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Full length Research paper

Evaluation of spatial variability and diversity indices application of seed bank of Sinai Peninsula

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Understanding the diversity level of seed bank is important for designing conservation and restoration programs especially in arid ecosystems. A diverse of diversity indices has been used in evaluating seed communities regardless of its suitability to measure the ecological quality of the targeted biological community. The current study aims to evaluate the spatial variability in the seed bank of Sinai Peninsula, and to evaluate the suitability of different diversity indices for application. Two hundred and twenty samples were collected from fifty- nine sites representing twenty-three localities in North and South Sinai. These localities belong to four main geomorphological districts; Mediterranean coast, northern anticlines, northern inlands, and southern mountainous massif. The content of soil seed bank in each sample was estimated by emergence method. Thirty-two species were identified including eight endemic and near-endemic species. The suitability of indices was evaluated by testing the relationships of the indices with the associating environmental factors and contribution of each index to group separation. The results of the study show that Sinai has a large scale of soil seed bank diversity that could be used in any conservation and restoration plans. The study suggests also, that the most suitable diversity indices to measure this diversity are Margalef and Q-Statistic without neglecting the importance of reporting on abundance and richness.

Key words: Sinai, soil seed bank, arid environments, diversity indices, conservation, restoration.

INTRODUCTION

Soil seed banks are considered as essential constituents of plant communities (Harper, 1997), since they contribute significantly to ecological processes. The recoveryability of vegetation after disturbance is believed to lie mainly in the buried seed populations (Uhl et al., 1981, 1982; Marks and Mohler, 1985; Lawton and Putz, 1988; Kalamees and Zobel, 2002). The replacement of individuals from the seed bank may have profound effects on the composition and patterns of the vegetation within the community (Egler, 1954; Harper, 1983; Cheke et al., 1979; Fenner, 1985). Therefore, conservation and restoration of plant species diversity rely on understanding the available levels of diversity, spatial distribution and processes that influence these levels, and the pathways by which plant species colonize sites.

In arid ecosystems soil seed banks are characterized by high spatial and temporal variability (Thompson, 1987; Rundel and Gibson, 1996), and are particularly affected by spatial patterns of vegetation (Guo et al., 1998) . The interaction between the effects of soil texture on plant community composition (Anderson, 1983), and the scarcity and irregular patterns of precipitation found in arid regions leads to the potential for spatial variability in processes important to the storage of germinable seeds (Pungaire and Lazaro, 2000).

While knowledge of the species richness and abundance of the soil seed bank in desert ecosystems is critical to understand its role in regeneration, little is documented on the seed patterns and diversity in arid regions (Knipe and Springfield, 1972; Bullock, 1976; Pake and Venable, 1996; Zaghloul, 1997; Salman, 2004). The soil seed bank studies in the deserts had been started by Went (1948), Abdel- Rahman and Batanouny (1959) in the eastern desert of Egypt, Rosch (1977) in South Africa, and then by Reichman (1984) in the Sonoran deserts of U.S.A. Alaily et al. (1987) carried out a seed bank study in the south-western desert of Egypt, while the seed bank study on soils of the most prominent

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communities in Wadi Feiran was carried out by Ramadan (1988) and Batanouny et al. (1991) to give approximate estimations of the potential viable seed flora of such a desert area. Zaghloul (1997) studied the soil seed bank in St. Catherine area, South Sinai. Salman (2004) studied the soil seed contents in some Wadi basins in South Sinai. Neither of these studies had dealt with spatial variability in Sinai Peninsula as a geographical region. Therefore, the first objective of this study was to evaluate the spatial variability in the seed bank of Sinai Peninsula by sampling sites with different soil texture in different geomorphological districts of Sinai.

To measure diversity in Sinai soil seed bank (arid to extremely arid ecosystems), one should apply an appropriate diversity index. Different types of diversity indices were designed to measure different ecological qualities, and that each of these qualities provides useful but different information on the status of the biological community. The soil seed bank in arid and extremely arid ecosystems has a nature of low emergence and species richness, and high variability in emergence between replicates representing the same area or site. Therefore, applying any diversity index without referring to its characteristics may lead to misinterpretations due to not reflecting the actual diversity situation. The second objective of this study was to evaluate the suitability (less biased) of different diversity indices for application on soil seed bank data collected from arid and extremely arid ecosystems.

MATERIALS AND METHODS

Study area

Sinai Peninsula is conventionally and administratively divided into Northern and Southern territories. Its geomorphology is summarized as a plateau tilting upward towards the south (Said, 1990). It has different distinct geomorphological districts including Mediterranean coastal plain, Wadi El-Arish, northern anticlines, inland plateau, and southern elevated mountainous massif (Hammad, 1980; Said, 1990).

