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Vegetation of Thumamah Nature Park: a managed arid land site in Saudi Arabia

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Abstract Thumamah Nature Park is located at about 100 km north of Arriyadh (Saudi Arabia), having an area of 170 km^2. The Park was established since 30 years ago. The aim of this study is to analyze the vegetation structure in relation to the environmental factors in different habitat types. The phenological activities around the year of the 20 dominant species were monitored. 119 species were identified, of which 51 (43 %) annuals and 68 (57 %) perennials after 30 years of exclusive human impact. The Saharo-Arabian component species were the highest among the monoregional species (64 %) in most life forms, while the Sahelien-Somali Masai attained the highest among the biregionals (46 %). The TWINSPAN, DCA and CCA analyses separated seven vegetation groups. The first two groups were dominated by psammophytic species, which occupy the lower sandy plain as shown in group I with *Rhanterium epapposum–Rhazya stricta* and group II with *Pennisetum divisum–Haloxylon salicornicum*. The escarpment habitat was characterized by three groups, viz., group III with *Acacia gerrardii–Panicum turgidum*, group IV with *Panicum turgidum* and group V with *Acacia ehrenbergiana–Lasiurus scindicus*. Vegetation in the upland plateau was represented by the remaining two groups; group VI with *Helianthemum lippii* and group VII with *Helianthemum kahiricum*. The environmental variables that affect the species distribution and diversity in the park include the altitude, soil texture, pH, EC, Ca, Mg and Mn. The increased plant species richness, turnover, evenness and cover were mostly due to the increase of the herbaceous species. Plant populations showed interspecific variations in their relative timing of phenological phases with reproductive activity period ranged between 3 and 6 months with unimodal flowering peak. Three flowering-fruiting activities were recorded during late winter–spring, summer and late autumn–early winter. In an attempt to explain the vegetation dynamics after 30 years conservation, the progressive succession varied among the different habitat types, including the lower sandy sites, the escarpment and the upland rocky habitats, which reflect the relationship between altitude, edaphic factors and the type of vegetation units in each habitat type after exclusion of the human impact.

Keywords Keystone species · Landscape · Najd Plains · Psammophytic species · Succession

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1 Introduction

Spatial variations in the vegetation composition of the desert and the composition of life forms reflect the response of vegetation to certain environmental factors such as topography, climate and human impact (Zohary 1973; El-Demerdash et al. 1995; Shaltout and Mady 1996;

Hosni and Hegazy 1996; Hegazy et al. 1998; Hutchinson et al. 2000; Alday et al. 2010; Kürschner and Neef 2011; El-sheikh et al. 2012; Alatar et al. 2012). The relationship between vegetation dynamics and disturbance has long been a central focus in ecology. In desert ecosystems, climate fluctuates markedly and water is the dominant limiting factor that controls the plant growth. Nevertheless, like many other vegetation types, the dynamics of desert perennial vegetation can be affected by site history, climatic factors, life history of the dominant species and recovery after disturbances (Brown et al. 1997; Qinfeng 2004). Most early studies in arid ecosystems addressed climatic effects on annuals rather than perennial plants, mainly because the latter required longer observations. The greater longevity of many perennials, especially woody species, may lead to greater time lags in their response to disturbances or climatic changes than observed for annuals (e.g., Cody 2000; Valone et al. 2002; Qinfeng 2004). Desert ecosystems are fragile ecosystems and nearly always regeneration is slow, since primary production is low (Batanouny 1983; Qinfeng 2004).

Arabian Desert is subjected to major environmental disturbances that often leave the landscape with no vegetation and poor soil-forming material on which an ecosystem can develop. In recent years, Saudi Arabia has suffered from the effects of desertification, mainly due to climatic fluctuation resulting in drought, soil erosion and inappropriate land practices that disturb the ecological balance of ecosystems. In many cases, the human impacts and the ill-advised land-use are the main reasons in the deterioration of many ecosystem types (Hajara and Batanouny 1977; El-Sheikh et al. 2010). In desert habitats of central Saudi Arabia, water and temperature are the limiting ecological factor for vegetation establishment. Sporadic rainfall occurs in low amounts, often at irregular intervals and with large inter-annual variability (Batanouny 1973; Springuel et al. 2006). The desert vegetation in Najd region is found mainly in runnels, wadis, rangelands, sandy plains and raudhas (depressions), that possess variations of species abundance and diversity (Kürschner and Neef 2011; Alatar et al. 2012). Vegetation is generally of xeromorphic type and consists of an approximately continuous herb-layer, which is dominated by annual and perennial grasses, and varying densities of shrubs and trees (Vesey-Fitzgerald 1957; Schulz and Whitney 1986; Van der Merwe and Kellner 1999; El-Sheikh and Abbadi 2004; Alatar et al. 2012).

Camping and picnicking have significantly increased over the past few decades and helped to accelerate the deterioration of the once intact and ecologically balanced desert habitats (Al-Farraj 1989; Hajara and Batanouny 1977). Whereby, establishment of natural parks was taken much attention to support management of the recreation activities and conservation of wild plant diversity against human impacts. Thumamah Nature Park (Saudi Arabia) had been designed in 1983, owing to the unique and variable habitat types including escarpments, foothills, wadi systems, rock and gravel deserts, and sandy plains. The diversity and complexity of the flora and vegetation are exceptionally high. Owing to the management of the area since 30 years ago this minimized the recreational and grazing impacts. Thumamah Nature Park has unique macro and micro-habitats varying from sandy plain lowland to escarpment and upper land plateau. This variation and heterogeneity in the habitats increase the species diversity (Abbady and El-Sheikh 2002; El-Sheikh et al. 2010). Therefore, landscape designers' were taken into their consideration in the conservation of wild plant diversity and created the camp in the empty areas far away from the major plant associations.

