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FACTORS AFFECTING THE FLORISTIC DIVERSITY AND NESTEDNESS IN THE ISLETS OF LAKE BARDAWIL, NORTH SINAI, EGYPT: IMPLICATIONS FOR CONSERVATION

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Running head: Floristic diversity and nestedness in islets of Lake Bardawil
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ABSTRACT:

The aim of this study is to investigate the ecological mechanisms related to the observed pattern of floristic diversity and nestedness in the Lake Bardawil islets on the Mediterranean coast of Sinai Peninsula before the execution of the North Sinai Agricultural Development Project (NSADP) that will threaten the ecosystem of the lake. Plant species on 15 islets were identified and categorized into ecological groups related to their life-form, salt tolerance and succulence. Richness of total plant species and their ecological groups were positively correlated with islet area, number of habitats and elevation, and negatively with disturbance index. The temperature calculator detected highly significant nestedness for the entire flora and all ecological groups. Distance from the mainland had no effect on either species richness or nested pattern of total plant species and their ecological groups.

Both the analyses of species richness and nested distribution yielded evidence for a positive species-area relationship. Although nestedness was detected for the entire plant species and their ecological groups, many species and islets exhibited idiosyncratic distribution. Idiosyncrasies could be mainly attributed to demographic stochasticity which is an important character for species interaction and diversity maintenance in arid regions. Therefore, in developing conservation strategies for the Lake Bardawil islets, it is important to incorporate spatial and temporal stability of populations.

INTRODUCTION:

A critical issue in biogeography is to determine the mechanisms behind the richness and nestedness of biota that inhabit fragmented habitats and islands of terrestrial and aquatic ecosystems. Once these mechanisms are better understood conservation biologists will be able to better prioritize conservation efforts. Island biogeography theory and nestedness are two relevant and important concepts in biogeography and conservation (Lomolino and Smith, 2003).

Island biogeography theory (MacArthur and Wilson, 1967) attempts 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, recent studies have demonstrated numerous other variables such as island elevation, habitat diversity, disturbance, soil type and geological age as potential predictors of insular species richness (Kohn and Walsh, 1994). Therefore, 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 (Brown and Lomolino, 1989; Whittaker, 2000).

Another important consideration in examining the determinants of insular species distribution and richness is the degree of nestedness among the set of islands under study. Nestedness occurs where assemblages in depauperate sites are comprised of species that constitute subsets of species that occur in successively richer ones (Patterson, 1990; Fleishman *et al.*, 2007). It has been interpreted as a measure of biogeographic order in the distribution of species (Atmar and 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).

Furthermore, nestedness analysis enables the detection of species and sites significantly non-nested distributions as a result of species or habitat checker boarding or spatial turnover (Gotelli and McCabe, 2002). Where significant nesting does exist, species that conform to the overall assemblage nestedness pattern can be differentiated from taxa which depart from nestedness (known as idiosyncratic taxa), which occur more frequently than one would predict in species poor sites (Atmar and Patterson, 1993, 1995).

Although island biogeography theory and nestedness have been readily applied to investigate the plant species richness and pattern on oceanic and lacustrine islands (Kadmon, 1995; Moody, 2000), few studies exist on lakes archipelagoes in arid regions (Khedr and Lovett-Doust, 2000; Moody 2000; Duarte *et al.*, 2008). On these 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 shorelines and islets of Lake Bardawil on the Mediterranean coast of Sinai Peninsula are unique habitats for vulnerable, endangered and endemic flora and fauna (Baha El Din, 1992; El-Bana *et al.*, 2002). The lake was designated a wetland nature reserve under the International Ramsar convention of 1988 (Ramsar, 1991). However, the execution of North Sinai Agricultural Development Project (Fig. 1) will change the ecology of the lake and might cause a complete loss of many unique natural habitats. In addition, new habitats and new species are expected to appear after the execution of the project. Therefore, it is critical both from an academic and from a conservation perspective to catalogue the biodiversity in this lake, and to determine the factors affecting plant richness and distribution on its islets. The main goal of the present study was to determine the factors affecting floristic diversity and pattern of nestedness on the threatened arid islets of Lake Bardawil.

It has been noted that pooling all species in nestedness analyses can obscure important patterns (Fisher and Lindenmayer, 2005) as a

result of the idiosyncratic responses of more mobile and less specialized species. Therefore, comparing the nestedness of ecologically distinct groups will reveal those that are more nested and hence more vulnerable to extinction (Martinez-Morales, 2005). For testing this hypothesis, the present study examines the richness and distribution of plant ecological groups that related to life-form, succulence and salt tolerance to see whether they follow nested subset patterns.

MATERIALS AND METHODS:

Study area:

Lake Bardawil ($32^0 40^\backslash$E, $31^0 03^\backslash$N) is located at the northern tip of Sinai Peninsula, half-way between the Suez Canal and the city of El-Arish (Fig. 1). It is the only oligotrophic hypersaline lake along the Mediterranean coast of Egypt (Krumglaz *et al.*, 1980). The lake is of tectonic origin and its sediments resemble that of inland desert wadis and River Nile (Shaheen 1998). Lake Bardawil is shallow with a mean depth of 0.5–1.5 m, in some places reaching 3 m. It is separated from the Mediterranean sea by a sandbar, 300 to 2000 m wide. The existence of Lake Bardawil depends on its connection with the Mediterranean through four inlets. Nearly 51 islets are scattered throughout the lake characterized by different size and anthropogenic pressure, and include a variety of habitat types. The original morphology of many islands in the lake has been modified by wind and lake waves (Shaheen, 1998) and there is some variation in geomorphology and elevation among the islands (Shaheen, 1998; El-Bana *et al.*, 2002). The shore may rise gently to be followed by salt marshes and sandy plains, or be marked by playas, and some islands feature mobile and stabilized sand dunes. The islands provide resting and feeding grounds for birds migrating along the Africa-Palearctic flyway (Baha El Din, 1992). Most of the islands are subjected to heavy grazing and shrub cutting by local Bedouins and fishermen.

The Lake Bardawil climate is arid; the Emberger's degree of aridity is about 13.6 (Shaheen 1998). Annual precipitation averages 82 mm with high variability, and usually extends from October to May (Zahran and Willis, 1992; El-Bana, 2006). The monthly mean relative humidity varies between 68% and 74% with an annual mean of 72%. Soils of the study islets are with textural classes varying from sand to clayey and silty sand (Shaheen, 1998).