The Mediterranean coastal desert of North Sinai is formed of wide sandy plains that slope towards the Mediterranean. It receives less rain than the Western Desert Mediterranean Coastal Zone and is therefore more sparsely vegetated. While this area is generally rather featureless, aeolian sand dunes of 10 to 80 m high are common. The broad outwash of Wadi El-Arish, fed by numerous tributaries, was historically known for its agriculture and olive and palm groves are still found there. This zone covers the triangular area extending between the Mediterranean coast line and the line between the Bitter Lakes and Rafah and covers an area of about 8000 km^2 or 13% of the area of the peninsula. It narrows in the east because of the presence of Gebel Maghara.

The North Sinai strongly-folded area (Frontal folds) covers 13,000 km^2 and extends in a northeast direction to south of the Mediterranean foreshore area. This portion of Sinai is characterized by the presence of relatively pronounced mountain ranges oriented in a northeast direction. These represent elevated anticlinal structures separated by synclinal areas that occupy the modern topographic lows. This district includes G. Maghara (735 m a.s.l.), G. Halal (890 m a.s.l), G. Libni (441 m a.s.l.) and G. Yi'alleq (1094 m a.s.l.).

The southern mountainous massif lies in the southern part of the peninsula. It is a triangular mass of mountains with its apex at Ras Mohammed to the south, 7500 km^2 in surface area, formed of igneous and metamorphic rocks, chiefly granites. This mass of mountains is intensively rugged and dissected by a complicated system of deep Wadis, some of which reach a considerable length (e.g. Wadi Feiran) and some are shorter, narrow and steeper, and represent tributaries of the main Wadis; e.g. Wadi El-Arbae'en, Wadi El-Sheikh and Wadi Saal (Said, 1990).

Sampling and germinating protocols

Two hundred and twenty samples were collected from fifty nine sites representing twenty three localities in North and South Sinai (Table 1 and Figure 1). These localities belong to four main geomorphological districts of Sinai; Mediterranean cost, northern anticlines (G. Halal, G. Maghara, G. Libni, and G. Yi'alleq), northern inlands, and southern mountainous massif. According to heterogeneity and diversity of standing vegetation, each site was represented by up to five samples with an average of 3.7 sample/site. A 25 x 25 cm^2 aluminum quadrate embedded into a 3cm- depth in the ground was used to collect representative soil samples, which were later labeled, air-dried and stored in laboratory conditions until sowing. Sampling was timed thoroughly to ensure that seed germination for the last season was completed and seed dispersal of the current season had occurred. So, the viable seeds found in the soil constitute the total soil seed bank (persistent and transit).

Before soil sowing, the bottoms of circular plastic-trays (23 cm in diameter) were filled with 2 cm deep pre-washed sterilized sand. This substrate allows only the viable seeds of the investigated soil sample to germinate and stimulate a quick development of roots searching for nutrients. An amount of 100 cm^3 from each sample was spread in a 0.25 - 0.5 cm thick layer over the sterilized sand. Trays were shielded from aerial seed contamination and were watered as needed to keep the soil continually moist. Two replicates were made of each sample and four trays containing only the underlying soil were used as negative control to get assure that the substrate soil is free of seeds. The germinated seedlings were marked by color-headed pins every two weeks and coded, over a period of 10 weeks. The results were expressed as mean numbers of seeds m^{-2} (Roberts, 1981).

When the seedlings succeeded to form foliage leaves, they were transplanted in pots containing nutrient-rich soil (Sand, Vermiculite, and Peat moss in ratio 1:1:1) to grow up for complete identification. Identification and nomenclature were carried out according to Täckholm (1974) and Boulos (1999, 2000, 2002 and 2005) . A list of the identified species is given in Table 2. Some seedlings failed to grow up and died in early young stages, so they were treated as unknowns but classification into morphological species was carefully performed.

Diversity Measurements

Eleven different indices for describing the species alpha diversity of the soil seed bank were measured. Total seed abundance was calculated following Butler and Chazdon (1998) as the observed number of seedlings in the sample soil. It was expressed as per square meter by dividing it by the total area of soil sampled. The mean and standard deviation were calculated for each locality and shown in Table 3. The eleven diversity indices were calculated for each of the fifty-nine sampled sites and means of each studied location (twenty-three) by pooling samples for each location. To minimize misinterpretation, diversity measures for G. Libni were excluded from comparing with other indices as it have just one species emerged from samples collected from just one site. Samples form Tasa - Gifgafa, Bir El-Abd – Gifgafa, and Lehfen –

Figure 1. Location maps showing the sampled sites.

Hassana did not give any emergent seedlings, and therefore they were also excluded from comparisons.