Hitherto, there are no thorough vegetation studies on Thumamah Nature Park except the first unpublished report (Baierle and Kürschner 1985) describing the vegetation in the early stages of the Park establishment. The objectives of this study are to: (1) study the vegetation structure, in relation to the prevailing environmental variables affecting the floristic composition and species diversity in the landscape habitat types after 30 years protection, (2) monitor the phenology of the keystone species dominating the habitat types in the Park, and (3) propose and explain the potential progressive succession in different habitat types in response to the park conservation management.

2 Materials and methods

2.1 Study site

Thumamah Park is a unique natural ecosystem and popular entertainment center due to its scenic surroundings and proximity to the Arriyadh City. It is about 100 km from the central Arriyadh, covering an area of approximately 170 km^2. The study area is located between 25°14′ 02.53″ N–46°37′ 12.15″ E and 25°18′ 14.33″ N–46° 41′ 27.51″ E (Fig. 1). The Park is a large and shallow depression, which receives runoff water several times the amount of the actual rainfall. It is flanked by Aramah escarpment and adjoining wadis. Aramah escarpment, which is capped with upper Cretaceous limestone, extends, 250 km northeast of Arriyadh with maximum elevation of 805 m a.s.l. and 120 m above the nearby sandy plains (Al-Nafie 2008).

The Thumamah Park is divided into different zones, each with a specific purpose, from limited camping area to 'high energy activity areas'. A large portion of the study

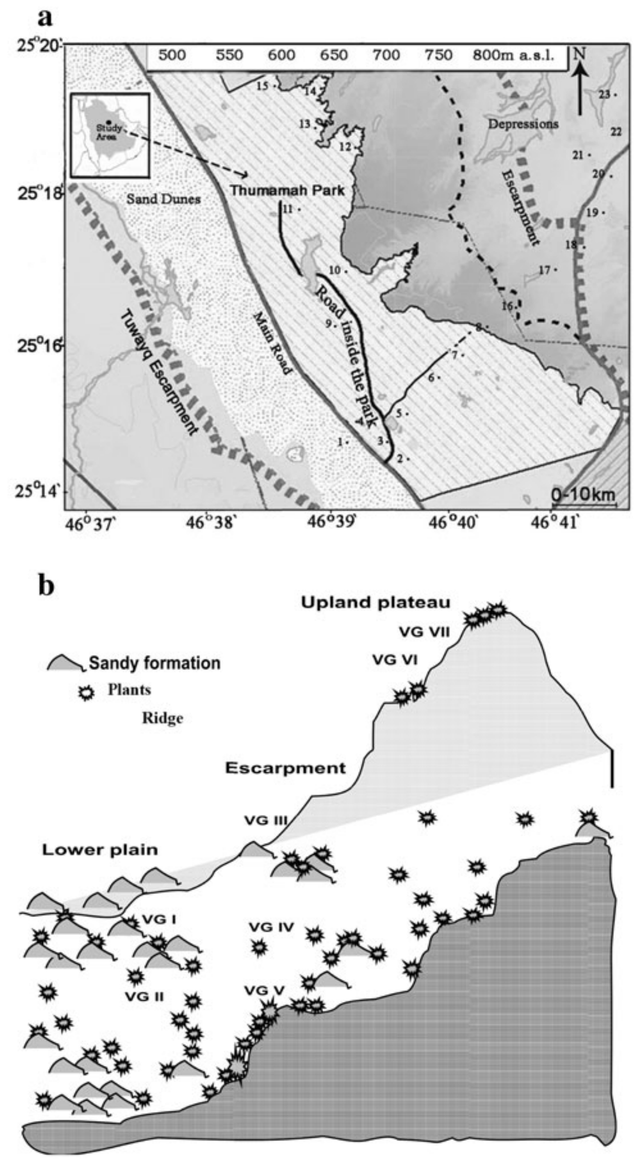


Fig. 1 **a** Map of the study area and landscape of the sampled stands (1–23: •). **b** Landscape units of the study area. The vegetation groups after identified by TWINSPAN are: VG I: *Rhanterium epapposum–Rhazya stricta*, VG II: *Pennisetum divisum–Haloxylon salicornicum*), VG III: *Acacia gerrardii–Panicum turgidum*, VG IV: *Panicum turgidum*, VG V: *Acacia ehrenbergiana–Lasiurus scindicus*, VG VI: *Helianthemum lippii* and VG VII *Helianthemum kahiricum*

area is also left unattended which is now regarded as a protective desert zone and currently serving as a land bank for future recreation use. Geomorphologically its landscape, is identified into three fundamental components: lower plain (lowland), escarpment and upland plateau. The average highest point on the site is 805 m a.s.l and the average lowest point is 560 m a.s.l giving altitudinal range of 245 m. The lowland is composed of flatlands including: depressions of various areas, crossing wadis and run off channels, sandy and gravel plains. The escarpment is the dominant component of the site and characterized by both sloping and vertical cliffs interrupted by well developed wadi system, sand and gravel areas, and small mosaic depressions (Brown 1960). The upland plateau is mostly bare gravel land interrupted by small depressions "grooves" which support few plant growths (Fig. 1).

The rainfall in the area is highly variable. The mean annual precipitation is <20 mm; of which 80 % is received from December through April and the prevailing winds from north. The mean minimum and maximum annual temperature is 15 and 37 °C. The maximum temperature often reaches 47 °C during July–August, while the lowest minimum temperature touches below 3 °C in some extreme cold days during winter (Fig. 2).