Data collection:

A total of fifteen islets in Lake Bardawil were surveyed for vascular plants over the period of Mid November 2003 – May 2005. Random sampling was used in selecting the surveyed islets to represent an array of sizes, which ranged in area from 0.32 ha to 12.3 ha. All plant species were identified in each islet following Täckholm (1974), and Latin names were updated following Boulos (1995). Plant species were categorized in terms of their life-forms (therophytes, hemicryptophytes, geophytes, chamaephytes and phanerophytes), salt tolerance (halophytes and glycophytes), succulence (succulents and non-succulents) and floristic categories following many authors as quoted by El-Bana (2003). Life-forms of the plants were determined according to Raunkiaer classification (Raunkiaer 1934). This classification was used as the processes and factors that underlie species richness in these groups differ, resulting in different richness patterns (Khedr and Lovett-Doust, 2000; El-Bana *et al.*, 2002; Khedr *et al.*, 2002). The recorded species were ranked in one of four abundance classes: very rare, rare, common or

very common according to their presence percentage in the surveyed islets.

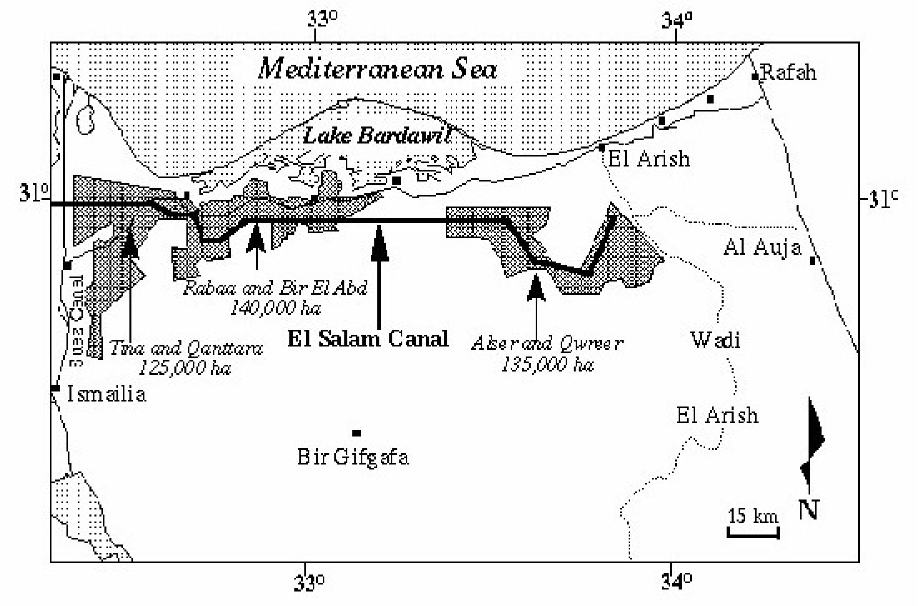

Fig. (1): Map of North Sinai showing the location of Lake Bardawil and North Sinai Agricultural Development Project (hatched area)

Area (ha), distance (km) to the nearest mainland, and maximum elevation (m) of each surveyed islet were obtained from the maps of the Egyptian Government Fishing Authority. In addition, the areas of some small islets were obtained by planimetry of local maps extrapolated to scale. A disturbance index was created to quantify the extent of human disturbance on each islet. The index comprised four components (animal grazing, burning, cutting and trampling), each of which was given a categorical scale ranging from 0 to 3 to indicate the absence of the human influence and the greatest degree of the influence, respectively. The disturbance index was determined by multiplying the scores of each of the four components to yield one overall score (Khedr and Lovett-Doust, 2000). Habitat types present on each islet were identified according to the physical characteristics of presumed importance to plants e.g. soil type and site wetness. Six main habitat types were recognized: mobile sand dunes, stabilized sand dunes, sand flats, dry saline marshes, wet saline marshes, and small lagoons.

Analyses:

The current study examined the relationship of species richness with islet area, distance to the nearest mainland, number of habitats, maximum elevation and disturbance index by simple linear and multiple regressions. The response variable in all regression analyses was total plant species richness, or number of species in each plant ecological group. Plant species richness, area, distance, and number of habitats were all $\log_{10}$ transformed to normalize distributions. Elevation and disturbance index were square root transformed. According to IBT (MacArthur and Wilson, 1967), a log-log

scale was used to determine the species-area relationship, a treatment often used to apply the power function $S=cA^z$ (where S is species richness, A is area, and c and z are constants).

To analyse nestedness, I set up a presence/ absence matrix in which species were arranged in columns by decreasing number of islets occupied, whereas islets were ordered by decreasing species richness. The degree of nestedness was analysed with the "temperature" method, which estimates the maximum nestedness in a given matrix by re-arranging species and islets in such a way as to minimize unexpected species occurrences (Atmar and Patterson, 1993). The Temperature Calculator software program (Atmar and Patterson, 1995) was used to achieve maximal packing of the incidence matrix, such that there was minimum unexpectedness in the distribution of species among islets. It generates an index, the temperature (T°), which indicates the degree of nestedness of the maximally packed matrix and can range from 0° (perfectly nested) to 100° (random). To assess statistical significance of (T°) the temperature calculator (Atmar and Patterson, 1995) uses Monte Carlo simulations to calculate T for each of n randomized matrices, and compares the observed value of (T°) to the distribution of temperatures generated by simulation. Therefore, the temperature of the observed matrix was compared to an expected temperature derived from Monte Carlo simulations (n=500) under a null model of equiprobable occurrences (Wright *et al.*, 1998) in order to determine the probability of randomly producing a matrix colder (more nested) than the observed matrix (Atmar and Patterson, 1993, 1995). This method was applied because of its good statistical properties and because it offers some valuable tools for the detailed study of biotic communities such as identification of the number of idiosyncratic species and sites in the system (Sfenthourakis *et al.*, 2004). Idiosyncratic species and sites are those having a 'temperature' above that of the overall matrix (Atmar and Patterson, 1993). Their distributional patterns differ from randomness, and may be disconnected from the primary biogeographic event of the system. The degree and significance of nestedness were determined for the entire set of plant species and for their ecological groups.

The Nested Temperature statistic (T°) provides a rigorous standardized metric of nestedness but the program reorders matrix columns and rows to minimize unexpectedness. This is neutral with respect to causation and sometimes leads to false conclusions (Fischer and Lindenmayer, 2005). Sfenthourakis *et al.*, (1999) compared the efficiency of the "temperature" method and the "departures" method of Lomolino (1996) for investigating the pattern of nestedenss. They concluded that the "temperature" method is more suitable for evaluating the level of nestedness, while the "departures" method is more efficient in determining casual factors of nestedness. Therefore, I used Lomolino's (1996) 'departures' nested method to assess the causality of nestedness for the entire plant assemblage and the ecological groups. With this method, matrices were sorted according to the islet characteristics, and then the unexpected presences of species from perfect nestedness were calculated. The statistical significance was obtained by comparing the observed number of departures to that of randomly generated matrices (1000 simulations), and a metric known as percent perfect nestedness (% PN) was calculated according to Lomolino (1996). All of these calculations were performed with 'Nested program' developed by Donnelly (Fleishmen *et al.*, 2007).