The indices were calculated using GenStat for Windows 10th Edition computer general statistics package software (Payne et al., 2007) and following Magurran (2004). Species richness was calculated as the total number of species (Barbour et al., 1987). The Q statistic was calculated by: $Q = (0.5 \times n_{R1} + \sum_{r = R1+1 \ldots R2-1} \{ n_r \} + 0.5 \times n_{R2}) / \log(R2 / R1)$, where n_r is the total number of species with abundance r, $R1$ and $R2$ are the 25% and 75% quartiles, n_{R1} is the number of species where R1 lies, and n_{R2} is the number of species where R2 lies (Kempton, 1979). The Shannon-Weiner index was evaluated by: $H = - \sum_i (n_i / N) \times \log(n_i / N)$, where n_i are the individuals, N is total number of individuals (Zar, 1984). The Shannon-Weiner evenness (Pielou J) was given by: $J = H / \log(S)$, where H is the Shannon index and S is the total number of species (Pielou, 1975). The Brillouin index was given by: $HB = (\log(N!) - \sum_i \{\log(n_i!)\}) / N$, where n_i is the individual in species i and N is total number of individuals (Huston, 1994). The Brillouin evenness index was then calculated by: $E = HB / Hbmax$ and $HBmax = 1 / N \times \log(N! / ((N/S)!^{S-r} \times ((N/S)+1)!^{r})$, where N/S is the integer of N/S and $r = N\text{-}S(N/S)$ (Huston, 1994). Simpson's index D was calculated by: $D = \sum_i \{n_i \times (n_i - 1)\} / (N \times (N - 1))$ and was expressed in the output as both 1-D and 1/D (Simpson, 1949). The Margalef's index is: $Dmn = (S - 1) / \log(N)$, where S is total number of species and N is total number of individuals (Huston, 1994). McIntosh's measure of diversity was expressed as: $D = (N - (\sum_i \{n_i^2\} / (N - (N))$ and the evenness measure was given by: $E = (N - (\sum_i \{n_i^2\}) / (N - N / (S))$, where n_i is the individual in species i and N is total number of individuals (McIntosh, 1967). The Berger-Parker index is $d = Nmax / N$, where $Nmax$ is the number of individuals in the most abundant species (May, 1975).

Soil analyses

Soil samples were collected for quantitative physical and chemical analyses. Fifty-four soil samples were collected to represent the studied localities (thirty-one from the South Sinai and twenty-three from the North Sinai). Typically, particle size analyses, as well as other standard soil analyses, are made on the fine fraction (less than 2 mm) (Ball, 1976; Hausenbuiller, 1985). In laboratory, soil sample were dried in air, and then passed manually through a 2mm

Table 1. Summary of sampled locations**.**

Geomorphological District	Location	No. of Sites	No. of samples
Southern mountainous massif	W. El-Arbaeen	5	16
	Kahf El-Ghola	1	2
	W. Shagg Musa	6	18
	W. Gragnia	3	10
	Musa's Gorge	3	11
	W. Sharig	6	24
	W. El-Deir	4	16
	W. Abou Teweta	1	4
	G. Munigha	1	6
Sub-total	*9*	***30***	***107***
Mediterranean cost	Romana	***4***	***12***
Northern inland	Ismailia - Gifgafa	5	24
	Bir El-Abd - Gifgafa	1	6
	Bir El-Abd	3	9
	Tasa – Gifgafa	1	2
	Lehfen - Hassana	1	1
	W. El-Arish – El-Rawafa'a dam	1	8
Sub-total	*6*	***12***	***50***
Northern anticlines	G. Maghara	6	19
	G. Libni	1	5
	G. Halal	3	23
	G. Yi'alleq	3	4
Sub-total	*4*	***13***	***51***
Total	**23 Location**	**59**	**220**

Table 2. A list of identified species emergent from soil seed bank.

1- *Arenaria deflexa Decne.*
2- *Conyza bonariensis (L.) Cronquist*
3- *Eruca sativa Mill.*
4- *Fagonia arabica L.*
5- *Fagonia mollis Delile*
6- *Ficus palmata Forssk.*
7- *Galium parisiense L.*
8- *Hypericum sinaicum Boiss.*
9- *Juncus rigidus Desf.*
10- *Kickxia macilenta (Decne.) Danin*
11- *Launea sp.*
12- *Lavandula coronopifolia Poir*
13- *Mentha longifolia (L.) Huds.*
14- *Micromeria sp.*
15- *Nepeta septemcrenata Benth.*
16- *Origanum syriacum L.*
17- *Phlomis aurea Decne.*
18- *Panicum coloratum L.*
19- *Polypogon monspeliensis (L.) Desf.*
20- *Portulaca sp.*
21- *Primula boveana Duby*
22- *Pulicaria incisa (Lam.) DC.*
23- *Rostraria cvistata (L.) Tsvelev*
24- *Scrophularia sp.*
25- *Serphedium herba-album (Asso) Soják*
26- *Schismus barbatus (L.) Thell.*
27- *Tamarix nilotica (Ehrenb.) Bunge*
28- *Thymus decussates Benth.*
29- *Trichodesma africanum (L) R. Br.*
30- *Trigonella stellata Forssk.*
31- *Verbascum sinaiticum Benth.*
32- *Veronica kaiseri Täckh.*

sieve to evaluate gravel percent. Particle size analysis was determined by pipette method for sand, silt, and clay according to Richards (1954). The organic matter content of soil samples was determined by loss on ignition method after oven drying at 600°C for 3 h. The pH was measured in 1:2.5 extract and electric conductivity (EC) was measured in water extract 1:1 (Page, 1982).