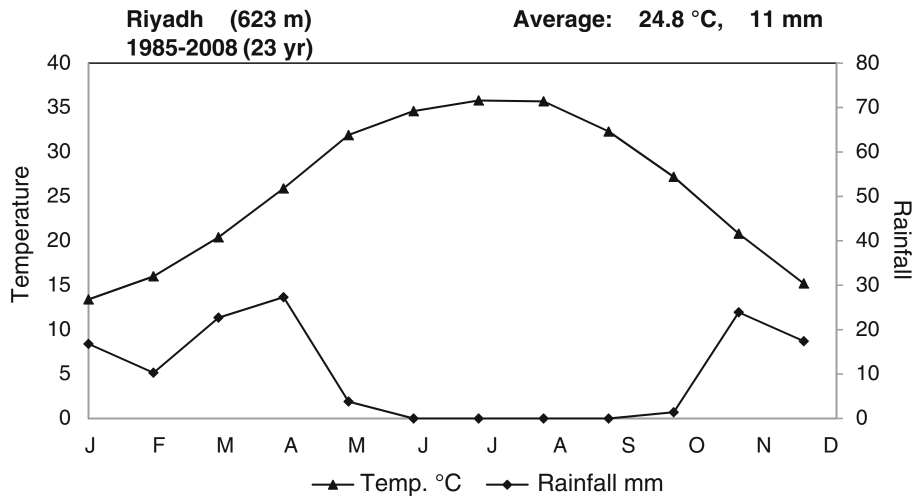
2.2 Sampled stands

A total of 23 stands were distributed to cover the various landforms and succession stages (5 in sandy plain outlet, 15 in the escarpment and 3 in the upland plateau). The sampling process was carried out during spring when most species were expected to be growing. In each stand listing of all species and their life forms and chorotypes were determined. Species nomenclature followed Chaudhary (1999, 2001) and Collenette (1999). In each stand, species present were recorded and plant cover was estimated quantitatively using the line intercept method (Canfield 1941), with five parallel lines each of 50 m long. The lengths of interceptions by each species in each stand were measured in centimeter, summed up and related to the total length of lines stretched in that stand. The cover was expressed as m 100^{-1} m. Phenological observations were recorded on randomly chosen individuals of each plant population. Permanent plots each of (10 × 10 m) were placed at the sampled stands in the nature park. Periodic observations were carried out every 10 days during spring 2011 (the peak growing season of most species) and monthly during the other seasons. Five phenological phases were defined: vegetative growth, flowering, fruiting, seed dispersal and dormancy. For each species, at least 20 marked individual plants were observed. Mean values of individuals of every species were determined.

2.3 Soil analysis

Three soil samples, down to 50 cm depth, were collected from each stand and mixed as one composite sample for each stand. Soil texture was determined by hydrometer method (Allen et al. 1989). Total organic matter was determined based on loss-on-ignition at 450 °C. Soil water extract was prepared (1:5), by dissolving 100 g air dried soil in 500 ml distilled water for estimation of pH and electrical conductivity (EC) as mS cm^{-1}. Soil nutrient elements (Ca, K, Na, Mg, Fe, N and P) were determined

Fig. 2 Clima-diagram of Arriyadh Region (1985–2008: 23 years)



using Spectrophotometer (model ICP MSEOS 6000 Series). All procedures are outlined by Allen et al. (1989).

2.4 Data analysis

The cover estimates of 119 species were recorded in 23 stands, and were subjected to multivariate analysis. Two data matrices of common species cover data were created: (1) matrix of 23 stands × 119 common species cover value and (2) matrix of 23 stands × 48 of the most common species cover values × soil variables. The first matrix was subjected to a numerical classification using two-way indicator species analysis "TWINSPAN" (Hill 1979a). TWINSPAN produces a hierarchical classification of vegetation groups (i.e. plant communities). Plant communities were named after their dominant species. The Detrended Correspondence analysis "DCA" (Hill 1979b) was applied to the same first matrix data sets in order to obtain an efficient graphical representation of ecological structure of the vegetation groups identified using TWINSPAN. To detect correlations of the derived vegetation associations with environmental data, Canonical Correspondence Analysis "CCA" according to (Ter Braak and Smilauer 2002) was conducted with very common species cover, stands and soil variables "Second matrix".

Gamma species diversity (γ-diversity) was calculated as the total species number in each landscape or vegetation group. Species richness (α-diversity) of the vegetation cluster was calculated as the average number of species per stand. Species turnover (β-diversity) are calculated as ($\alpha\ \gamma^{-1}$). Shannon–Wiener index $\hat{H} = -\sum_{i=1}^{s} p_i \log p_i$ for the relative evenness, and Simpson index $C = \sum_{i=1}^{s} p_i^2$ for the relative concentration of dominance were calculated for each stand on the basis of the relative cover p_i of the ith species (Pielou 1975; Magurran 1988). Relationships between the ordination axes on one hand, and community and soil variables on the other hand were tested using Pearson's simple linear correlation coefficient (r). The variation in the species diversity, stand traits and soil variables in relation to plant community were assessed using one-way analysis of variance (SAS 1989, 1996).

3 Results

3.1 Floristic diversity and chorotypes

Total of 119 species (51 annuals and 68 perennials), belonging to 95 genera and 37 families were recorded from various stands, of which the most represented families are Asteraceae (17 %) and Poaceae (11 %). Therophytes constituted 46 species (41 %) followed by 33 Chamaephytes (30 %) and 18 hemicryptophytes (15 %). Species of ruderal habitats were recorded, such as *Cynodon dactylon*, *Malva parviflora*, *Senecio glaucus* and *Calotropis procera*, and parasitic species *Cuscuta planiflora* and *Cistanche tubulosa* (Appendix and Fig. 3). Regarding the chorotypes, the monoregionals were highly represented in most life forms except for the phanerophytes where the biregionals were the highest. Saharo-Arabian components were the highest among the monoregionals (about 64 %), while the Sahelien-Somali Masai were the highest among the biregionals (46 %).