RESULTS:

Species richness pattern:

A total of 119 vascular plants (25 halophytes, 94 glycophytes, Appendix 1) were recorded on the 15 surveyed islets. Fig. (2) shows that the majority of these species were restricted to a few islets. Species richness on the islets ranged from 6 on the poorest islet (El-Wataweet) to 82 on the richest (El Rumiyat), and averaged 30.8. Plant of lake shores and wet salt marshes communities were recorded on all islets. The three most common halophytes on the fifteen islets were *Arthrocnemum macrostachyum, Halocnemum strobilaceum* and *Zygophyllum album* with occurrence on thirteen islets. The four most common glycophytes, on the other hand, were *Artemisia monosperma, Panicum turgidum, Retama raetam* (with occurrence on only eight islets) and *Thymelaea hirsuta* (with occurrence on nine islets).

The combined floristic relationship of the life-form and the chorotype spectrum is demonstrated in Fig. (3), showing that the monoregional taxa represent at least 50% of each life form. Considering the global phytogeographical distribution, most of the species belonged to the Saharo-Arabian region (32.6% monoregionals+18.4% bi-regionals+ 5.3% pluri-regionals), followed by Mediterranean species (9.4% monoregionals+ 14.6% bi-regionals + 6.3% pluri-regionals). Two species were endemic to Sinai (*Astragalus camelorum* and *Bellevalia salah-eidii*). Therophytes are the predominant life-form and constitute 49.7% of all recorded species, followed by chamaephytes (24.6%), hemicryptophytes (12.3%) and geophytes (9.1%). The scarcity of phanerophytes is the outstanding of the vegetation, representing only 4.9% of the total plant species.

Simple linear regression analysis indicated that four of the five explanatory variables were significant in explaining the variation in total plant species numbers or species numbers by ecological group (Table1). Plant species richness was positively significant correlated with islet area, number of habitats, and elevation, but was negatively correlated with disturbance index. Islet area was significantly correlated with number of habitats (Fig. 4), and elevation ($r= 0.78, P<0.001$). Islet area individually explained most of the variation in plant species richness (Fig. 4 and Table 1). Moreover, when the flora of each islet was classified into different ecological groups and logS/logA was constructed, it appeared that each group had significantly different regressions. In all regression analyses, distance to nearest mainland had no effect on either total species numbers or species numbers by ecological group.

The results of the stepwise multiple regressions showed that number of plant species was strongly associated with islet area, number of habitats and disturbance index (Table 2). These variables explained 87.5% of the variation in number of species. With respect to life span groups, area and elevation were the only variables affecting the richness of annuals, while area and disturbance index accounted for richness of perennials. Concerning growth form groups, number of habitats was the only variable that entered the model of semi-shrubs, while area and elevation explained 70% of the variance for shrubs (Table 2). For salt tolerance groups, glycophytes were explained by area and number of habitats, while halophytes were accounted for by area only. Different islet characteristics (or combinations of characteristics) apparently govern species richness of each group.

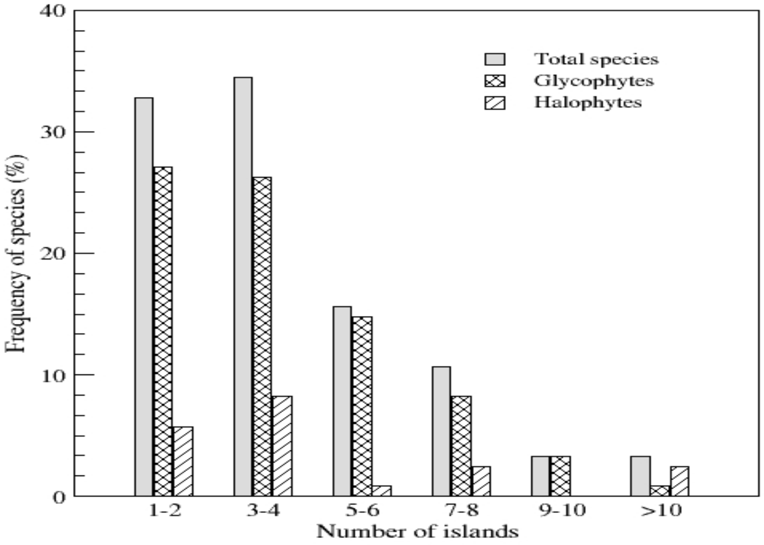

Fig. (2): The incidence of plant species on 15 islets surveyed in Lake Bardawil

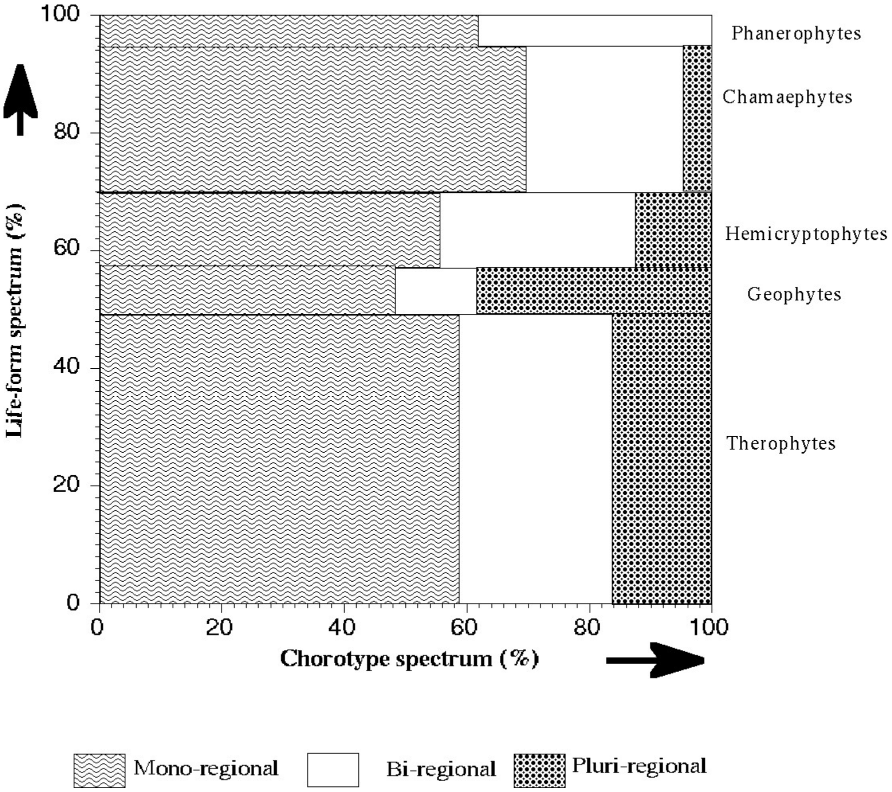

Fig. (3): Layer diagram of life form and chorotype spectrum of the recorded plant species on 15 islets in Lake Bardawil

