identify possible effects of island size, elevation, number of habitats and distance from species pool. We also examine the best fit model for the total species richness, as well as the special patterns exhibited by certain important taxonomic and ecological subgroups of plant species.

2. Materials and methods

2.1 Study area

The Farasan archipelago consists of more than 36 vegetated islands and extends between longitudes 41° 20' and 42° 25' E and latitudes 16° 20' and 17° 10' N along the southern Red Sea (Figure 1). The islands, with elevation in the order of tens of metres, range in size from very small, a few m², to the very large island of Farasan Alkabir, about 319.5 km². All islands are an uplifted coral reef that formed during the Pleistocene on a foundation of salt diapirs (i.e. domes of salt rocks from the Miocene; Dabbagh et al., 1984). There is some variation in geomorphology among the islands despite their similar origin. 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 such as Zifaf and Sasu islands are hilly. Large boulders, gravels and small stones are found in the steep runnels of these islands.

The islands are an important habitats for both local and migrating birds. In addition, the islands home for the threatened and endemic Arabian gazelle and other mammals (Masseti, 2010). Most of the islands are subjected to heavy human activities such as overgrazing and wood cutting. Furthermore, the exotic and invasive tree *Prosopis juliflora* was introduced for greening landscape along roadsides in Farasan Alkabir island. It has escaped the cultivated sites and invaded the rich natural habitats such as Wadi Mattar.

Unfortunately, there are no climatic records available for Farasan Islands. The climate at Jizan city (42 km from Farasan 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 is the high year-round humidity, mitigated by winds. The mean annual rainfall is about 70 mm at Jizan. As in other arid regions, the condensation of dew is very important for the growth of vegetation on these islands (Osborne, 2000).

2.2 Data collection

Vegetation surveys were commenced in 2009 and 2010 during the rainy season from January to April. Random sampling was used in selecting 20 islands to represent an array of sizes, which ranged in area from 0.081 km² to 319.5 km² (Figure 1). Area (km²), distance (km) to the

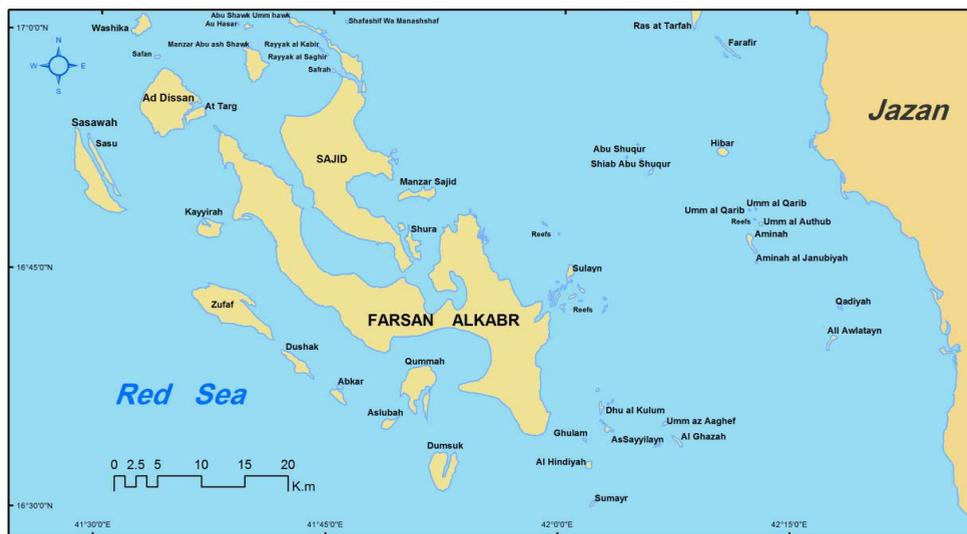


Fig. 1. Farasan archipelago showing the location of the 20 studied islands (Abkar, Abu Shawk Umm Hawk, Ad Dissan, Al Hindiyah, Aslubah, At Targ, Dumsuk, Dushak, Farasan Alkabr, Kayyirah, Manzar Abu Shawk, Manzar Sajid, North Reefs, Rayyak Al Kabir, Safrah, Sajid, Shura, South Reefs, Sulayn and Zufaf).

nearest large island, and elevation (m) of each surveyed island were calculated by the program (Arc*GIS, 2008 USA). Two hundred and ten stands were selected to represent the main habitats on each island. Seven main habitat types were recognized: wet saline marshes, dry saline marshes, sand plains, mobile sand dunes, wadi channels, and coral rocky crevices and runnels. The stand size was about 10 m × 10 m in all habitats, except for the salt marshes and the rocky crevices and runnels where vegetation appeared as strips; the shape was modified to 5 m × 20 m. In each stand, shoot presence/absence of all vascular plant species was recorded. The position of each sampled stand was georeferenced using GARMIN GPS map 276.

All plant species were identified in each island following Chaudhary (1989, 2000); Collenette (1999). Plant species were categorized in terms of their life-forms (therophytes, hemicryptophytes, geophytes, chamaephytes and phanerophytes), salt tolerance (halophytes and glycophytes) and succulence (succulents and non-succulents). Life-forms of the plants were determined according to Raunkiaer classification (Raunkiaer, 1934). This classification is of special importance for the vegetation in arid regions. These categories reflect adaptation and tolerance of vegetation to the main environmental factors such as drought and salinity. Furthermore, this classification was used as the processes and factors that underlie species richness in these groups differ, resulting in different richness patterns (Khedr & Lovett- Doust, 2000; Panitsa et al., 2006; El-Bana, 2009).

2.3 Statistical analyses

To identify factors that were important in determining the distribution of plant species and their ecological subgroups, simple linear regression was performed on the species/ecological group richness and biogeographical variables to characterize the functional relationships

between the variables, as well as to generate predictive values from empirically fitted regression models. Stepwise multiple regression analysis also was used to identify the best predictor of total species richness and the partitions of the data set of ecological subgroups, using area, elevation, shortest distance from the nearest large island and number of habitats as predictor variables. It is not always clear which measure of geographical isolation to use, i.e. distance from the mainland, the nearest large island, or just the nearest island, and usually a different measure might be necessary for different islands (Turchi et al., 1995; Sfenthourakis, 1996; Morand, 2000; Brose, 2003). In the present case, we chose distance from the nearest large island (Farasan Alkabir) because this island is the most likely candidate for serving as species pools for the other islands examined here. The regressions were run using both logarithmic and arithmetic values for all variables and the best functions according to the behaviour of residuals and the total variance explained (R^2) were chosen. All regressions and the estimations of parameters were carried out with SPSS v.16. We calculated Cole and Mao- Tau sample-based rarefaction curves (Colwell et al., 2004) using EstimateS software (Colwell, 2005, version 7.5).

2.4 Nested analyses

The data was prepared by constructing presence/absence matrices (1= present, 0 = absent) where columns and rows represented species and islands, respectively. The islands (rows) were rank ordered in relation to decreasing number of species and the species (columns) were rank ordered in relation to decreasing number of sites occupied. We then conducted nestedness analyses at two different spatial scales (entire species richness) and the ecological subgroup scales. To determine nestedness of assemblages we used the Nested Temperature Calculator computer program (Atmar & Patterson, 1995). This program calculates a temperature value (T) for the matrix ranging from 0 to 100, based on its presence/absence structure. A temperature of 0, indicates maximum order (maximum nestedness) and 100, indicates disorder (complete lack of nestedness) (Atmar & Patterson, 1993). To determine the significance of T (observed temperature) it is compared with the distribution of simulated temperatures produced by randomization of the matrix in Monte Carlo simulations (500 iterations). This method was used because of its statistical properties and because it can be directly compared among different taxonomic and ecological groups (Wright et al., 1998).