3.2 Multivariate analysis of plant communities

TWINSPAN dendrogram divided the data set into seven major vegetation groups (i.e., plant communities) at level 3. These communities were named after the dominant and subdominant species as follows: the first two groups (VG I: *Rhanterium epapposum–Rhazya stricta*, and VG II: *Pennisetum divisum–Haloxylon salicornicum*) only dominated by psammophytic species, which occupied the lower sandy plain. The escarpment habitat was dominated by VG III (*Acacia gerrardii–Panicum turgidum*), VG IV (*Panicum turgidum*) and VG V (*Acacia ehrenbergiana–Lasiurus scindicus*). The remaining two groups occupied the upland plateau (VG VI: *Helianthemum lippii* and VG VII: *Helianthemum kahiricum*). The application of DCA and CCA confirmed the separation between these communities and indicated the relationships between some environmental and topographic gradients of the park area (Fig. 4a, b).

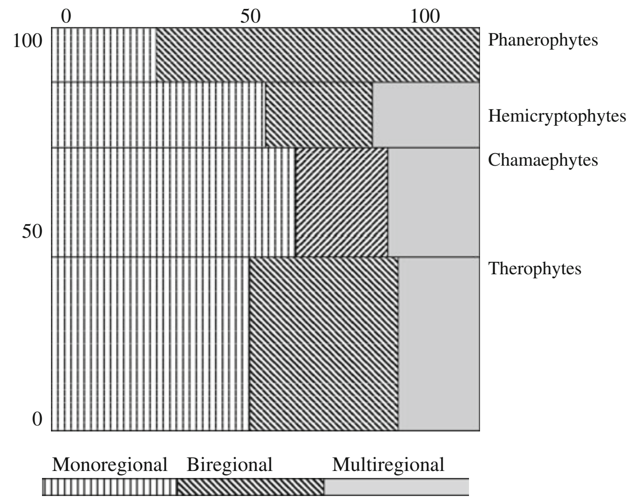
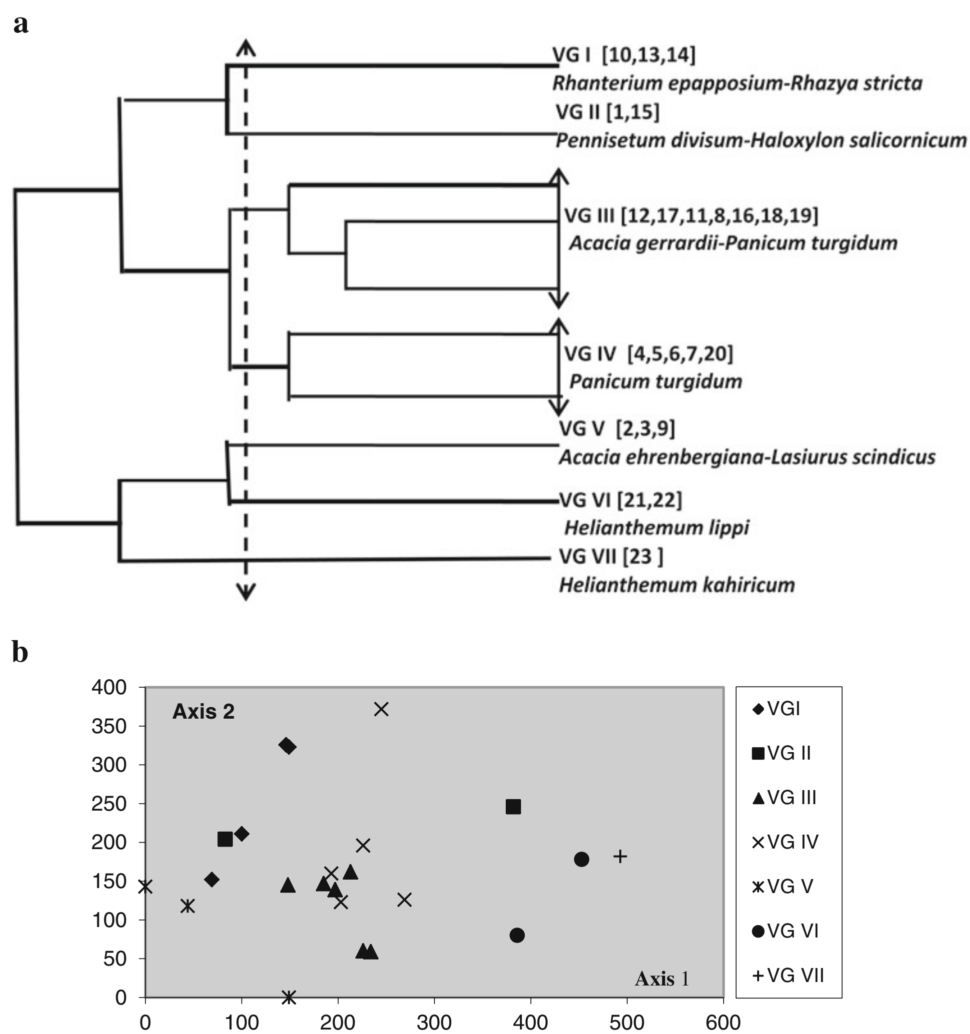


Fig. 3 Layer diagram of the life form and chorotype spectra of Thumamah Park

3.3 Plant communities–environment relationships

CCA ordination was used to verify the correlation analysis between the dominant environmental factors and CCA axes (Fig. 5a, b; Table 1). Correlation analysis indicated that the separation of the species along the first axis is positively affected by altitude, EC and Mn content ($r = 0.79$, 0.40 and 0.40, respectively). On the other hand, organic matter ($r = 0.64$) and K ($r = 0.44$) are positively correlated with the second axis, while Ca is negatively correlated ($r = -0.53$) (Table 1). Steppe species type in communities I and II (e.g., *Rhanterium epapposum*, *Rhazya stricta*, *Pennisetum divisum*, *Haloxylon salicornicum*, *Stipagrostis*