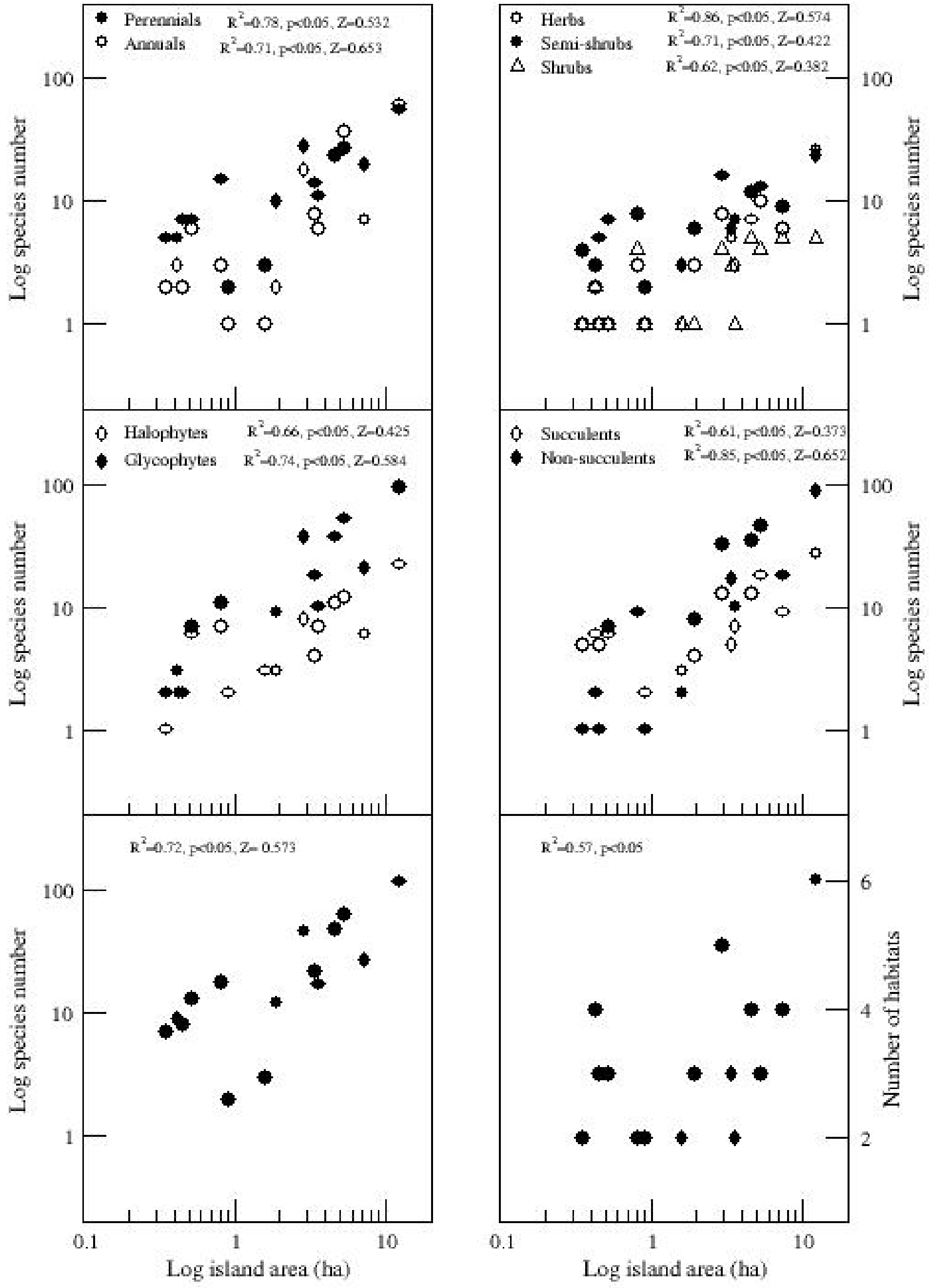

Fig. (4): Relationships of total species richness, ecological group richness and number of habitats with islet area

Table (1): Coefficients of determination (R^2) of total plant species number and species number by ecological subgroup against island area, disturbance index, number of habitats, elevation and distance to the mainland. Bold values indicate significant regressions ($P < 0.05$)

Species richness (S)	Area	Disturbance*	Number of habitats	Elevation	Distance
All species	**0.723**	**0.530**	**0.438**	**0.451**	0.034
Life span:					
Annuals	**0.714**	**0.485**	**0.351**	**0.416**	0.043
Perennials	**0.783**	**0.551**	**0.525**	**0.485**	0.021
Growth-form:					
Semi-shrubs	**0.715**	**0.445**	**0.551**	0.274	0.016
Herbs	**0.863**	**0.551**	**0.391**	**0.321**	0.047
Shrubs	**0.619**	**0.495**	**0.573**	**0.561**	0.009
Succulence:					
Succulents	**0.613**	0.301	0.251	0.231	0.015
Non-Succulents	**0.852**	**0.541**	**0.435**	**0.368**	0.042
Salt-tolerance:					
Halophytes	**0.658**	**0.431**	0.281	0.263	0.071
Glycophytes	**0.744**	**0.544**	**0.451**	**0.472**	0.027

*** Correlation indicates the relationship is negative**

Table (2): 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

Data set	Function	Adjusted R^2	*P*-value
All species	log (S) = 0.41+1.34 log (A)+0.35 log(H)+0.59 log (E)	0.875	< 0.001
Life span:			
Annuals	S = 3.95+13.43 log (A)+18.62 log(E)	0.656	< 0.001
Perennials	S = 7.71+9.65 log (A) – 19.27 log (D)	0.723	< 0.001
Growth form:			
Semi-shrubs	S = 0.20+18.87 log (H)	0.587	< 0.002
Shrubs	S = -0.82+3.12 E+0.51 log (A)	0.704	< 0.001
Herbs	S = 2.45+1.78 log (A) - 14.63 log (D)	0.596	< 0.001
Succulence:			
Succulents	S = 7.54+6.56 log (A)+10.34 log (H)	0.493	< 0.005
Non-succulents	S = 5.76+15.25 log (A) – 19.86 log (D)	0.682	< 0.001
Salt tolerance:			
Halophytes	S = 3.78+8.92 log (A)	0.424	< 0.01
Glycophytes	S = 6.85+14.46 log (A)+20.85 log(H)	0.641	< 0.001

S abbreviates to species richness, A to island area, H to number of habitats, E to elevation, D to disturbance index

Table (3): Results of the nestedness analyses with number of idiosyncratic species and islands as calculated by the nestedness temperature calculator for total plant species and the ecological subgroups