The effects of island area, number of habitats, isolation, and elevation on the degree of nestedness were evaluated by correlating the ranking order of islands in the observed matrix (arranged to maximize nestedness, Atmar & Patterson, 1995) with the order of islands after re-arranging the matrix in relation to the aforementioned factors using Spearman rank correlation. A significant relationship indicates that species are packed in a predictable order owing to the influence of a given factor (Atmar & Patterson, 1995). This procedure has proven useful for indicating possible mechanisms involved in nested structure (Atmar & Patterson, 1995; Kadmon, 1995; Honnay et al., 1999).

3. Results

3.1 Species richness

We detected a total of 191 species among 129 genera and 53 families on the surveyed islands. Most species occurred on relatively few islands (Figure 2a). About 95.5% (183 of 191) of the species occurred on ≤ 10 islands. Likewise, most islands contained relatively few

species (Figure 2b). About 80% (16 of 20) of the islands contained less than 60 species. Rarefaction curves of Cole and Mao-Tau for species richness (Figure 3) reached the asymptote before 18 islands, indicating that the sampling effort was sufficient to fully capture the richness and diversity of plant species assemblages.

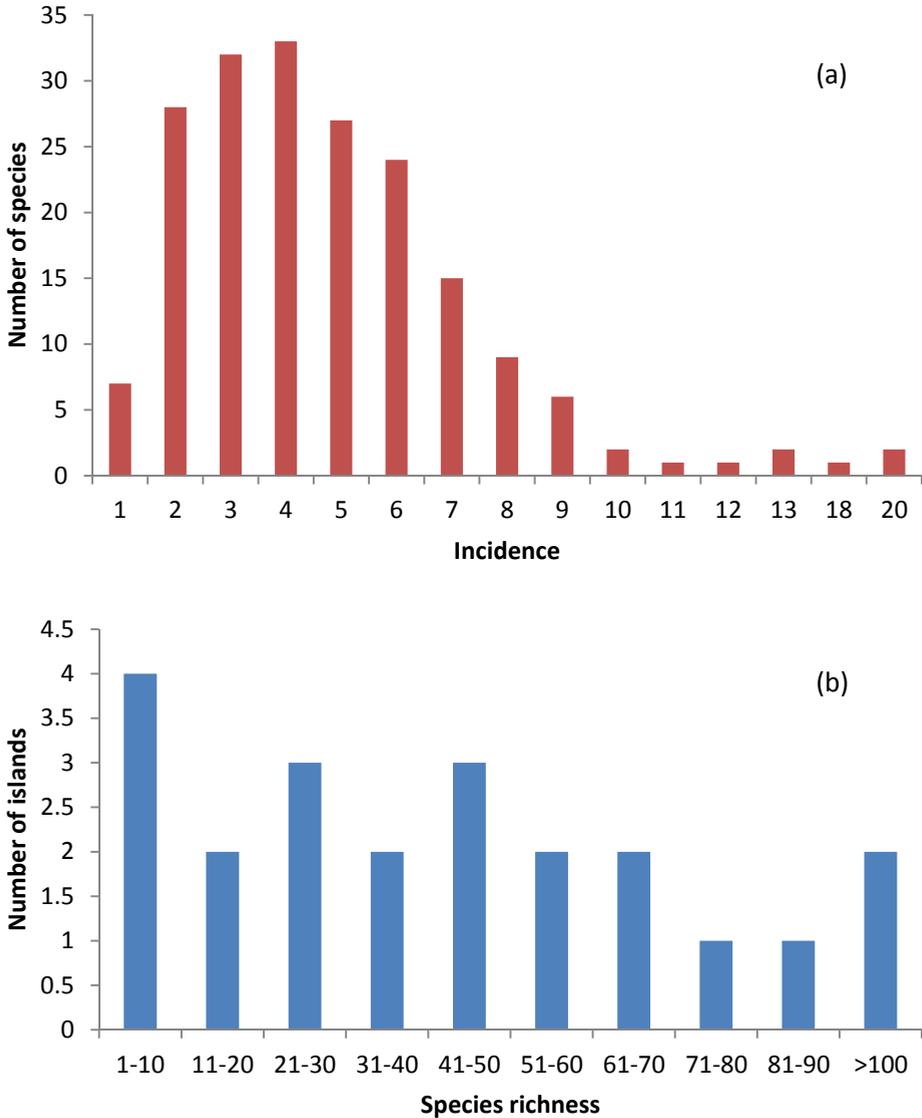


Fig. 2. Frequency distributions of incidence (i.e., the number of islands on which a species occurred) (a) and species richness (i.e. the number of species on an island) (b) for the total flora of the Farasan archipelago.

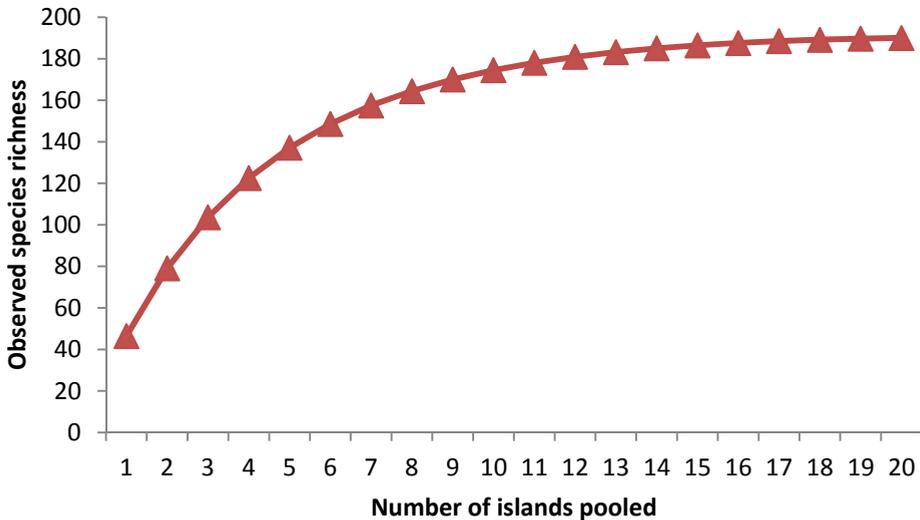


Fig. 3. Relationship between the number of islands pooled and the observed species richness of Farasan archipelago by rarefaction analysis. The asymptotic shape of the curve indicates that analysis of 18 islands provided sufficient sampling to fully capture the richness and diversity of plant species assemblages.

There was a significant positive relationship between island area and total plant species (Figure 4) with $r^2 = 0.732$ and $Z = 0.491$, $P < 0.0001$. Moreover, when the flora of each island was classified into different ecological groups and $\log S/\log A$ was constructed, it appeared that each group had significantly different regressions. There were positive relationships between island area and each of perennials ($r^2 = 0.735$ and $Z = 0.312$, $P < 0.0001$) and annuals ($r^2 = 0.691$ and $Z = 0.168$, $P < 0.0001$) (Figure 4). Similarly, island area showed positive relationships with halophytes ($r^2 = 0.426$ and $Z = 0.049$, $P < 0.041$) and glycophytes ($r^2 = 0.737$ and $Z = 0.439$, $P < 0.0001$) (Figure 5). For succulence ecological groups, island area related positively with succulents ($r^2 = 0.669$ and $Z = 0.056$, $P < 0.0001$) and non-succulents ($r^2 = 0.73$ and $Z = 0.434$, $P < 0.0001$) (Figure 5). For the different growth forms, island area showed positive relationships with shrubs ($r^2 = 0.673$ and $Z = 0.087$, $P < 0.0001$), herbs ($r^2 = 0.729$ and $Z = 0.189$, $P < 0.0001$), trees ($r^2 = 0.816$ and $Z = 0.055$, $P < 0.0001$) and grasses ($r^2 = 0.684$ and $Z = 0.069$, $P < 0.0001$) (Figure 6).