Fig. 4 Relationship between the seven plant communities after the application of TWINSPAN (**a**) and DCA (**b**)



plumosa) on the negative axis 1 are correlated with fine sand and Fe content. These combinations are typical in the runnels and depressions of lowland plain. The cliff plant species of communities VI and VII (e.g. *Helianthemum* species, *Fagonia bruguieri*, *Farsetia depressa*, *Salvia spinosa*) on the positive axis 1 are correlated with altitude, EC and Mn. These combinations are typical in the fissures of upland plateau. The grass-shrubby species in community V (e.g., *Acacia ehrenbergiana*, *Lasiurus scindicus*, *Plantago boissieri*, *Stipagrostis drarii*, *Convolvulus austro-aegyptiacus*, *Salvia aegyptiaca*) on the positive axis 2 is correlated with organic matter. These species are typical in the deep depressions at the foothills of the escarpment. On the other hand, the species of pseudo-savanna communities

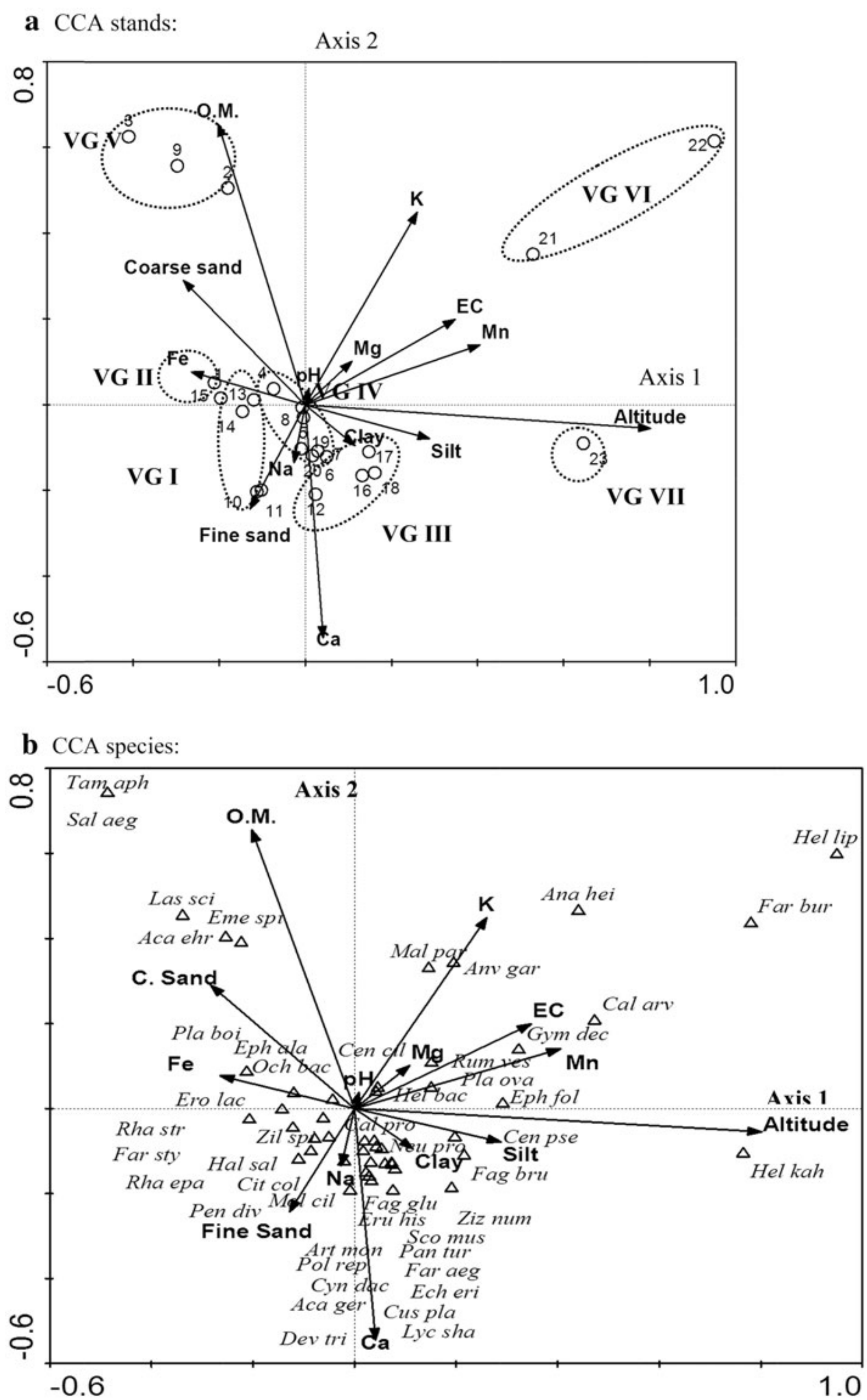


Fig. 5 CCA biplot with environmental variables (*arrows*), the stands **a** abundant species **b**. For complete species name, see "Appendix"

III and IV (e.g., *Acacia gerrardii*, *Panicum turgidum*, *Aristida adscensionis*, *Ziziphus nummularia*, *Lycium shawii* and *Hyparrhenia hirta*) on the center of the CCA diagram without clear distribution. These combinations are typical in the main wadi channels and narrow runnel of the escarpment. (Fig. 5a, b).