Data set	Total number of species	Matrix temperature (^0C)	Random temperature (^0C)	*P* $(T<T_{observed})$	Number and (percentage) of idiosyncratic species	Number of idiosyncratic islands
All species	119	3.27	56.05	<0.0001	32 (26.9%)	4
Life-forms:						
Therophytes	57	4.36	51.63	<0.0001	11 (9.3%)	3
Geophytes	11	0.23	35.40	<0.0001	2 (1.7 %)	1
Hemicryptophytes	15	8.38	44.46	<0.0001	4 (3.4%)	2
Chamaephytes	30	8.62	54.03	<0.0001	8 (6.7)	4
Phanerophytes	6	1.85	38.43	<0.0001	2 (1.7%)	3
Succulence:						
Succulents	28	4.73	52.41	<0.0001	11 (9.3%)	4
Non-Succulents	91	4.83	55.14	<0.0001	20 (16.8)	5
Salt-tolerance:						
Halophytes	25	5.49	47.85	<0.0001	7 (5.9%)	3
Glycophytes	94	5.85	57.02	<0.0001	20 (16.8%)	1

Nestedness:

The temperature nestedness calculator detected a high degree of nestedness for the entire flora as well as for each of the ecological subgroups (Table 3). The temperature of the maximally packed matrix (T^0_{matrix}=3.27) for the entire flora was significantly lower than the mean temperature of the random matrices generated by the Monte Carlo-derived null model (T^0_{random}=56.05, *P*<0.0001). When each ecological group was analysed separately, the species distributions were significantly nested for all subgroups. For example, the life-form distributions were significantly nested for all forms, and most strongly for the geophytes and phanerophytes. However, idiosyncratic islets and species were found in all tested data sets. About 31% of both islets and species were idiosyncratic in their distribution. Therophytes and chamaephytes were relatively well represented by idiosyncratic species. Species with idiosyncratic distributions were either common species such as *Artemisia monosperma, Retama raetam, Thymelaea hirsuta, Ifloga spicata* and *Lotus halophilus*, or rare ones such as *Argyrolobium uniflorum, Limonium pruinosum* and *Suaeda vermiculata*. Similarly, the species-rich islets like Qalas, and Om Kama, as well as species-poor islets like Om Mehsen and Om Gebesh showed idiosyncrasy.

The results of the ranked islets with causal factors by the 'departures' method indicated that islet area, number of habitats, elevation and disturbance index were significant determinants for nested pattern of total species (Table 4). Within each ecological subgroup, nested structure was determined by area alone for chamaephytes, succulents and halophytes, whereas islet area, number of habitats, elevation and disturbance were significant for the other ecological subgroups. As was also the case for species richness, distance from the mainland did not affect nested pattern.

Table (4): Percent perfect nestedness (% PN) as calculated by the algorithm of Lomolino (1996) of matrices for the entire plant assemblage and their ecological subgroups when islands are ranked by area, number of habitats, distance to mainland, elevation and disturbance index

Subgroup	Area	Number of habitats	Distance	Elevation	Disturbance
All species	79.8***	51.1**	20.9	32.8*	40.5***
Life-forms:					
Therophytes	80.5***	71.4***	33.2	73.7***	75.5***
Geophytes	95.6***	82.3***	19.3	60.6**	67.2**
Hemicryptophytes	70.4***	58.7**	17.6	51.7**	48.5**
Chamaephytes	60.6***	21.6	13.4	29.8	43.8**
Phanerophytes	80.8***	40.7**	15.9	60.5**	64.9**
Succulence:					
Succulents	36.4*	27.2	7.4	15.6	23.4
Non-Succulents	49.2**	44.8**	3.8	38.4*	43.3*
Salt-tolerance:					
Halophytes	55.4**	21.6	9.7	24.5	28.7*
Glycophytes	73.8***	59.4**	14.6	63.7**	69.4**

$^*P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$

DISCUSSION:

Species richness and nestedness:

The flora of Lake Bardawil islets consist of an assemblage of plant species diverse in life forms, salt tolerance, succulence, and floristic categories. From a phytogeographical viewpoint, the importance of the study area may be due to its position on the Sinai Peninsula, which is located in the intersection of the four phytogeographical regions: Mediterranean, Saharo-Arabian, Irano-Turanian and the Sudano-Zambezian region. Analysis of the floristic data revealed that the Saharo-Arabian chorotype forms the major component (53%) of the floristic structure of Lake Bardawil islets. The dominance of the monoregional Saharo-Arabian chorotype relative to the inter-regional chorotypes (bi- and pluriregionals) is in accordance with Danin and Plitman (1987) and with the bimodal floristic nature of the Mediterranean coast of Sinai (Gibali, 1988).

The equilibrium theory of island Biogeography (MacArthur and Wilson, 1967) identifies island size and distance from the mainland as the two most important factors affecting species richness. However, similar to several other studies (Buckley, 1985; Khedr and Lovett-Doust, 2000; Koh *et al.*, 2002; Panitsa *et al.*, 2006), there was no effect of distance from the mainland on total species richness, nor on richness of the ecological subgroups, in the current study. This could be attributed to the close spatial proximity of the islets to the mainland source pool (e.g., the distant and the richest islet of El Rumiyat is only 3.2 km from the mainland). Additionally, most of our species were annuals (about 60%) that can be dispersed across long distance by wind (Gutterman, 1994). This probably also explains the lack of significant relationship between nested rank order and distance from mainland. Several authors (e.g., Patterson, 1990; Cook, 1995) have suggested that differences in dispersal ability among species may interact with geographic isolation to produce nested species subsets.

The present study showed that several factors other than distance affected the richness and distribution of plant species and their ecological subgroups on the islets of Lake Bardawil. Species richness was determined primarily by islet area, number of habitats, disturbance and elevation. Similar results have been reported by studies on small islands in the Mediterranean (Khedr and Lovett-Doust, 2000; Panitsa *et al.*, 2006), the tropics (Buckley 1985), and the Pacific Ocean near California (Moody, 2000). Islet area was the best predictor for richness of plant species and entered into many of the stepwise regressions. Furthermore, this relationship existed across all ecological groups despite the differences in processes and factors that affect diversity of these groups (El-Bana *et al.*, 2002). The relationship between area and species richness may be due to the correlations of area with number of habitats and elevation. Area has often been considered to be primarily a surrogate for habitat diversity and elevation, which have been found to be important predictors in a number of studies (Buckley, 1985; Kohn and Walsh, 1994; Rosenzweig, 1995; Duarte *et al.*, 2008).

Disturbance index was the second best single predictor for total species richness and richness of ecological groups, and was selected together with area for the models of perennials, herbs and non-succulents in the stepwise regressions. Disturbance index was found to be correlated with islet area ($r = 0.75$, $P < 0.001$). Large and elevated islets like El-Malty and El-Gewaynat (maximum elevation 11.8 m and 13.2 m, respectively) are subjected to heavy disturbance as they are inhabited by Bedouins with their herds of goats, sheep and camels.