The number of habitats was related positively with the island area ($r^2 = 0.516$, $P < 0.001$) (Figure 7a). In addition, the total number of species had a positive relationship with the number of habitats ($r^2 = 0.847$, $P < 0.0001$) (Figure 7b), and elevation ($r^2 = 0.366$, $P < 0.003$, data not shown). However, the distance from the largest island (Farasan Alkabir) has no effect on the species richness ($r^2 = -0.061$, $P < 0.887$).

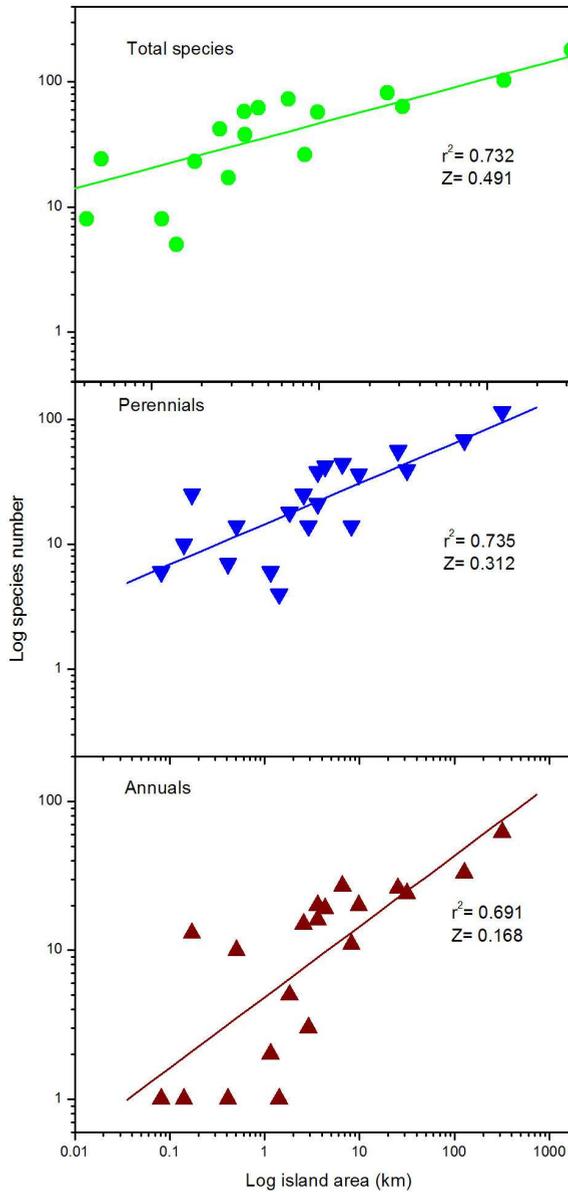


Fig. 4. Relationships of total species richness, number of perennials and annuals with island area of Farasan Archipelago

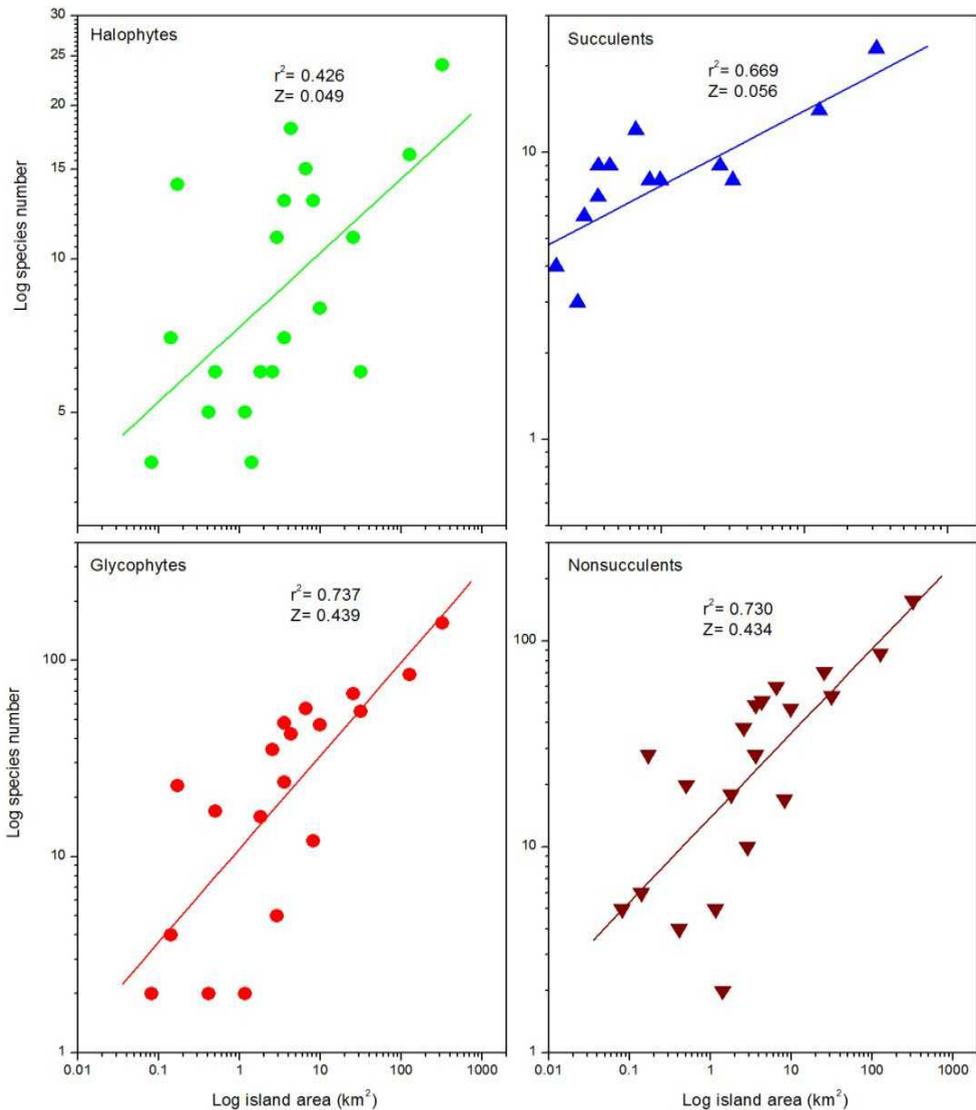


Fig. 5. Relationships of ecological groups (halophytes, glycophytes; succulents and nonsucculents) with island area of Farasan Archipelago.

According to the stepwise regressions (Table 1), both island area and number of habitats affect species richness. When the same analyses were applied separately for each ecological groups, elevation was also significant parameter entering the model for perennials and annuals. Area, number of habitats and elevation explained a high percentage (88.7%) of total variance for annuals, while they explained about 72.3% of variance for the perennials. On

the other hand, the number of habitats was not entering the model for shrubs, trees, non-succulents and halophytes (Table 1). Area and number of habitats entered the models of grasses, herbs, succulents, and glycophytes. Area and elevation were the only variables that entered the model for both trees and non-succulents, while area alone counted for shrubs (89.2%) and halophytes (76.2%). Distance from nearest large island (Farsan Alkabr) did not affect either the total species richness or any ecological groups.