Suitability of different diversity indices

Two procedures for comparing the indices were used. Firstly, the relationships of the indices to the environmental factors (soil physiccal and chemical properties) were determined by statistical (correlation and regression) techniques. Secondly, contribution to group (geomorphological districts) separation was done by testing significance of variation in diversity measurements between groups by Kruskal-Wallis nonparametric test and descriminant analysis.

Correlation and regression between diversity indices and environmental factors

Pearson linear correlation analysis in MINITAB 14 computer software (Minitab Inc., 2003) was used to investigate the relationship between different used indices. Multiple regression analysis was performed to investigate the relation between each diversity index and measured environmental factors. Each diversity index, in turn, was used as dependant variable, while measured soil factors were used as independent variables. The aim was to figure out the most reliable diversity index through figuring out the most signify-cant regression equation

Variation in diversity between different geomophological districts

Variation between diversity measures in the four studied districts was tested for significance by Kruskal-Walllis nonparametric test that all used diversity measures failed normality test. Anderson-Darling test was used to test significant departures from normality in MINITAB 14 computer software.

Discriminant analysis

Linear discriminant analysis in MINITAB 14 computer software was used to investigate how different diversity indices contribute to group (geomorphological districts) separation. With linear discriminant analysis, all groups are assumed to have the same covariance matrix. Cross- validation technique was used to compensate for an apparent error rate. The apparent error rate is the percent of misclassified observations. The cross-validation routine works by omitting each observation one at a time, recalculating the classify-cation function using the remaining data, and then classifying the omitted observation.

RESULTS

A total of sixty-four morphological species recruited from soil samples collected from studied areas. Thirty-two species were identified (Table 2). These species included eight endemic and near-endemic (recorded from Egypt and other country) species: *Hypericum sinaicum*, *Kickxia macilenta*, *Nepeta septemcrenata*, *Origanum syriacum*, *Phlomis aurea*, *Primula boveana, Thymus decussates,* and *Veronica kaiseri*. Gramineae included *Panicum coloratum, Polypogon monspeliensis*, *Rostraria cristata*, and *Schismus barbatus*. The list of emergent species includeed a group of species that are indicators to the grazing pressure: *Fagonia mollis, Eruca sativa, Onopordum ambiguum,* and *Portulaca* sp. The very rare species (because they are selectively cut for medicinal uses) are represented by *Lavandula coronopifolia, Mentha longifolia, Nepeta septemcrenata, and Thymus decussatus.* The identified species included three species usually grow after a high degree of disturbance (*Onopordum ambiguum, Trichodesma africanum*, and *Verbuscum sinaiticum*). The other emergent species could not be taxonomically identified because the seedlings were died in a very young vegetative stage.

Spatial variability

Soil seed bank density

The emergence seedlings from soil seed bank samples showed the highest density in Wadi El-Arish at El-Rawfa'a dam site (1350.0 ± 1806.7 seedling/ $m^{2,}$ Table 3) while samples from Bir El-Abd – Gifgafa, El-Tasa – Gifgafa, and Bir Lehfen – El-Hassana showed no seedlings at all. At the locality scale, the northern anticlines showed the highest mean density of seedlings (264.7 ± 653.0 seedling/m^2) followed by southern mountainous massif (88.64 ± 216.56 seedling/m^2) and Mediterranean cost (50.00 ± 29.66 seedling/m^2). Samples from the northern inland areas showed the lowest density of seedlings (29.66 ± 161.5 seedling/m^2).

Species richness

The highest number of species (42 species) was recorded in southern mountainous massif. The richness is highly variable between locations with the highest (22 species) recorded in W. El-Arbaeen followed by W. El-Deir (18 species), W. Sharig (16 species), and Shagg Musa (16 species). W. Abou Teweta, G. Munigha, Musa's Gorge, and W. Gragnia showed the lowest species richness in collected soil seed bank samples (5, 6, 7, and 9, respectively). While the North Sinai anticlines and inland showed a very close pooled species richness (15 and 14, respectively), three out of six areas (Tasa – Gifgafa, Bir El-Abd – Gifgafa, and Lehfen – El- Hassana) of inland sites showed no seed bank content at all (Table 3). Gebel El-Halal has the highest soil seed bank species richness in North Sinai (10 species), followed by G. Maghara (7 species). Species richness showed no significant correlation with the soil seed density. Therefore, while W. El-Arish – El-Rawafa'a dam site resulted in the highest soil seed bank density, it has low species richness (5 species) (Table 3).

Q-Statistic

The results of Q-Statistic measure indicated that W. Gragnia has the highest diversity (4.08) although it does not have the highest species richness or density (Table 3). W. Sharig and W. El- Deir have the following highest diversity (3.47 and 3.32, respectively) . W. El- Arish (El-Rawafa'a dam) followed by W. Abou Teweta have the lowest diversity (0.57 and 0.60, respectively). Generally, the Q- statistic is in consistence with species richness that South Sinai massif has the highest soil seed bank diversity (3.39) compared to North Sinai anticlines (2.1), Inland (1.87), and Mediterranean coast (1.44).