Table 1 Interset correlations of environmental variables with CCA axes

Variable	AX1	AX2
Altitude m^{-1}	0.79***	−0.05
EC mS cm^{-1}	0.35*	0.19
pH	0.01	0.04
Bulk soil (%)		
O.M.	−0.20	0.64***
Coarse sand	−0.28	0.28
Fine sand	−0.13	−0.24
Silt	0.29	−0.08
Clay	0.11	−0.09
Minerals soil (ppm)		
Ca	0.04	−0.53**
K	0.26	0.44*
Na	−0.03	−0.13
Fe	−0.26	0.07
Mg	0.11	0.09
Mn	0.40*	0.14

Significant at * $p \leq 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$

According to correlation analysis of species diversity and edaphic variables (Table 2), the species richness, turnover and evenness are positively correlated with total cover ($r = 0.56$, 0.30 and 0.40, respectively) and negatively with pH ($r = -0.47$, −0.45 and −0.41, respectively) and Mn ($r = -0.40$, 0.30 and −0.41, respectively). On the other hand, the species dominance correlated negatively with cover ($r = -0.30$) and positively with pH, coarse sand, and Mn ($r = 0.31$, 0.34 and 0.30, respectively). The altitude correlated positively with EC, silt and Mn ($r = 0.46$, 0.54 and 0.46, respectively), but negatively with coarse sand (−0.43).

3.4 Species diversity

The lowland habitat demonstrated the high value of concentration of dominance (0.33) and lower species relative evenness (0.73) (Table 3). The escarpment habitats are characterized by high values of species cover, gamma diversity, species richness, species turnover and species relative evenness (163.6, 111.0, 25.0, 4.4 and 1.09, respectively) and low value of species dominance (0.17).

Table 2 Correlation analysis (Pearson correlation coefficient = *r*) of the species diversity and environmental variables

Variable	Species richness	Species turnover	Species rel. evenness	Species dominance	Species cover	Altitude
Species richness (α) (sp $stand^{-1}$)	1.00					
Species turnover (β) ($\gamma\ \alpha^{-1}$)	**0.52****	1.00				
Species relative evenness Shannon evenness ($\hat{H}$)	**0.78*****	**0.36**	1.00			
Species dominance Simpson dominance (C)	**−0.50****	−0.04	**−0.68*****	1.00		
Cover (m 100^{-1})	**0.56****	**0.30***	**0.40***	**−0.30***	1.00	
Altitude m^{-1}	0.01	0.05	0.02	−0.23	−0.14	1.00
EC mS cm^{-1}	−0.12	−0.06	0.07	−0.20	−0.31	**0.46***
pH	**−0.47***	**−0.45***	**−0.41***	**0.31***	−0.19	−0.04
Bulk soil (%)						
Org. matter	−0.19	−0.12	−0.11	0.12	−0.15	0.02
Coarse sand	0.01	−0.02	−0.03	**0.34***	−0.20	**−0.43***
Fine sand	0.17	0.02	−0.14	0.05	0.13	−0.08
Silt	0.01	**0.31***	0.05	−0.16	0.07	**0.54****
Clay	−0.09	−0.24	0.06	−0.22	0.07	−0.05
Minerals soil (ppm)						
Ca	−0.21	−0.21	−0.19	−0.05	0.07	0.02
K	−0.28	0.02	−0.22	0.11	−0.03	0.26
Na	−0.05	−0.25	−0.11	0.07	0.05	0.35
Fe	0.08	**0.52****	0.15	−0.03	**0.40***	−0.24
Mg	−0.14	0.12	0.01	−0.17	−0.03	0.37
Mn	**−0.40***	**−0.30***	**−0.41***	**0.30***	−0.13	**0.46***

Significant at * $p \leq 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$, and significant values are in *bold*

On the other hand, the upland habitat showed low value of species cover, gamma diversity, species richness and species turnover (73.33, 32.0, 14.0 and 2.28, respectively).

3.5 Edaphic variables

The plant communities in the low altitude habitats support soils with high value of fine sand (22.8 %), Ca (1171.8 ppm), Na (1646.8 ppm) and Fe (6752.6 ppm), low salinity (120.2 mS cm^{-1}) and organic matter (0.66 %) (Table 4). The escarpment habitat is characterized by high values of coarse sand (26.23 %), and low values of pH, silt, clay, Ca, K, Mg and Mn (7.17, 30.1 %, 23.6 %, 669.8 ppm, 705.5 ppm, 1,607.2 ppm and 40.6 ppm, respectively) (Table 4). On the other hand, the upland habitat has low value of coarse and fine sand (7.2 and 11.8 %), and high values of salinity, pH, silt, clay, K, Mg and Mn (266.7 mS cm^{-1}, 7.27, 50.8 %, 30.0 %, 2750 ppm, 3,056.7 ppm, 118.3 ppm, respectively).

As for *Rhanterium epapposum–Rhazya stricta* community (I) that inhabits the sandy sheet of lowland had the highest values of fine sand (24.6 %) and Ca (1237 ppm); but with the lowest of organic matter (0.63 %) and Fe (324 ppm) (Table 4). *Panicum turgidum* community (IV) which inhabits the slope runnels of escarpment attained the high value of Na (2,069 ppm) and the lowest of pH (7.12), clay (16.8 %) and Mn (28.4 ppm). *Acacia ehrenbergiana–Lasiurus scindicus* community (V) that inhabits the depression of escarpment had the highest of organic matter (2.4 %) and coarse sand (42.7 %), but lower values of altitude, EC, silt, Ca, and Mg (582.7 m, 97.0 mS cm^{-1}, 23.6 %, 171.3 and 1,348.0 ppm, respectively). On the other hand, *Helianthemum lippii* (VI) that inhabits the upland grooves had high contents of EC, silt, K, Mg and Mn (310.0 mS cm^{-1}, 53.5 %, 3,261.50, 3,580.00 and 144.00 ppm, respectively), but lower values of the fine sand (10.5 %). *Helianthemum kahiricum* community (VII) dominated the upland habitats at 782.0 m, which is characterized by neutral pH (7.31) and (36.0 %) clay content, with low values of coarse sand (3.6 %) and Na (1,009 ppm) contents.