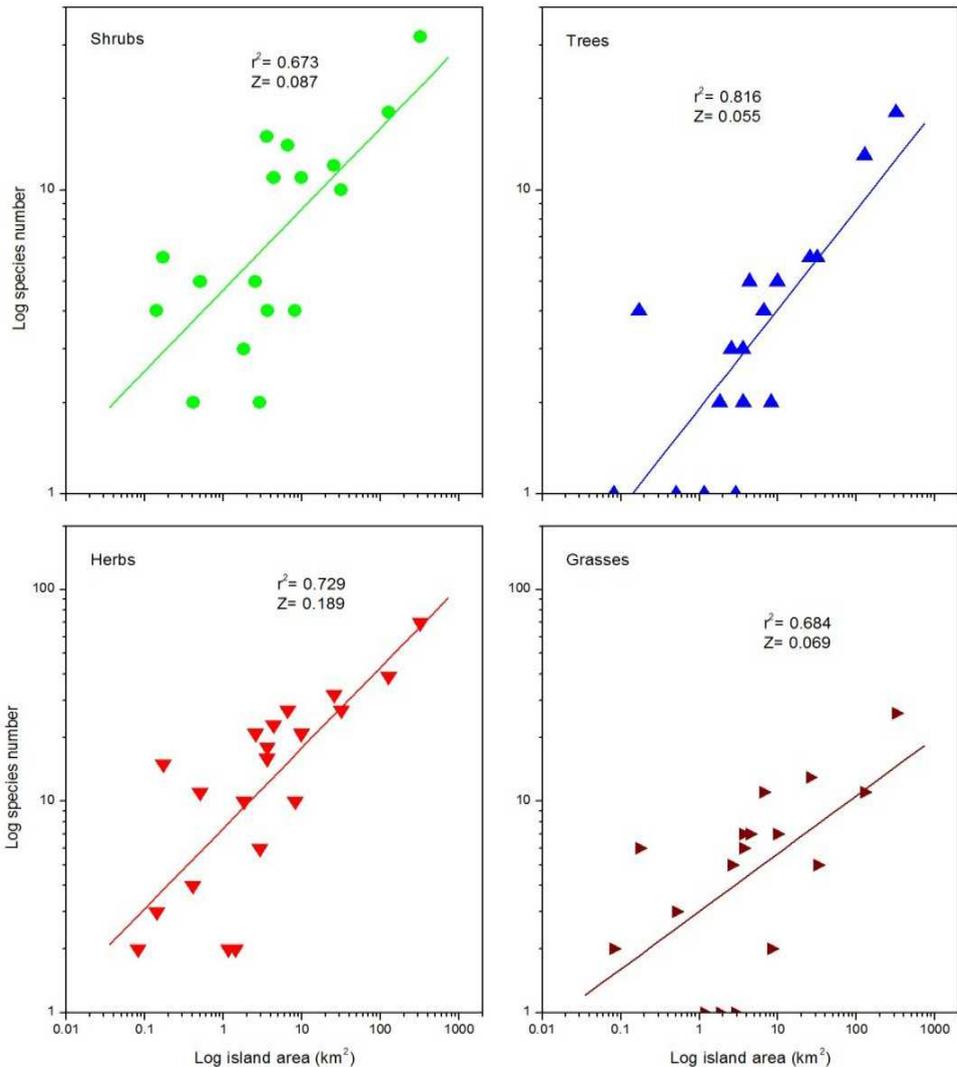


Fig. 6. Relationships of ecological groups (growth forms) with island area of Farsan Archipelago.

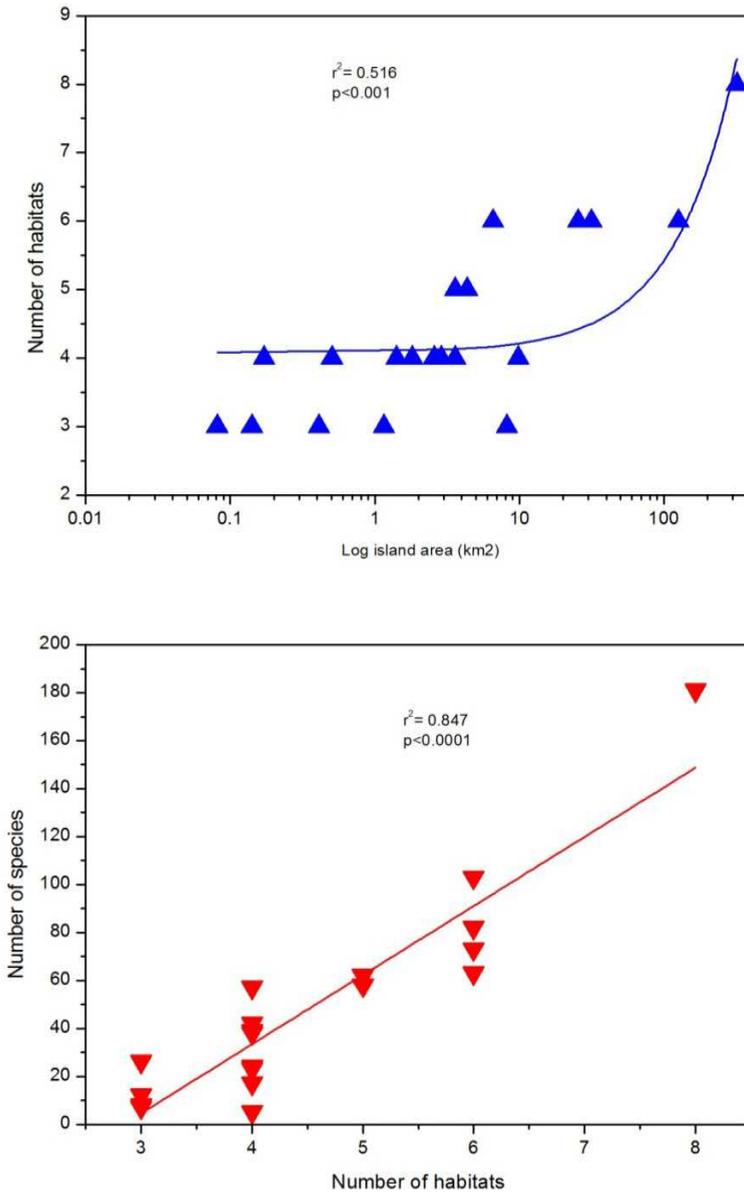


Fig. 7. Relationships of the number of habitats with island area (top) and with the total number of species (bottom) of Farasan Archipelago.

3.2 Nestedness pattern

The temperature nestedness calculator detected a high degree of nestedness for the entire flora as well as for each of the ecological subgroups (Table 2). The temperature of the maximally

packed matrix ($T_{\text{matrix}} = 12.87^{\circ}$) for the entire flora was significantly lower than the mean temperature of the random matrices generated by the Monte Carlo-derived null model ($T_{\text{random}} = 63.06^{\circ}$, $P < 0.0001$). Therefore, the plant communities were significantly nested.

Data set	Function	Adjusted R ²	P-value
All species	$S = 0.41 + 4.16 A + 6.55 H$	0.856	< 0.001
Life span			
Annuals	$S = 6.12 + 4.61A + 2.66 H + 3.52 E$	0.887	< 0.001
Perennials	$S = 7.71 + 8.39 A + 9.85 H + 1.32 E$	0.723	< 0.001
Growth form			
Grasses	$S = 3.67 + 5.05 A + 8.43 H$	0.849	< 0.003
Shrubs	$S = 4.58 + 3.19 A$	0.892	< 0.001
Herbs	$S = 2.45 + 2.31 H + 1.78 A$	0.715	< 0.001
Trees	$S = 4.28 + 2.35 A + 5.38 E$	0.921	< 0.000
Succulence			
Succulents	$S = 3.25 + 6.23 A + 2.12 H$	0.733	< 0.007
Non-succulents	$S = 6.22 + 14.12A + 1.45 E$	0.832	< 0.003
Salt tolerance			
Halophytes	$S = 3.59 + 1.16 A$	0.762	< 0.016
Glycophytes	$S = 7.64 + 4.93 A + 14.73H$	0.899	< 0.004

Table 1. Stepwise linear regressions of total species number and species number by ecological subgroup. Only variables that enter the model are shown, with the total variance explained and the statistical significance of the respective model. S abbreviates to species richness, A to island area, H to number of habitats and E to elevation.