Shannon-Weiner H and J

While Shannon-Weiner H diversity index (Table 3) showed that W. El-Deir followed by W. El-Arbaeen has the highest diversity (2.46 and 2.01, respectively) and W. Abou Teweta, G. Yi'alleq, and Musa's Gorge have the lowest diversity (1.01, 1.1, and 1.14, respectively), the Shannon-Weiner J showed that G. Yi'alleq, Kahf El-Ghola, and Romana area (Mediterranean coast) have the highest diversity (1.00, 0.95, and 0.95, respectively) although they are among the areas have the lowest species richness (only three species). These differences were reflected in subtotals, where Shannon-Weiner H indicated that the South Sinai massif has the highest diversity (2.33) but Shannon-Weiner J indicated that Mediterranean cost has the highest diverse soil seed bank (0.95). Meanwhile, Shannon-Weiner H referred to Musa's Gorge to have the lowest diversity value (1.14) while Shannon-Weiner J referred to W. Sharig (0.57).

Simpson 1-D and 1/D

Both Simpson 1-D and 1/D measures agreed with Shannon-Weiner H in indicating that soil seed bank in W. El-Deir has the highest diversity (0.93 and 13.41, respectively) and W. Abou Teweta has the lowest (0.55 and 2.23, respectively). Both measures also indicated that South Sinai mountainous massif is the area which has 0.71 and 3.46, respectively) and (0.71 and 3.42, respect-tively and Mediterranean coast (0.64 and 2.76, respectively). Simpson 1/D was more sensitive in as-signing diversity values than Simpson 1-D (Table 3).

Berger-Parker D

Berger-Parker D agreed with Shannon-Weiner H and Simpson 1-D and 1/D in indicating that W. El-Deir has the highest seed bank diversity (0.20). It also agreed with them and Q-statistics in indicating that W. Abou Teweta has the lowest diversity (0.61). This measure introduced W. Sharig to have a lowest diversity just as W. Abou Teweta (Table 3).

McIntosh D and E

While McIntosh E agreed with Shannon-Weiner J in referring to G. Yi'alleq has the highest diversity (1.00) followed by Kahf El-Ghola and Romana (0.92), it agreed with only Shannon-Weiner J and Berger-Parker D that W. El-Fera'a has the lowest diversity (Table 3). It disagreed with other indices in ordering localities where it referred to Mediterranean cost as having the highest diversity (0.92) followed by southern mountainous massif, then northern anticlines and inland (0.62) (Table 3)

Brillouin index and evenness

Brillouin index, disagreeing with all other indices, referred to W. El-Arbaeen to show the highest diversity (1.92) and to Kahf El- Ghola to have the lowest diversity (0.86). Meanwhile, Brillouin evenness referred to Mt. Yi'alleq to have the highest diversity (0.96), agreeing with Shannon-Weiner J and McIntosh D. It referred to Musa's gorge to have the lowest diversity (0.56), disagreeing with all the other indices. Also, while Brillouin index distinguished the studied localities according to the diversity of soil seed bank to be in the order of southern mountainous massif, then northern anticlines, northern inlands, and finally Mediterranean coast, Brilouin evenness referred to them in inconsistent order; Mediterranean coast, then northern inland, southern massif, and finally northern anticlines (Table 3).

Margalef

Margalef index agreed with Shannon-Weiner H, Simpson 1-D and 1/D, Berger -Parker D, and McIntosh D in referring to W. El-Deir to have the highest diversity, but with non of them in referring to G. Yi'alleq as the lowest diversity (Table 3). It agrees with all other indices except McIntosh E and Brillouin evenness in ordering the localities as southern massif, then northern anticlines and inland, and finally the Mediterranean coast.

Suitability of diversity indices

Correlation between diversity indices

Soil seed bank density did not show any significant correlation with any of the other measured diversity indices (Table 4). Shannon-Weiner H, Simpson 1-D, Simpson 1/D, Berger-Parker D, and McIntosh D have very highly significant correlation with all other diversity indices. Unlike other diversity indices, in Berger-Parker D index, decreasing *d* values reflects increasing diversity. So, this measure has highly significant negative correlations with all the other indices. Shannon-Weiner J followed by McIntosh E and Margalef has the lowest number of significant correlations with other indices. Q- statistic results are significantly correlated with all other indices except Shannon-Weiner J and McIntosh E beside total density (Table 4). Although Shannon-Weiner H is significantly correlated with Brillouin and Margalef indices, Shannon-Weiner J is not. But still both measures are significantly correlated (C.C. = 0.315, *P* 0.05). Simpson 1-D and 1/D measures are highly to very highly significantly correlated. While McIntosh D is very highly correlated with all other indices, McIntosh J does not signifycantly been correlated with species richness, Q-statistics, and Margalef. Margalef index has very highly significant correlation with only eight out of eleven diversity indices. It has no significant correlation with Shannon-Weiner H, McIntosh E, and Brillouin evenness (Table 4).