Bedouin activities include overgrazing, overcutting for fuel wood and uprooting of shrubs. The combinations of these activities with irregular severe drought are likely to influence extinction and colonization processes of several species (El-Bana *et al.*, 2003). Despite these influences, species-area relationships were significant, probably due to the adaptation of the species to the long history of disturbance and human association (El-Kady and El-Shourbagy, 1994; Sternberg *et al.*, 2000; El-Bana *et al.*, 2007).

It has been suggested that the value of the exponent Z should vary between 0.2 and 0.4 (MacArthur and Wilson, 1967; Rosenzweig, 1995), but its values exceed 0.4 in all datasets of the present study. The strong correlation of species richness with islet area, number of habitats and elevation suggests that these quite steep slopes would not be due to the existence of a small islet effect (Gentile and Argano, 2005). The division of islet flora into different ecological groups revealed that the slopes of the species area regressions differed by group. For example, the slope of the log (A)/log (S) regression of glycophytes growing on the interior sandy habitats was higher than that of halophytes growing on the shorelines of islets. A similar pattern has been recognized by other studies of island and islet floras (e.g. Nilsson and Nilsson, 1982; Buckley, 1985; Rosenzweig, 1995; Panitsa *et al.*, 2006).

This study shows that the distribution of plant species exhibited a pattern of nestedness that is commonly observed in other studies (Kadmon, 1995; Wright *et al.*, 1998; Honnay *et al.*, 1999; Koh *et al.*, 2002). Not only was the entire pool of plant species significantly nested, but all ecological groups that I examined were also nested - halophytes and glycophytes, succulents and non-succulents, and plants corresponding to different life-forms. Lomolino's departure method shows area to be the best correlates of nested pattern, although number of habitats and disturbance index were also important. All three of these interrelated factors are likely to act together to shape nestedness. Large islets with high number of habitats and low disturbance index tend to be the most species rich. Furthermore, it has to be noticed that nearly 67% of the species, on average, tended to occupy larger than smaller islets. This suggests that the strong association of species richness and nestedness with area may be due to direct effects of area on differential extinction (Atmar and Patterson, 1993; Lomolino, 1996; Wright *et al.*, 1998; Honnay *et al.*, 1999).

Although all the ecological groups were significantly nested, there were differences in the degrees of nestedness among groups. For example, geophytes as a life-form were more highly nested than their counterparts. This can be explained by dispersal and reproduction mode (Kadmon, 1995; Honnay *et al.*, 1999). Perennial species such as geophytes tend to be long- lived, lack adaptations for long-range dispersal, and spread mainly by bulbs and tubers (Gutterman, 1994). In addition, geophytes persistence is less dependent on seed production compared to annuals (Sternberg *et al.*, 2000). It has been documented that wind- and bird-dispersed species contribute less to the nestedness pattern, whereas species lacking adaptations for long-range dispersal show the strongest affinities towards the nestedness pattern (Butaye *et al.*, 2001).

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 islets of Lake Bardawil 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-Bana *et al.*, 2002). Additionally, the positive and highly significant relationship of islet area with number of habitats and elevation indicates that habitats accumulate in an orderly fashion as area increases. Therefore, certain species with specific requirements such as endemics (*Bellevalia salah-eidii*) and endangered species *(Cyperus laevigatus*, *Iris mariae* and *Leopoldia bicolor*) in Sinai Peninsula (Boulos and Gibali, 1993; El-Bana *et al.*, 2002), tended to occupy only the stabilized dunes of interior areas on large islets. Furthermore, these specialized habitat species mainly belong to geophytes, which are highly nested compared to their counterparts.

Causes of idiosyncrasy:

Idiosyncratic islands and species are those which elevate the temperature of the matrix, implying that those islands and species do not conform to a nested pattern of occupancy (Atmar and Patterson, 1993). Idiosyncrasy can be caused by several factors including habitat heterogeneity, contrasting biogeographic histories, demographic stochasticity, and habitat specialization among islands and species (Atmar and Patterson, 1993; Wright *et al.*, 1998; Patterson and Atmar, 2000). In the present study, idiosyncrasies were detected among islets, species and ecological groups. In general, the idiosyncrasy of species could be mainly attributed to demographic stochasticity (Patterson and Atmar, 2000), which is an important character for species interaction and diversity maintenance in arid and semi-arid regions (Goldberg *et al.*, 1999; Chesson *et al.*, 2004). In these regions, temporal and spatial variability of rainfall and resources master the establishment and survival of plant species (Goldberg *et al.*, 1999; Tielbörger and Kadmon, 2000; Shilo-Volin *et al.*, 2005; El-Bana *et al.*, 2007). This would also explain the higher idiosyncrasy for therophytes, of which population fluctuations mainly depend on rainfall pulses (Tielbörger and Kadmon, 2000).

Idiosyncrasy simply reflects that the idiosyncratic species on islands have not uniform distribution on the mainland (Atmar and Patterson, 1993), and that such variation are reflected in species composition on nearby islands. In accordance with this, idiosyncratic species such as *Artemisia monosperma*, *Calligonum polygonoides, Retama raetam* (and *Thymelaea hirsuta* are recorded as indicators of the vegetation associations in the study area (El-Bana *et al.*, 2002), and in the east-southern desert of Negev (Tielbörger, 1997; Danin, 1996). In addition, these generalist species have been shown to play an important ecological role for maintaining plant richness by trapping windblown sediments and inducing environmental and vegetational heterogeneity within or around their canopies (El-Bana *et al.*, 2003, 2007).

Conservation implications:

Nestedness analysis has been suggested as a practical tool in the conservation of islands and fragmented habitats, and reserve selection (Boecklen, 1997; Patterson and Atmar, 2000; Koh *et al.*, 2002). If biota are perfectly nested, and species richness increases uniformly with area, then a greater number of species will be conserved in a single large reserve than in several smaller reserves of equal total area. However, targeting conservation strategies around patch sizes per se may not always be the best approach, even in significantly nested assemblages (Fisher and Lindenmayer, 2005). The results from this study found a strong area effect on species richness and nestedness, while

many species and islets exhibiting idiosyncratic distribution. Therefore, conservation of individual islet may not be sufficient for the conservation of the entire floristic diversity. Furthermore, in developing conservation strategies at the species and community level, it is important to incorporate spatial and temporal stability of populations (Faith and Walker, 1996; Whittaker, 2000; Maron *et al.*, 2004; Werner and Buszko, 2005).