When each ecological group was analyzed separately, the species distributions were significantly nested for all subgroups (Table 2). For the life span subgroups, the mean matrix temperatures for perennials and annuals were 13.36° and 12.69° that significantly different from the mean matrix temperatures of 62.64° and 58.92° generated randomly by Monte Carlo simulations, respectively (Table 2). The life-form distributions were significantly nested for all forms. The mean matrix temperatures were more strongly nested for therophytes, geophytes and chamaephytes with 11.14° , 13.35° and 13.63° compared to random temperatures of 58.44° , 59.87° and 58.92° , respectively ($P < 0.0001$ for all). The mean matrix temperatures of hemicryptophytes, and phanerophytes were 29.48° and 17.27° , respectively. While, their random temperatures recorded 55.48° and 45.18° , respectively. For the salt tolerance subgroups, glycophytes were more nested with a matrix temperature of 13.35° compared to the random temperature of 59.78° generated by Monte Carlo simulations. On the other hand, the matrix temperature of halophytes was 22.33° which significantly different from the random temperature of 61.43° .

The ordered accumulation of species was affected mainly by island area and number of habitats, and to a lesser degree by elevation (Spearman's rank correlation, Table 3). Island area and number of habitats were also correlated for the different ecological groups. This indicates such that species appeared to accumulate in orderly fashion with increasing area and number of habitats. However, isolation was correlated neither to the total species richness nor to the ecological groups.

Data set	Total number of species	Matrix temperature (°C)	Random temperature (°C)	P ($T < T_{\text{Observed}}$)
All species	190	12.87	63.06	<0.0001
Life span				
Perennials	123	13.36	62.64	<0.0001
Annuals	68	12.69	58.92	<0.0001
Life-forms				
Therophytes	56	11.14	58.44	<0.0001
Geophytes	19	13.35	59.87	<0.0001
Hemicryptophytes	27	29.48	55.48	<0.0001
Chamaephytes	50	13.63	58.92	<0.0001
Phanerophytes	21	17.27	45.18	<0.0001
Growth forms				
Trees	19	19.47	45.82	<0.0001
Shrubs	35	14.62	57.03	<0.0001
Grasses	29	15.48	54.07	<0.0001
Herbs	74	12.5	60.97	<0.0001
Succulence				
Succulents	25	16.33	58.77	<0.0001
Non-Succulents	166	12.14	61.78	<0.0001
Salt tolerance				
Halophytes	26	22.68	61.43	<0.0001
Glycophytes	165	13.35	59.78	<0.0001

Table 2. Results of the nestedness analyses as calculated by the nestedness temperature calculator for total plant species and the ecological subgroups.

4. Discussion

The equilibrium theory of island biogeography (MacArthur & Wilson, 1967) identifies island size and distance from the mainland as the two most important factors affecting species richness. In the present study, there was no effect of isolation from the largest island (Farasan Alkabir) on total species richness, or on richness of the ecological subgroups. However, all categories of plants increase in richness with island size. This shows that (a) Farasan islands adhere to the species-area relationship; and (b) this relationship exists across ecological groups despite differences in the processes and factors that govern diversity for these groups. It has been suggested that the value of the exponent Z should vary between 0.2 and 0.4 (MacArthur & Wilson, 1967; Rosenzweig, 1995). In the present study, the value of the exponent Z for the total species richness is larger than 0.4. However, this is in agreement with the reported values larger than 0.4 for the exponent Z in several other studies of plants on islands (Rydin & Borggård, 1988; Médail & Vidal, 1998; Panitsa et al., 2006; El-Bana, 2009). For example, the Z value of the log-log model for the Mediterranean arid islands is 0.56 (El-Bana, 2009). Rydin & Borggård (1988) recorded values varying between 0.36 and 0.56. The strong correlation of species richness with island area, number of habitats and elevation suggests that these quite steep slopes would not be due to the existence of a small island effect (Gentile & Argano, 2005).

Data set	Area	Number of habitats	Isolation	Elevation
All species	0.84**	0.65**	-0.28	0.49*
Life span				
Perennials	0.73**	0.58*	-0.19	0.53*
Annuals	0.92**	0.63**	-0.08	0.60**
Life-forms				
Therophytes	0.88**	0.71**	-0.06	0.57*
Geophytes	0.79**	0.63**	-0.22	0.47*
Hemicryptophytes	0.68**	0.53*	-0.3	0.38
Chamaephytes	0.63**	0.48	-0.04	0.35
Phanerophytes	0.93**	0.70**	-0.18	0.61*
Growth forms				
Trees	0.86**	0.61*	-0.02	0.49*
Shrubs	0.64**	0.55*	-0.22	0.22
Grasses	0.68**	0.47	-0.34	0.33
Herbs	0.71**	0.57*	-0.28	0.50*
Succulence				
Succulents	0.63**	0.39	-0.04	0.28
Non-Succulents	0.82**	0.72**	-0.31	0.52*
Salt tolerance				
Halophytes	0.54*	0.32	-0.23	0.31
Glycophytes	0.87**	0.67**	-0.12	0.55*

* and ** indicate the values are significant at < 0.05 and 0.001 , respectively.

Table 3. Spearman's rank correlations between the ranking order of islands in the observed matrix and the islands were ranked by area, number of habitats, isolation and elevation for the entire plant assemblage and their ecological groups.

In the present dataset the division of island flora into different ecological groups revealed that the slopes of the species area regressions are significantly different for each subgroup. For example, the slope of the $\log S/\log A$ regression of glycophytes growing on the interior rocky and sandy habitats was higher than that of halophytes growing on the shorelines of islands. Similarly, the slope regression of succulents of saline habitats is lower than those of non-succulents. A similar pattern has been recognized by other studies of island and islet floras (Rydin & Borgegård, 1988; Panitsa et al., 2006; El-Bana, 2009). Buckley (1985) divided the floras of small coastal islands on the basis of geographical origin. He found that the slope of $\log S/\log A$ curves was smallest for the salt flat group growing on the coastlines of the islands ($Z= 0.18$) and greatest for the sand ridge group ($Z= 0.6$) which only occurred at the center of each island. Panitsa et al. (2006) found a difference in Z value between halophytes, therophytes, leguminosae and graminiae. El-Bana (2009) reported that the slope of $\log A / \log S$ regression for the halophytes was smaller than that of psammophytes ($Z = 0.48$ vs. $Z= 0.64$).

Nestedness appears to be a common phenomenon of insular flora (Kadmon, 1995; Wright et al., 1998; Honnay et al., 1999; Koh et al., 2002). Similarly, the present study detected a high degree of nestedness for the entire flora and for each ecological group. Wright et al. (1998) suggested that four filters operate to screen species occurrence in insular habitats and produce nested biotas. Among these were area and distance effects, passive sampling and

habitat nestedness. The area filter appears to be the most important in Farasan archipelago. Species-specific resource requirements and differential minimal area requirements result in different patterns of incidence on the islands.