Correlation and regression between different diversity indices and environmental factors

Pearson correlation results (Table 5) showed that Margalef index is the diversity measure that has the highest number of significant correlations with environmental factors (EC, gravel, sand, and silt) followed by Q-statistics (gravel, sand, and silt), while McIntosh E, Brillouin index, and Brilouin evenness have no correlations at all. The multiple regression analysis confirmed this result that Margalef index (r^2 = 46.0 and *P* = 0.007) followed by Q-Statistic (r^2 = 42.8 and *P* = 0.033) are those gave significant reliable regression equation with the measured

Table 4. Pearson correlation between diversity indices at sampled locations.

	Seed Density	Species Richness SR	Q-Statistic	Shannon-Weiner H	Shannon-Weiner J	Simpson 1-D	Simpson 1/D	Berger-Parker D	McIntosh D	McIntosh
Species Richness SR	0.227									
Q-Statistic	-0.162	0.651***								
Shannon-Weiner H	0.142	0.866***	0.792***							
Shannon-Weiner J	-0.212	-0.174	0.085	0.315*						
Simpson 1-D	0.103	0.719***	0.748***	0.958***	0.637***					
Simpson 1/D	-0.049	0.694***	0.765***	0.888***	0.457**	0.852***				
Berger-Parker D	-0.079	-0.702***	-0.713***	-0.947***	-0.670***	-0.978***	-0.881***			
McIntosh D	-0.005	0.681***	0.774***	0.938***	0.639***	0.982***	0.906***	-0.963***		
McIntosh E	-0.174	-0.052	0.088	0.418**	0.985***	0.717***	0.532***	-0.766***	0.702***	
Brillouin index	0.240	0.882***	0.723***	0.981***	0.216	0.926***	0.824***	-0.922***	0.878***	0.329*
Brillouin evenness	-0.052	0.093	0.338*	0.516***	0.942***	0.744***	0.490***	-0.725***	0.709***	0.916***
Margalef	-0.064	0.903***	0.808***	0.891***	0.022	0.789***	0.829***	-0.754***	0.815***	0.102

*** *P* 0.000, ** *P* 0.02, and * *P* 0.05.

Table 5. Pearson correlation between diversity indices and soil factors at sampled locations.

Diversity index	pH	EC mhos/cm	O.M.	Gravel	Sand	Silt	Cla
Total abundance	0.195	0.183	-0.322	-0.449**	-0.131	0.185	-0.2
Species Richness SR	-0.017	-0.264	0.164	0.226	0.327*	-0.318	-0.2
Q-Statistic	-0.062	-0.221	0.103	0.517**	0.353*	-0.371*	-0.1
Shannon-Weiner H	-0.065	-0.199	0.222	0.371*	0.251	-0.251	-0.1
Shannon-Weiner J	0.079	0.111	-0.051	0.169	-0.111	0.100	0.14
Simpson 1-D	-0.088	-0.114	0.243	0.418**	0.173	-0.182	-0.0
Simpson 1/D	-0.141	-0.222	0.281	0.433**	0.228	-0.241	-0.0
Berger-Parker D	0.041	0.086	-0.187	-0.313	-0.090	0.100	0.01
McIntosh D	-0.158	-0.161	0.320	0.523**	0.222	-0.241	-0.0
McIntosh E	0.058	0.095	-0.006	0.178	-0.095	0.083	0.13
Brillouin index	-0.015	-0.146	0.154	0.227	0.211	-0.202	-0.2
Brillouin evenness	0.065	0.074	-0.049	0.175	-0.085	0.069	0.15
Margalef	-0.093	-0.375*	0.281	0.512**	0.412**	-0.421**	-0.2

** *P* 0.02, and * *P* 0.05.

Table 6. Multiple regression analysis between each diversity index as dependant variable and soil characters as independent variables.

Diversity index	Multiple	
	R-Sq	*P*
Total abundance	**37.70**	**0.038**
Species Richness SR	24.50	0.266
Q-Statistic	**42.80**	**0.033**
Shannon-Weiner H	23.60	0.295
Shannon-Weiner J	14.40	0.672
Simpson 1-D	21.00	0.390
Simpson 1/D	24.80	0.258
Berger-Parker D	12.00	0.777
McIntosh D	31.00	0.113
McIntosh E	10.90	0.822
Brillouin index	15.40	0.629
Brillouin evenness	12.70	0.748
Margalef	**46.00**	**0.007**

soil factors. Although total abundance resulted also in a significant regression (*P* = 0.038), it has a fairly low r^2 (Table 6). So, the correlation and regression analyses suggest that Margalef and Q-statistic indices are more suitable for estimating diversity in soil seed bank data in the studied areas.

Variation in diversity between different geomorphological districts

As Anderson-Darling test indicated that the results of all measured diversity indices have not normal distribution, Kruskal-Wallis nonparametric test was used to figure out the significance of variation between different geomorphological districts (Table 7). Shannon-Weiner J, McIntosh E, and Brilouin evenness did not show significant variation between the studied districts. The most signifycant variation was obtained by Margalef index (H = 23.39, *P* 0.000) followed by Q-statistics (H = 16.77, *P* 0.02) and McIntosh D (H = 16.26, *P* 0.02). This result indicates that Margalef and Q-statistics are the most suitable indices to describe diversity in soil seed bank of the studied areas.