The results of this study have the following implications for conserving the plant diversity on the islets of Lake Bardawil. First, the richest islets such as El Rumiyat not only had the highest number of plant species among the fifteen islets surveyed, they also encompassed several rare species and species extinct elsewhere. The highest priority should therefore be given to preserving this islet. Second, my results showed that the majority of idiosyncratic species were found on small salty islets (e.g., Om Mehsen and Om Gebesh). This highlights the relative uniqueness of their plant assemblages and points to the importance of water circulating through managing the four inlets which connect the lake to the Mediterranean (El-Bana *et al.*, 2002). Third, the significant effect of the disturbance index on both species richness and nested pattern suggests that high disturbance could increase the convergence of communities to nested subsets (Honnay *et al.*, 1999), leading to dominance of tolerant and widespread species over low-tolerant and rare species. Therefore, management strategies such as placing enclosures specifically on highly disturbed islets (six enclosures of 100 m × 100 m each were recently installed by the author through the MedWetCoast project on El-Malty and El-Gewaynat islets) would act as a buffer against this. Local variations in topography, water level and soil depth in theses two large islets create habitat heterogeneity within communities, which probably accounts for their higher species richness (El-Bana *et al.*, 2002, 2003, 2007). These large islets furthermore include many rare and confined species that do not occur elsewhere in the region. A long term monitoring program for the endangered, rare and endemic species on the islets of Lake Bardawil is thus warranted and needed. This will support any management plan for conserving the threatened species and monitoring the invasion of exotic species due to the execution of North Sinai Agricultural Development Project.

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Appendix (1): List of plant species with their salt tolerance (ST), succulence (SU), life form (LF), floristic category (FC) and presence percentage (%P) recorded on 15 islets of Lake Bardawil

Species	ST	SU	LF	FC	%P
Adonis dentata Delile	G	N	T	SA+IT	31.3
Aegilops kotschyi Boiss.	G	N	T	SA+IT	12.5
Allium curtum Boiss. & Gaill.	G	N	G	ME+IT	12.5
Allium papillare Boiss.	G	N	G	SA	12.5
Anabasis articulata (Forssk.) Moq.	G	S	C	SA	50.0
Anchusa humilis (Desf.) I.M.Johnst.	G	N	T	ME	12.5
Argyrolobium uniflorum (Decne.) Jaub. & Spach	G	N	C	SA	12.5
Artemisia monosperma Delile	G	S	C	SA	53.3
Arthrocnemum macrostachyum (Moric.) K.Koch	H	S	C	SA+ME	100
Asparagus stipularis Forssk.	G	N	G	SA+ME	31.3
Asphodelus viscidulus Boiss.	G	N	T	SA	25.0
Astragalus annularis Forssk.	G	N	T	SA	25.0
Astragalus boeticus L.	G	N	T	ME	12.5
Astragalus camelorum Barbey	G	N	C	SA	6.3
Astragalus fruticosus Forssk.	G	N	H	SA	18.8
Astragalus kahiricus DC.	G	N	H	SA	12.5
Atractylis carduus (Forssk.) C.Chr.	G	N	C	SA	25.0
Avena sativa L.	G	N	T	COSM	18.8
Bassia muricata (L.) Asch.	H	S	T	SA+IT	12.5
Bellevalia zoharyi Feinbrun	G	N	G	IT	6.3
Brachypodium distachyum (L.) P.Beauv.	G	N	T	ME+IT	18.8
Brassica tournefortii Gouan	G	N	T	SA+ME	18.8
Bromus rubens L.	G	N	T	SA+ME+IT	12.5
Buplerum semicompositum L.	G	N	T	SA+ME+IT	31.3
Cakile maritima Scop.	G	S	T	ME+IT	25.0
Calligonum polygonoides L.	G	N	P	SA+IT	12.5
Centaurea calcitrapa L.	G	N	C	SA	25.0
Centropodia forskalii (Vahl) Cope	G	N	H	SA+IT	12.5
Cistanche phelypaea (L.) Cout.	G	S	P	SA+IT	31.3
Cistanche salsa (C.A.Mey.) Beck	H	S	T	IT	12.5
Convolvulus lanatus Vahl	G	N	C	SA	31.3
Cornulaca monacantha Delile	G	N	C	SA	37.5
Cotula cinerea Delile	G	N	T	IT	12.5
Cressa cretica L.	H	S	H	ME+IT	25.0
Crucianella membranacea Boiss.	G	N	T	SA	12.5
Cutandia dichotoma (Forssk.) Trabut	G	N	T	SA+IT	31.3
Cynodon dactylon (L.) Pers.	G	N	G	COSM	12.5
Cyperus conglomeratus Rottb.	G	N	H	ME	31.3
Cyperus laevigatus L.	G	N	H	SA+ME+IT	12.5
Daucus littoralis Sibth. & Sm.	G	N	T	ME	25.0
Deverra tortuosa (Desf.) DC.	G	N	C	SA	12.5
Dipcadi erythraeum Webb & Benth.	G	N	G	SA	12.5
Echinops spinosissimus Turra	G	N	H	ME+SA	12.5
Echiochilon fruticosum Desf.	G	N	C	SA	18.8
Echium angustifolium Mill.	G	N	C	ME	25.0
Eremobium aegyptiacum (Spreng.) Boiss.	G	N	H	SA	31.3
Erodium laciniatum (Cav.) Willd.	G	N	T	ME	31.3
Erucaria hispanica (L.) Druce	G	N	T	ME	18.8
Euphorbia granulata Forssk.	G	N	H	SA	12.5
Fagonia arabica L.	G	N	C	SA	6.3
Filago desertorum Pomel	G	N	T	SA+IT	25.0
Frankenia pulverulenta L.	H	N	T	ME+IT+ES	18.8
Frankenia revoluta Forssk.	H	N	C	ME+IT+ES	12.5
Gymnocarpos decander Forssk.	G	S	C	SA	25.0
Halocnemum strobilaceum (Pall.) M.Bieb.	H	S	C	SA+ME+IT	100
Haloxylon scoparium Pomel	H	S	C	SA+IT	12.5
Haplophyllum tuberculatum (Forssk.) A.Juss.	G	N	C	SA	25.0
Helianthemum stipulatum (Forssk.) C.Chr.	G	N	C	SA	43.8
Heliotropium digynum (Forssk.) C.Chr.	G	N	C	SA	25.0
Herniaria hemistemon J.Gay	H	N	H	SA	43.8
Herniaria hirsuta L.	G	N	T	ME+ES+IT	18.8
Hippocrepis areolata Desv.	G	N	T	SA+ME	25.0

Cont. Appendix (1):