Area- and species-dependent extinction rates have been suggested to play important roles for species richness of oceanic islands (MacArthur & Wilson, 1967), species composition structure (Nekola & White, 1999) and nestedness in land-bridge islands and in habitat fragments (Patterson & Atmar, 1986; Cutler, 1991; Simberloff & Martin, 1991; Wright et al., 1998). Also, differential immigration may be important in producing nestedness (Simberloff & Martin, 1991; Kadmon & Pulliam, 1993). In the current study, there was a lack of several species on smaller but not on larger islands. The reason could be area-dependent extinction and/or differential immigration, and, if so, one or both of these mechanisms may be influencing nestedness in the Farasan archipelago. The largest and the smallest islands surveyed differ in area by 3 orders of magnitude. The large islands are over 319 km² and the small islands <0.5 km² in area. For the entire flora and each ecological group, the distance has no effect on either species richness or nested pattern. This may suggest that the distance is short enough for recurrent colonization (the rescue effect, Brown & Kodric-Brown, 1977), which may affect nestedness (Cook, 1995; Hecnar et al., 2002). Taking into account that most of the recorded species are wind- and bird dispersed species. This dispersal mode with the short distances from the mainland and large island can explain the absence of isolation in the nestedness pattern (Butaye et al., 2001). Therefore, rescue effects (Brown & Kodric-Brown, 1977) and/or intra-island dispersal (King, 1988) may commonly operate but would be masked considering the wide range of areas and low isolation of the islands in the current study.

Habitat nestedness could induce nested structure in species assemblages because certain habitat specialists will be restricted to less common habitats found only on large islands (Wright et al., 1998; Honnay et al., 1999). The habitats among the islands of Farasan are not distributed randomly as the vegetation is characterized by clear zonation from the shorelines to the centre of islands resulting from both chemical and hydrophysical processes (El-Demerdash, 1996). Smaller islands tend to be salty with halophytic vegetation, while larger islands often have a combination of shoreline types (salt marsh, sand formations) and their interiors are usually rocky and have shrubs and trees. Furthermore, the positive and highly significant relationship of island area with number of habitats and elevation indicates that habitats accumulate in an orderly fashion as area increases.

Although all the ecological groups were significantly nested, there were differences in the degrees of nestedness among groups- halophytes and glycophytes, succulents and non-succulents, and plants corresponding to different life-forms. Despite the fact that halophytes and glycophytes share some similarities as xero-halophytic groups, they also have important differences (Danin, 1999). For example, halophytes are relatively more aquatic and tolerant to water logging and salt spray. On the other hand, glycophytes are more terrestrial and tolerant to sand burial (El-Bana et al., 2007). Therefore, it is not surprising that glycophytes were more highly nested than halophytes. This is can be explained by the increased representation of salt habitats in which halophytes tolerate, but which other plants cannot tolerate. Most of the surveyed shorelines of islands are exposed to the effects of seawater, thus sustaining more halophytes. These factors may enable halophytes to dominate the plant communities of shorelines (El-Demerdash, 1996), also taking the fact into

account that halophytes are not affected by human disturbance, such as wood cutting and grazing.

Another mechanism which has been suggested for nested pattern is passive sampling whereby, larger islands capture more dispersing individuals than do smaller islands (Lomolino, 1990; Wright et al., 1998), and common species are more likely to be encountered than rare species. In the current study, passive sampling may account for nestedness. The result of the rarefaction suggests larger islands are capturing more richness and diversity of plant species assemblages. Consistent with this is the suggestion that those species most likely to occur on islands already are widely distributed regionally (King, 1988). For example, *Cyperus conglomerates*, *Arthrocnemum macrostachyum*, *Halopeplis perfoliata*, *Limonium axillare*, *Aeluropus lagopoides* *Zygophyllum coccineum* and *Zygophyllum simplex* have the highest incidence on the islands and they are also the species having the highest incidence on the coast of Saudi Arabia and southern Yemen (El-Demerdash et al., 1994; Hegazy et al., 1998; Kürschner et al., 1998). This suggests that a sampling filter (sensu Cutler, 1994) also may be operating in Farasan archipelago.

As suggested by Wright et al. (1998), many factors act as filters influencing the distribution of species on islands, and this differs by taxon and geographic setting (Atmar & Patterson, 1995). In this particular case, the nestedness of habitats, the tendency of common species to be widely distributed, rare species and habitats to be restricted to large islands and the differences in scale between large and small islands likely contribute jointly to nested pattern in Farasan archipelago.

5. Conclusion

In the current study, the high level of nestedness, the strong effect of area on total plant species richness and ecological groups, and the similarity of vegetation composition on the islands has several implications for conservation. First, the large and richest islands in Farasan archipelago such as Farasan Alkabir conserve higher diversity than an equivalent area of several smaller islands. This island also includes rare habitats like coral rocks and rare species. Second, the invasion of the unique habitats such as wadi channels and water catchments in this island by the exotic tree *Prosopis juliflora* should be managed to conserve the native biodiversity. Third, the current anthropogenic expansion on this island should be managed to conserve the existence of the rare habitats such as mangal vegetation where *Avicennia marina* and *Rhizophora mucronata* co-occur. Fourth, the protection of such critical mangal habitat is important on the other large island (e.g. Zufaf), due to its limited distribution in the country (Mandura, 1997; El-Juhany 2009, Zahran 2010).

6. Acknowledgment

We would like to thank Prince **Bander Bin Saud Bin Mohammad, Secretary General of the Saudi National Commission for Wildlife Conservation and Development (NCWCD)** for his assistance and access to the facilities at the Farasan Protected Area. The authors extend their appreciation to the Deanship of Scientific Research at King Saud University for funding the work through the research group project No RGP-VPP-031. We are also indebted to anonymous reviewers for fruitful comments on the manuscript. Many thanks are also given to Prof. Dr. A. Assaeed for his kind support and encouragement.

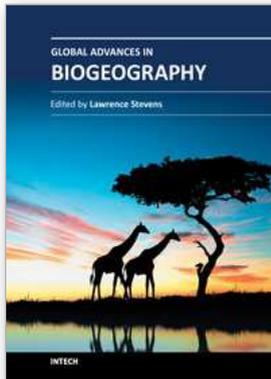
7. References

- Atmar, W. & Patterson, B.D. (1993). The measure of order and disorder in the distribution of species in fragmented habitat. *Oecologia* Vol. 96, No. 3 (June 1993), pp. 373-382, ISSN 00298549
- Atmar, W. & Patterson, B.D. (1995). The Nestedness Temperature Calculator: visual basic program, including 294 presence absence matrices. AICS Research, Inc., University Park, NM and the Field Museum, Chicago
- Bergmeier, E. & Dimopoulos, F. (2003). The vegetation of the islets in the Aegean and the relation between the occurrence of the islet specialists, island size, and grazing. *Phytocoenologia*, Vol. 33, No. 2 (January 2003), pp. 447-474, ISSN 0340-269X
- Brose, U. (2003). Island biogeography of temporary wetland carabid beetle communities. *Journal of Biogeography*, Vol. 30, No. 6 (June 2003), pp. 879-888, ISSN 03050270
- Brown, J.H. & Kodric-Brown, A. (1977). Turnover rates in insular biogeography: effect of immigration on extinction. *Ecology*, Vol. 58, No. 2 (March 1977), pp. 445-449, ISSN 0012-9658
- Buckley, R.C. (1985). Distinguishing the effects of area and habitat types on island plant species richness by separating floristic elements and substrate types and controlling for island isolation. *Journal of Biogeography*, Vol. 12, No. 6. (November 1985), pp. 527-535, ISSN 03050270.
- Butaye, J., Jacquemyn, H. & Hermy, M. (2001) Differential colonization causing non-random forest plant community structure in a fragmented agricultural landscape. *Ecography*, Vol. 24, No. 4 (August 2001), pp. 369-380, ISSN 09067590
- Chaudhary, S. (2000). *Flora of the Kingdom of Saudi Arabia*, In Ministry of Agriculture & Water, ISBN 9960-18-013-1, Riyadh, KSA
- Chaudhary, S. (1989). *Grasses of Saudi Arabia*, In Ministry of Agriculture & Water, ISBN 89-60345 Riyadh, KSA
- Collenette, S. (1999). Wildflowers of Saudi Arabia, In National Commission for Wildlife Conservation and Development, ISBN 9960614093, Riyadh, KSA
- Colwell, R. K. (2005). EstimateS: Statistical estimation of species richness and shared species from samples. Version 7.5. User's Guide and application, 20.02.2011, Available from <http://purl.oclc.org/estimates>
- Colwell, R.K., Mao, C.X. & Chang, J. (2004). Interpolating, extrapolating, and comparing incidence-based species accumulation curves. *Ecology*, Vol. 85, No. 10 (October 2004), pp. 2717-2727, ISSN 0012-9658
- Cook, R.R. (1995) The relationship between nested subsets, habitat subdivision and species diversity. *Oecologia*, Vol. 101, No. 2 (February 1995), pp. 204-210, ISSN 00298549
- Cutler, A. (1991). Nested faunas and extinction in fragmented habitats. *Conservation Biology*, Vol. 5, No. 4 (December 1991), pp. 496-505, ISSN 08888892
- Dabbagh, A., Hotzl, H. & Schnier, H. (1984). Farasan Island, In: *Quaternary Periods in Saudi Arabia*, Jado, A. & Zotl, I. (Eds.) Springer, 212-232, ISBN 10-0387814485, New York, USA
- Danin, A. (1999). Desert rocks as plant refugia in the Near East. *Botanical Review*, Vol. 65, No. 2 (April 1999), pp. 93-170, ISSN 00068101
- El-Bana, M.I. (2009). Factors affecting the floristic diversity and nestedness in the islets of Lake Bardawil, North Sinai, Egypt: implications for conservation. *Journal of Coastal Conservation*, Vol. 13, No. 1 (March 2009), pp. 25-37, ISSN 1400-0350