Discriminant analysis

Discriminant analysis results confirm he correlation and regression results where it showed that Q-Statistic followed by Margalef have the highest proportions (0.74 and 0.71, respectively) of correct classification of sampled stands into correspondence geomorphological districts (Table 8). Using the cross validation, Margalef index has the highest proportion (0.71) followed by Simpson 1-D (0.67). On the other hand, McIntosh E index followed by Shannon-Weiner J and Brillouin evenness showed the lowest proportion of correct classification (0.33, 0.36, and 0.42, respectively) and even when using cross vali-dation (0.31, 0.33, and 0.34, respectively). These results mean that both Q-Statistic and Margalef indices are best explain the diversity of soil seed bank samples from the studied areas. The results also indicate that McIntosh E, Shannon-Weiner J, and Brillouin evenness indices are not recommended to such type of data.

DISCUSSION

Understanding seed bank characteristics of a particular habitat can assist to manage the composition and structure of existing vegetation, and to restore or establish native vegetation in several ways (van der Valk and Pederson, 1989; Richter and Stromberg, 2005; Hui and Keqin, 2006). A description of the range of variability within relatively unaltered habitats can provide a reference standard that allows one to diagnose ecological degradation at nearby sites. An examination of the composition of the seed bank makes it possible to predict the initial composition of the post-recruitment vegetation, particularly on exposed substrates cleared of vegetation (van der Valk and Pederson, 1989; Leck et al., 1989). Seed banks can serve as a re-colonization source for some subset of species, upon restoration of processes or removal of stress (Rossell and Wells, 1999; Combroux et al., 2002). Soil seed banks are likely to be larger, and to be a primary source of regeneration source for vegetation, where disturbance is frequent (Holzel and Otte, 2001). Community regeneration from the seed bank following a disturbance is an important aspect of ecosystem resilience (Leps et al., 1982).

Finally, seed bank is potential tool in restoring plant species after destruction or disturbance of vegetation by fire, overgrazing, drought, flooding etc. (Grime, 1981; Roberts, 1981; van der Valk et al., 1992; Brown and Bedford, 1997; Burke, 1997). Realizing these potentialities hinges on knowledge of the abundance, diversity and spatial distribution of viable seeds in the soil of focus sites.

Diversity is a measure of community structure, which can be defined as (1) the number of different species that occur in an area or sample, (2) the number of individual organisms that are present, and (3) the distribution of these organisms among the different species. Various indices put different weight on the importance of these components because they were originally developed to examine widely differing concepts, some of which do not apply directly to the problems of the study area (Huston, 1994). Debate on the advantages and disadvantages of various diversity indices has continued over the last three decades (Hurlbert, 1971).

Q-statistics represents a bridge between the abundance models and diversity indices but without involving fitting a model. It differs from all other used diversity in-

Table 7. Statistical tests for significant differences in diversity measurements between studied geomorphological districts.

Index	Anderson-Darling Test (departure form Normality)	Kruskal-Wallis (adjusted for ties)
	AD	H
Total abundance	7.229**	15.31**
Species Richness SR	1.571**	13.86**
Q-Statistic	1.038**	16.77**
Shannon-Weiner H	1.062**	13.01**
Shannon-Weiner J	1.025**	1.99
Simpson 1-D	2.849**	14.68**
Simpson 1/D	1.089**	14.56**
Berger-Parker D	1.975*	10.48**
McIntosh D	1.342**	16.26**
McIntosh E	1.219**	1.51
Brillouin index	0.966**	9.06*
Brillouin evenness	2.203**	1.83
Margalef	1.116**	23.39***

** *P* 0.000, ** *P* 0.02, and * *P* 0.05.

Table 8. Discriminant analysis results of sampled stands by different diversity indices**.**

Diversity index	Proportion Correct	Cross Validation
Total abundance	0.65	0.63
Species Richness SR	0.56	0.56
Q-Statistic	0.74	0.54
Shannon-Weiner H	0.63	0.63
Shannon-Weiner J	0.36	0.33
Simpson 1-D	0.67	0.67
Simpson 1/D	0.65	0.65
Berger-Parker D	0.58	0.56
McIntosh D	0.65	0.65
McIntosh E	0.33	0.31
Brillouin index	0.54	0.54
Brillouin evenness	0.42	0.34
Margalef	0.71	0.71
All together	*0.94*	*0.82*
Q-Statistic and Margalef	0.79	0.72

dices in that it is based on measuring "inter-quartile slope" on the cumulative species abundance curve, while all other Alpha diversity indices are based on proportional species abundances. So, it doesn't weigh towards very abundant or rare species. It has not the drawback of species abundance models as being tedious and repetitive and problems arise if the data do not violate more than one model. On the other hand, Q-statistic may be biased in small samples.