3.6 Phenology of common species

The peak period of flowering and fruiting of most species in the study occurs between January and May where maximum fruiting occurs during late spring and early summer. A diagrammatic representation of the phenological stages of the most common plants in the study area is presented in (Fig. 6). Three major phenological categories feature the vegetation; (a) species vegetative all the year round, e.g., *Acacia gerrardii*, *Calotropis procera, Lycium shawii* and *Rhazya stricta*; (b) species dormant during summer/autumn months, e.g., grasses, *Achillea fragrantissima*, *Teucrium oliverianum*, *Pancratium tortuosum* and *Echium arabicum*; and (c) species with accidental flowering including *Fagonia bruguieri*, *F. glutinosa*, *Farsetia aegyptia*, *Lycium shawii* and *Zilla spinosa*. During the accidental flowering period, the fruits generally do not produce viable or mature seeds, but act as photosynthetic organs. All species exhibited reproductive activity during period 3–6 months with either unimodal or bimodal peaks for flowering and fruiting.

4 Discussion

Variations of the landscape in the study area reflect the vegetation and floristic differences among sites. The contribution of annual plants, that represented 43 % of the total flora in the region, is slightly lower than the woody plants. These results are comparable with those of Mandaville (1990) who estimated the annuals as 46 %, but not comparable with Alatar et al. (2012) on Wadi Al-Jufair (51 %). This variation in the life form reflects the difference in topography, human impacts, and aridity due to high temperature, low rainfall with unpredictable duration and distribution and hence soil instability (see Hutchinson et al. 2000; Kürschner and Neef 2011; Alatar et al. 2012; El-Sheikh et al. 2012).

Among the chorotypes, the Saharo-Arabian elements in the monoregional category constitute the major floristic component. This can be explained by the fact that the study area is located in the center of Saharo-Arabian region (Zohary 1973; Kürschner 1986; Ghazanfar and Fisher 1998; Hegazy et al. 1998; El-Ghanem et al. 2010; Kürschner and Neef 2011; Alatar et al. 2012). The Sahelien-Somali Masai elements were the highest among the bi-regionals for phanerophytes. Due to most of the southwestern and southern part of Arabia are strongly influenced by a tropical climate and monsoonal rainfalls. Zohary (1973) proposed a Sudanian floral region for this area also, which already belongs to the Palaeotropic floristic kingdom. As a meeting point, the flora in the region is the product of historical and former phytogeographical migration routes (Zohary 1973; Mandaville 1990; White and Leonard 1991; Hegazy et al. 1998; Ghazanfar and Fisher 1998; Alfarhan 1999; Kürschner and Neef 2011; Alatar et al. 2012).

Vegetation in the lowland habitat in the outlet of sandy wadis are colonized by two pseudo-steppe clusters, *Rhanterium epapposum–Rhazya stricta* community (I) on the deep sandy plain sheets and *Pennisetum divisium–Haloxylon salicornicum* community (II) on the shallow gravel runnels depression. These communities are almost similar to the communities described 30 years ago (Baierle and Kürschner 1985) in the study area. These communities

Table 3 Presence and cover percentage of the characteristic species and the diversity variables (mean ± standard deviation) of seven vegetation units in different habitats of Thumamah Park

Landscape habitat (Macro habitat)	Lowland			Escarpment				Upland plateau			Total Mean	*F*-value
Microhabitat	Sandy sheets	Depres. channel	Mean	Wadi cliffs	Slope runnels	Depres.	Mean	Grooves	Grooves	Mean		
Community unit	VG I	VG II		VG III	VG IV	VG V		VG VI	VG VII			
Stand No.	10,13,14	1,15		8,11,12, 16,17,18,19)	4,5,6,7,20	2,3,9		21,22	23			
G/P (%)	13	9	22	31	22	13	65	9	4	13		
Percentage % and (cover m 100^{-1}) of Dominant species in landscape habitat												
I- Rhanterium epapposum- Rhazya stricta	**100 (61)**	–	60 (37)	72 (10)	80 (11)	–	60 (8)	–	–	–		
	100 (12)	100 (49)	**100 (27)**	14 (2)	–	–	7 (0.7)	–	–	–		
II- Pennisetum divisum - Haloxylon salicornicum	100 (16)	**100 (30)**	**100 (26)**	29 (10)	20 (0.2)	–	20 (5)	–	–	–		
	100 (9)	100 (23)	100 (15)	85 (13)	80 (5)	–	67(8)	50 (0.5)	–	25 (0.3)		
III- Acacia gerrardii-	–	–	–	**86 (22)**	40 (6)	–	**54 (13)**	–	–	–		
Panicum turgidum	–	50 (1)	20 (0.4)	86 (22)	100 (21)	–	73 (18)	–	–	–		
IV-Panicum turgidum	–	50 (1)	20 (0.4)	86 (22)	**100 (21)**		**73 (18)**	–	–	–		
V-Acacia ehrenbergiana-	–	–	–	–	20 (6)	**67 (13)**	**20 (5)**	–	–	–		
Lasiurus scindicus	–	100 (28)	40 (12)	43 (3)	–	**100 (24)**	**40 (6)**	–	–	–		
VI-Helianthemum lippii	66 (1)	–	40 (0.6)	43 (0.7)	20 (0.2)	–	27 (0.4)	100 (17)	–	**50 (9)**		
VII- Helianthemum kahiricum	–	–	–	–	–	–	–	–	**100 (10)**	**50 (5)**		
Community or diversity variables												
Cover (m 100^{-1})	116.0 ± 15.5	187.0 ± 130.1	144.4 ± 76.5	**215.9** ± 74.9	116.4 ± 56.4	120.0 ± 28.1	**163.6** ± 77.4	93.0 ± 26.8	**34.0**	**73.33** ± 39.0	147.6	2.61*
Gamma diversity (γ) Total species no.	16.0	25.0	34.00	51.0	42.0	29.0	**111.0**	24.0	7.0	**32.00**	119.0	
Species richness (α) (sp $stand^{-1}$)	10.67 ± 1.1	16.50 ± 9.1	13.00 ± 5.6	**29.28** ± 7.1	24.4 ± 3.8	16.0 ± 3.4	25.00 ± 7.3	17.00 ± 2.82	**8.0**	14.00 ± 5.5	21.0	6.59***
Species turnover (β) ($\gamma\ \alpha^{-1}$)	1.49 ± 0.12	1.52 ± 0.5	2.60 ± 29.3	1.74 ± 0.23	1.72 ± 0.15	**1.81** ± 0.21	**4.44** ± 19.4	1.41 ± 0.16	**0.88** 1.0	**2.28** ± 0.12	3.1	0.01
Species relative evenness	**0.57**	0.96	**0.73**	**1.16**	1.10	0.88	**1.09**	0.97	0.83	0.93	0.99	5.91**
Shannon evenness ($\hat{H}$)	±0.2	±0.19	±0.27	±0.07	±0.09	±0.28	±0.17	±0.17		±0.15		
Species dominance	**0.45**	0.15	**0.33**	**0.11**	0.12	0.43	**0.17**	0.18	0.15	**0.18**	0.21	5.84**
Simpson dominance (*C*)	±0.23	±0.04	±0.23	±0.03	±0.05	±0.17	±0.15	±0.08		±0.06		