- El-Bana, M.I., Li, Z.Q. & Nijs, I. (2007). Role of host identity in effects of phytogenic mounds on plant assemblages and species richness on coastal arid dunes. *Journal of Vegetation Science*, Vol. 18, No. 5 (October 2007), pp. 635-644, ISSN 1654-1103
- El-Demerdash, M.A. (1996). The vegetation of the Farasan Islands, Red Sea, Saudi Arabia. *Journal of Vegetation Science*, Vol. 7, No. 1 (February 1996), pp. 81-88, ISSN 1654-1103
- El-Demerdash, M.A., Hegazy, A.K. & Zilay, A.M. (1994). Distribution of the plant communities in Tihamah coastal plains of Jazan region, Saudi Arabia. *Vegetatio*, Vol. 112, No. 2 (July 1994), pp. 141-151, ISSN 1385-0237
- El-Juhany, L. (2009). Present Status and Degradation Trends of Mangrove Forests on the Southern Red Sea Coast of Saudi Arabia. *American-Eurasian Journal of Agricultural and Environmental Sciences*, Vol. 6, No. 3 (February 2009), pp. 328-340, ISSN 1818-6769
- Fleishman, E., Donnelly, R., Fay, J. & Reeves, R. (2007). Applications of nestedness analyses to biodiversity conservation in developing landscapes. *Landscape and Urban Planning*, Vol. 81, No. 4 (July 2007), pp. 271-281, ISSN 0169-2046
- Gentile, G., Argano, R. (2005). Island biogeography of the Mediterranean Sea: the species relationship for terrestrial isopods. *Journal of Biogeography*, Vol. 32, No. 10 (October 2005), pp. 1715-1726, ISSN 03050270
- Gilbert, F.S. (1980). The equilibrium theory of island biogeography, fact or fiction? *Journal of Biogeography*, Vol. 7, No. 3 (September 1980), pp. 209-235. ISSN 03050270
- Heaney, L.R. (2000) Dynamic disequilibrium: a long-term, large-scale perspective on the equilibrium model of island biogeography. *Global Ecology and Biogeography* Vol. 9, No. 1 (January 2000), pp. 59-74, ISSN 1466822X
- Heatwole, H. (1991). Factors affecting the number of species of plants on islands of the Great Barrier Reef, Australia. *Journal of Biogeography*, Vol. 18, No. 2 (March 1991), pp. 213-221. ISSN 03050270
- Hecnar, S.J., Casper, G.S., Russell, R.W., Hecnar, D.R. & Robinson, J.N. (2002). Nested species assemblages of amphibians and reptiles on islands in the Laurentian Great Lakes. *Journal of Biogeography*, Vol. 29, No. 4 (June 2002), pp. 475-485, ISSN 03050270
- Hegazy, A.K., El-Demerdash, M.A. & Hosni, H.A. (1998). Vegetation, species diversity and floristic relations along an altitudinal gradient in south-west Saudi Arabia. *Journal of Arid Environments*, Vol. 38, No. 1 (January 1998), pp. 3-13, ISSN 0140-1963
- Honnay, O., Hermy, M. & Coppin, P. (1999). Nested plant communities in deciduous forest fragments: species relaxation or nested habitats. *Oikos*, Vol. 84, No. 1 (January 1999), pp. 119-129, ISSN 00301299
- Johnson, M.P. & Simberloff, D.S. (1974). Environmental determinants of island species numbers in the British Isles. *Journal of Biogeography*, Vol. 1, No. 3 (September 1974), pp. 149-154, ISSN 03050270
- Kadmon, R. (1995). Nested species subsets and geographic isolation: a case study. *Ecology*, Vol. 76, No. 2 (March 1995), pp. 458-465, ISSN 00129658
- Kadmon, R. & Pulliam, H. R. (1993). Island biogeography: effect of geographical isolation on species composition. *Ecology*, Vol. 74, No. 4 (June 1993), pp. 977-981, ISSN: 0012-9658
- Khedr, A.A. & Lovett-Doust, J. (2000). Determinants of floristic diversity and vegetation composition on the islands of Lake Burullus, Egypt. *Applied Vegetation Science*, Vol. 3, No. 2 (December 2000), pp. 147-156, ISSN 14022001