All other alpha diversity indices are based on proportional species abundances. They have advantages over species abundance models in considering evenness and richness, no assumptions are made about species abundance distributions, and they are free of assumptions of normality "non-parametric". They could be differrentiated under two general categories, the first depends on information theory where diversity (or information) of a natural system is treated similar to information in a code or message. Shannon-Wiener and Brillouin indices are classified under this category. The second category depends on the species dominance measures where it weighs towards abundance of the commonest species and so the total species richness is down weighted relative to evenness. Simpson, McIntosh, and Berger-Parker are included in this category.

The current results of soil seed bank abundance showed that samples from Bir El-Abd – Gifgafa, El-Tasa – Gifgafa, and Bier Lehfen – El-Hassana showed no seedlings at all. This result doesn't mean that the actual soil seed content is zero. This result should not be misinterpreted that there is a possibility that there is a persistent seed bank which needs more pre-treatment. Seed banks normally contain seeds of a number of species, each of which has different seed germination characteristics (Thompson and Grime, 1979) and seedling survival characteristics (van der Valk and Pederson, 1989). Soil moisture and other environmental conditions such as soil temperatures, soil salinity, and photoperiod seem to be the major factors regulating recruitment (van der Valk and Pederson, 1989). A persistent seed bank in the arid and extremely arid habitats would enable species to key their germination to more favorable years, while assuring maintenance of some seeds in the soil during years of poor seed production (Kalin Arroyo et al., 1999).

Generally, the results reflect the very low content of seeds and raising warning signs, where species not represented in the seed bank are particularly vulnerable to elimination from standing vegetation (Brown and Oosterhuis, 1981; Fenner, 1985; O'Connor, 1991).

The results showed also a high degree of spatial heterogeneity which is common for desert seed banks (Nelson and Chew, 1977; Reichman, 1979; Price and Reichman, 1987). Because estimates of seed bank density are known to vary with sampling method (Roberts, 1981), as well as in time and space (Henderson et al., 1988, Coffin and Lauenroth, 1989), the wide range in seed bank estimates is not surprising (Cox, 2006) especially in especially in harsh environment (e.g. Henderson et al., 1988; Coffin and Lauenroth, 1989; Richter and Stromberg, 2005). Soil seed banks show both seasonal and annual fluctuations (Gross, 1990; Dalling et al., 1997, 1998) as well as variation in species composition and abundance (Thompson, 1992) within and among community types (Turner and Franz, 1986). The spatial distribution of plants in the communities may be also important to the variability in the number of stored seeds (Coffin and Lauenroth, 1989).

In this study eight endemic species were identified in soil seed bank. Also, other species such as *Conyza biloba*, *Conyza bonarienses*, *Galium parisiense*, and *Micromeria* sp. which are endangered in their natural habitats were identified. This result reflects the option to recruit them from the soil seed bank. The presence of species in a soil seed bank disposes of many problems associated with collecting, storing, and sowing seeds or transplanting individuals, but not eliminates uncertainties associated with seed germination and seedling survival (van der Valk and Pederson, 1989). Also, seed banks of these endangered species should optimize long-term po-pulation growth rates (Kalisz and McPeek, 1992; Mengistu et al., 2005), and extend extinction times (MacDonald and Watkinson, 1981; Kalisz and McPeek, 1993).

Many of the recruited endemic and/or endangered species face a suite of genetic challenges to their long-term survival (Falk and Holsinger, 1991; Ellstrand and Elam, 1993). Most of these challenges are related to the small populations size that often characterizes rare species including susceptibility to genetic drift and increase of the likelihood of inbreeding and inbreeding depression (Barrett and Kohn, 1991). Stochastic events, such as drought or floods, can reduce populations size further, producing genetic bottlenecks. However, a pool of dormant soil seeds could act as a genetic reservoir, increasing effective populations size (N_e) beyond the number of aboveground plants, thereby buffering populations from loss of genetic diversity and increasing the likelihood of persistence and maintaining the evolutionary potential of these species (Templeton and Levin, 1979; Brown and Venable, 1986; Levin, 1990; Kalisz and McPeek, 1993).

Upon the current study, one could recommends the following procedures in analyzing soil seed banks in desert ecosystems: (1) Either of Margalef or Q-statistics indices should be used, (2) The total number of species (species richness) and number of individuals emergent from a sample (abundance) should always be reported. Neither is an actual index of diversity, but each provides a valuable description of the sample. (3) Indices that are excessively sensitive to change in sample size, gear, or handling procedures (e.g. Shannon-Weiner H) should be avoided. (4) Diversity indices are generally good indicators of change in community structure, but they should not be used to evaluate the quality or the cause of the change. Such evaluations should be based on collaborative data. (5) Comprehensive seed bank investigations on desert microhabitats scale are still needed as a basis for beginning to understand the ecological role of seed banks in the arid and extremely arid ecosystems. (6) Comparison of the soil seed bank and extant flora of an ecosystem with others that have been more extensively altered by human activities would be useful in suggesting restoration measures for the degraded sites.

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