Species	ST	SU	LF	FC	%P
Ifloga spicata (Forssk.) Sch.Bip.	G	N	T	SA	50.0
Iris mariae Barbey	G	N	G	SA	12.5
Juncus rigidus Desf.	H	S	H	SA+IT	25.0
Launaea capitata (Spreng.) Dandy	G	N	T	SA	18.8
Launaea nudicaulis (L.) Hook.f.	G	N	H	SA	37.5
Launaea tenuiloba (Boiss.) Kuntze	G	N	T	SA	12.5
Leopoldia bicolor (Boiss.) Eig & Feinbrun	G	N	G	ME	6.3
Limoniastrum monopetalum (Linn.) Boiss.	G	S	C	ME	18.8
Limonium pruinosum (L.) Chaz.	H	N	C	SA	12.5
Linaria haelava (Forssk.) Delile	G	N	T	SA	18.8
Lobularia arabica (Boiss.) Muschl.	G	N	T	SA	31.3
Lotus halophilus Boiss. & Spruner	G	N	T	SA	43.8
Lycium shawii Roem. & Schult.	G	S	P	SA+SU	43.8
Malva parviflora L.	G	N	T	ME+IT	25.0
Mesembryanthemum crystallinum L.	H	S	T	ME+ES	18.8
Mesembryanthemum nodiflorum L.	H	S	T	ME+ES+SA	18.8
Moltkiopsis ciliata (Forssk.) I.M.Johnst.	G	N	C	SA	43.8
Neurada procumbens L.	G	N	T	SA	43.8
Nitraria retusa (Forssk.) Asch.	H	S	P	SA	50.0
Noaea mucronata (Forssk.) Asch. & Schweinf.	G	S	C	IT	31.3
Ononis serrata Forssk.	G	N	T	SA+ME	18.8
Orobanche cernua Loefl.	G	N	T	SA+ME+IT	68.8
Pancratium maritimum L.	G	N	G	ME	18.8
Pancratium sickenbergeri Aschers. & Schweinf. ex C. & W. Barbey	G	N	G	SA	37.5
Panicum turgidum Forssk.	G	N	G	SA+SU	53.3
Paronychia arabica (L.) DC.	G	N	T	SA	18.8
Phoenix dactylifera L.	G	N	P	SA	12.5
Phragmites australis (Cav.) Trin. ex Steud.	G	N	G	COSM	12.5
Plantago albicans L.	G	N	H	SA+ME	25.0
Plantago cylindrica Forssk.	G	N	T	SA	31.3
Plantago ovata Forssk.	G	N	T	SA+IT	37.5
Polycarpaea repens (Forssk.) Asch. & Schweinf.	G	N	C	SU	12.5
Polycarpon succulentum (Delile) J.Gay	G	S	T	SA	12.5
Reichardia tingitana (L.) Roth	G	N	T	ME+IT	37.5
Retama raetam (Forssk.) Webb	G	N	P	SA	53.3
Rumex pictus Forssk.	G	N	T	ME	12.5
Salicornia europaea L.	H	S	T	ME+ES	12.5
Salsola kali L.	H	S	T	COSM	25.0
Salsola tetragona Delile	H	S	C	SA	25.0
Salvia lanigera Poir.	G	N	H	SA+ME	12.5
Sarcocornia fruticosa (L.) A.J.Scott	H	S	C	ME	18.8
Schismus arabicus Nees	G	N	T	SA+IT	50.0
Senecio glaucus L.	G	N	T	SA+IT	43.8
Silene villosa Forssk.	G	S	T	SA	18.8
Spergularia marina (L.) Griseb.	H	S	T	ME+IT+ES	43.8
Stipa capensis Thunb.	G	N	T	SA+IT	12.5
Stipagrostis ciliata (Desf.) de Winter	G	N	H	SA	18.8
Stipagrostis plumosa (L.) Munro ex T.Andersson	G	N	H	SA+IT	50.0
Stipagrostis scoparia (Trin. & Rupr.) de Winter	G	N	H	SA	31.3
Suaeda aegyptiaca (Hasselq.) Zohary	H	S	C	SA	31.3
Suaeda vermiculata J.F.Gmel.	H	S	C	SA	18.8
Tamarix amplexicaulis Ehrenb.	H	S	P	SA+SU	18.8
Thymelaea hirsuta (L.) Endl.	G	N	P	SA+ME	60.0
Traganum nudatum Delile	H	S	C	SA	25.0
Trigonella stellata Forssk.	G	N	T	SA	25.0
Zygophyllum aegyptium Hosny	H	S	C	SA	18.8
Zygophyllum album L.fil.	H	S	C	SA	86.7

Salt tolerances are: H: halophytes and G: glycophytes. Succulence are S: succulent and N: non-succulent. Life-forms are: T: therophytes, G: geophytes, H: hemicryptophytes, C: chamaephytes and P: phanerophytes. The floristic regions are: SA: Saharo-Arabian, ME: Mediterranean, IT: Irano-Turanian, ES: Euro-Sibarian, SU: Sudanian and COSM: Cosmopolitan.

العوامل المؤثرة على التنوع والتوزيع المتداخل للفلورة الموجودة على الجزر الصغيرة في بحيرة البردويل بشمال سيناء: نتائج للحماية

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أجريت هذه الدراسة لتحديد العوامل البيئية المؤثرة على التنوع والتوزيع المتداخل للفلورة الموجودة على الجزر الصغيرة ببحيرة البردويل بشبه جزيرة سيناء قبل تشغيل المشروع الزراعي التنموي بشمال سيناء، والذي سيهدد النظام البيئي للبحيرة. وقد تم رصد الأنواع النباتية الموجودة على 15 جزيرة صغيرة، ومن ثم تقسيمها إلى مجموعات بيئية تبعاً للطرز الحياتية، وتحمل الملوحة، وقوامها العصيري.

وقد أظهرت النتائج وجود علاقة طردية بين تنوع الأنواع وكذلك مجموعاتها البيئية مع كلاً من مساحة الجزر، وعدد المواطن البيئية، والارتفاع عن سطح البحر. وقد أظهر حاسب الحرارة للتداخل وجود توزيع متداخل كلي للأنواع النباتية ومجموعاتها البيئية. وبينت نتائج الدراسة عدم تأثر تنوع الأنواع أو توزيعاتها المتداخلة على الجزر بالمسافة من البر الرئيسي.

ولقد دلل كلاً من تحليل تنوع الأنواع والتوزيع المتداخل على وجود علاقة موجبة بين الأنواع والمساحة. وعلى الرغم من وجود توزيع متداخل كلي للأنواع النباتية ومجموعاتها البيئية؛ فقد وجد عدد كبير من الأنواع والجزر ذات توزيع تمييزي، ويرجع ذلك التوزيع إلى الديموغرافية العشوائية، والتي تعتبر خاصية مميزة للتفاعل بين الأنواع والمحافظة على التنوع في المناطق الجافة. ومن خلال نتائج هذه الدراسة يتضح أهمية وضع استراتيجية للمحافظة على التنوع النباتي لجزر بحيرة البردويل، من خلال رصد التغيرات المكانية والزمنية للمجتمعات النباتية.