- King, R.B. (1988). Biogeography of reptiles on islands in Lake Erie, In: *The biogeography of the islands region of western Lake Erie*, J.F. Downhower, (Ed.), 125–133, Ohio State University Press, ISBN 0814204481, Columbus, Ohio
- Koh, L.P., Sodhi, N.S., Tan, H.T.W. & Peh, K.S.H. (2002). Factors affecting the distribution of vascular plants, springtails, butterflies and birds on small tropical islands. *Journal of Biogeography*, Vol. 29, No. 1 (January 2002), pp. 93–108, ISSN 03050270
- Kohn, D.D. & Walsh, D.M. (1994). Plant species richness—the effect of island size and habitat diversity. *Journal of Ecology*, Vol. 82, No 2, (June 1994) pp. 367–377, ISSN 00220477
- Kürschner, H., Al-Gifri, A. N., Al-Subai, M. Y. & Rowaished, A. K. (1998). Vegetational patterns within coastal salines in southern Yemen. *Feddes Repertorium*, Vol. 109, No. 1/2 (April 1998), pp. 147–159, ISSN: 1522-239X
- Lomolino, M. V. (1990). The Target Area Hypothesis: The Influence of Island Area on Immigration Rates of Non-Volant Mammals. *Oikos*, Vol. 57, No. 3 (April 1990), pp. 297–300, ISSN: 00301299
- Lomolino, M.V. (1994) Species richness patterns of mammals inhabiting nearshore archipelagoes: area, isolation, and immigration filters. *Journal of Mammalogy*, Vol. 75, No. 1 (February 1994), pp. 39–49, ISSN 00222372
- Lomolino, M.V. (2000a) A call for a new paradigm of island biogeography. *Global Ecology and Biogeography*, Vol. 9, No. 1 (January 2000), pp. 1–6, ISSN 1466-8238
- Lomolino, M.V. (2000b) A species-based theory of insular zoogeography. *Global Ecology and Biogeography*, Vol. 9, No. 1 (January 2000), pp. 39–58, ISSN 1466-8238
- MacArthur, R.H. & Wilson, E.O. (1967). *The theory of island biogeography*, In Princeton University Press, ISBN: 9780691088365, Princeton, USA
- Mandura, A. S. (1997). A mangrove stand under sewage pollution stress: Red Sea. *Mangroves and salt Marshes*, Vol. 1, No. 4 (March 1997), pp. 255–262, ISSN 1386-3509
- Maron, J.L., Vil, M., Bommarco, R., Elmendorf, S. & Beardsley, P. (2004). Rapid evolution of an invasive plant. *Ecological Monographs*, Vol. 74, No. 2 (May 2004), pp. 261–280, ISSN 00129615
- Masseti, M. (2010). The mammals of the Farasan archipelago, Saudi Arabia. *Turkish Journal of Zoology*, Vol. 34, No. 3 (July 2010), pp. 359–365, ISSN 1300-0179
- Médail, F. & Vidal, E. (1998). Organisation de la richesse et de la composition floristiques d'îles de Méditerranée occidentale (S.E. France). *Canadian Journal of Botany*, Vol. 76, No. 2 (February 1998), pp 321–331, ISSN 1916-2790
- Morand, S. (2000). Geographic distance and the role of island area and habitat diversity in the species–area relationships of four Lesser Antillean faunal groups: a complementary note to Ricklefs & Lovette. *Journal of Animal Ecology*, Vol. 69, No. 6 (December 2000), pp. 1117–1119, ISSN 1365-2656
- Nekola J. C. & White P. S. (1999). The distance decay of similarity in biogeography and ecology. *Journal of Biogeography*, Vol. 26, No. 4 (July 1999), pp. 867–878, ISSN 03050270
- Osborne, P.L. (2000). *Tropical ecosystems and ecological concepts*, In Cambridge University Press, ISBN 10-0521645239, Cambridge, UK
- Panitsa, M. & Tzanoudakis, D. (1998). Contribution to the study of the Greek flora: flora and vegetation of the E Aegean islands Agathonisi and Pharmakonisi. *Wildenowia*, Vol. 28, No. 1 (December 1998), pp 95–116, ISSN 05119618

- Panitsa, M. & Tzanoudakis, D. (2001) A floristic investigation of the islet groups Arki and Lipsi (East Aegean Area, Greece). *Folia Geobotanica*, Vol. 36, No. 3 (June 2001), pp 265-279, ISSN 12119520
- Panitsa, M., Tzanoudakis, D., Triantis, K.A. & Sfenthourakis, S. (2006). Patterns of species richness on very small islands: the plants of the Aegean archipelago. *Journal of Biogeography*, Vol. 33, No. 7 (July 2006), pp. 1223-1234, ISSN 03050270
- Patterson, B.D. (1987). The principle of nested subsets and its implications for biological conservation. *Conservation Biology*, Vol. 1, No. 4 (December 1987), pp. 323-334, ISSN 08888892
- Patterson, B.D. (1990). On the temporal development of nested subsets patterns of species composition. *Oikos*, Vol. 59, No. 3 (December 1990), pp. 330-342, ISSN 00301299
- Patterson, B.D. & Atmar, W. (1986). Nested subsets and the structure of insular mammalian faunas and archipelagos. *Biological Journal of the Linnean Society*, Vol. 28, No 1 (May 1986), pp. 65-82, ISSN 1095-8312
- Patterson, B.D. & J.H. Brown. 1991. Regionally nested patterns of species composition in granivorous rodent assemblages. *Journal of Biogeography*, Vol. 18, No. 4 (July 1991), pp. 395-402, ISSN 03050270
- Rafe, R.W., Usher, M.B. & Jefferson, R.G. (1985). Birds on reserves: the influence of area and habitat on species richness. *Journal of Applied Ecology*, Vol. 22, No. 2 (August 1985), pp. 327-335, ISSN 00218901
- Raunkiaer, C. (1934). *The life forms of plants and statistical plant geography*, In Oxford University Press, ISBN 0-405-10418-9, Oxford, UK
- Rosenzweig, M.L. (1995). *Species Diversity in Space and Time*, In Cambridge University Press, ISBN 0-521-499952-6, Cambridge, UK
- Rydin, H. & Borgegård, S.O. (1988). Plant species richness on islands over a century of primary succession in Lake Hjälmaren. *Ecology*, Vol. 69, No. 4 (August 1988), pp. 916-927, ISSN 0012-9658
- Sfenthourakis, S. (1996). A biogeographic analysis of terrestrial isopods (Isopoda, Oniscidea) from central Aegean islands (Greece). *Journal of Biogeography*, Vol. 23, No. 5. (September 1996), pp. 687-698, ISSN 03050270
- Simberloff, D. & Martin, J.L. (1991). Nestedness of insular avifaunas:simple summary statistics masking complex species patterns. *Ornis Fennica*, Vol. 68, No. 4 (June 1991), pp. 178-192, ISSN 00305685
- Turchi, G. M., Kennedy, P. L. , Urban, D. &Hein, D. (1995). Bird species richness in relation to isolation of aspen habitats. *Wilson Bulletin*, 107, No. 3 (June 1995), pp. 463-474, ISSN 00435643
- Whittaker, R.J. (2000). Scale, succession and complexity in island biogeography: are we asking the right questions? *Global Ecology and Biogeography*, Vol. 9, No. 1 (January 2000), pp. 75-85, ISSN 1466822X
- Wright, D.H. (1983). Species-energy theory: an extension of species-area theory. *Oikos*, Vol. 41, No. 3 (December 1983), pp. 496-506, ISSN 00301299
- Wright, D.H., Patterson, B.D., Mikkelson, G.M., Cutler, A. & Atmar, W. (1998) A comparative analysis of nested subset patterns of species composition. *Oecologia*, Vol. 113, No. 1 (June 1998), pp. 1-20, ISSN 00298549
- Zahran, M.A. (2010). *Climate-vegetation: Afro-Asian Mediterranean and Red Sea Coastal Lands*, In Springer, ISBN 978-90-481-8594-8, London, UK



Global Advances in Biogeography

Edited by Dr. Lawrence Stevens

ISBN 978-953-51-0454-4

Hard cover, 360 pages

Publisher InTech

Published online 30, March, 2012

Published in print edition March, 2012

Global Advances in Biogeography brings together the work of more than 30 scientific authorities on biogeography from around the world. The book focuses on spatial and temporal variation of biological assemblages in relation to landscape complexity and environmental change. Global Advances embraces four themes: biogeographic theory and tests of concepts, the regional biogeography of individual taxa, the biogeography of complex landscapes, and the deep-time evolutionary biogeography of macrotaxa. In addition, the book provides a trove of new information about unusual landscapes, the natural history of a wide array of poorly known plant and animal species, and global conservation issues. This book is well illustrated with numerous maps, graphics, and photographs, and contains much new basic biogeographical information that is not available elsewhere. It will serve as an invaluable reference for professionals and members of the public interested in global biogeography, evolution, taxonomy, and conservation.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Khalid Al Mutairi, Mashhor Mansor, Magdy El-Bana, Saud L. Al-Rowaily and Asyraf Mansor (2012). Influences of Island Characteristics on Plant Community Structure of Farasan Archipelago, Saudi Arabia: Island Biogeography and Nested Pattern, Global Advances in Biogeography, Dr. Lawrence Stevens (Ed.), ISBN: 978-953-51-0454-4, InTech, Available from: <http://www.intechopen.com/books/global-advances-in-biogeography/influences-of-island-characteristics-on-plant-community-structure-of-farasan-archipelago-saudi-arabi>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.