G/P the percentage of the stands representing each vegetation group in relation to the total sampled stand.* $p \leq 0.05$, ** $p \leq 0.01$ and *** ≤ 0.001, according to one-way ANOVA. Max. and min. values are in *bold*

Table 4 The edaphic variables of the seven vegetation groups (mean ± standard deviation) as identified after TWINISPAN: VG I-*Rhanterium epapposum–Rhazya stricta*, VG II-*Pennisetum divisum–Haloxylon salicornicum*, VG III-*Acacia gerrardii–Panicum turgidum*, VG IV-*Panicum turgidum*, VG V-*Acacia ehrenbergiana–Lasiurus scindicus*, VG VI-*Helianthemum lippii* and VII-*Helianthemum kahiricum*

Landscape macro habitat	Lowland			Escarpment				Upland plateau			Total Mean	*F*-value
Microhabitat	Sandy sheets	Depr. channel	Mean	Wadi cliffs	Slope runnels	Depr.	Mean	Grooves	Grooves	Mean		
Community unit	VG I	VG II		VG III	VG IV	VG V		VG VI	VG VII			
Stand no.	10,13,14	1,15		8,11,12, 16,17,18,19	4,5,6,7,20	2,3,9		21,22	23			
G/P (%)	13	9	22	31	22	13	65	9	4	13		
Edaphic (soil) variables												
Altitude m	618.7 ± 15.0	596.5 ± 27.5	**609.80**± 21.2	648.9 ± 40.9	619.6 ± 50.4	**582.7** ± 17.2	625.87 ± 46.5	753.0 ± 31.1	**782.0**	**762.67** ± 27.6	640.22	7.35***
EC mS cm-1	123.33 ± 18.9	115.50 ± 41.7	**120.19**± 25.2	138.57 ± 65.2	108.4 ± 22.0	**97.0** ± 29.1	120.20 ± 50.7	**310.0** ± 182	180.0	**266.67** ± 150.1	139.30	2.84*
pH	7.23 ± 0.15	7.30 ± 0.14	7.26 ± 0.13	7.18 ± 0.13	**7.12** ± 0.11	7.20 ± 0.10	**7.17** ± 0.11	7.25 ± 0.07	**7.31**	**7.27** ± 0.05	7.20	0.77
Bulk soil (%)												
OM (%)	**0.63** ± 0.26	0.72 ± 0.28	**0.66** ± 0.23	0.97 ± 0.61	0.61 ± 0.41	**2.40** ± 1.15	1.13 ± 0.92	1.35 ± 0.15	1.24	1.31 ± 0.12	1.06	3.40*
Coarse sand	18.02 ± 5.3	13.68 ± 13.6	16.29 ± 8.12	14.75 ± 15.6	32.43 ± 10.3	**42.67** ± 7.0	**26.23** ± 16.7	9.00 ± 7.5	**3.64**	7.21 ± 6.1	21.59	3.54*
Fine sand	**24.60** ± 3.4	20.02 ± 4.2	**22.77** ± 4.10	22.29 ± 11.3	19.61 ± 8.9	15.71 ± 2.5	20.08 ± 9.2	**10.51** ± 6.2	14.9	**11.97** ± 5.1	19.61	0.80
Silt	34.71 ± 12.7	35.30 ± 19.2	34.94 ± 13.2	32.11 ± 13.3	31.16 ± 9.4	**23.61** ± 6.7	**30.09** ± 10.9	**53.49** ± 11.3	45.46	**50.81** ± 9.2	33.85	1.46
Clay	22.67 ± 14.4	31.00 1.4	26.00 ± 11.2	30.86 ± 25.5	**16.8** 7.8	18.0 ± 5.3	**23.60** ± 18.7	27.0 ± 12.7	**36.0**	**30.00** ± 10.3	24.96	0.52
Minerals soil ppm												
Ca	**1,237.3** ± 100	1,073.5 ± 347	**1,171.80** ± 219.2	831.57 ± 407	742.4 ± 149.9	**171.33** ± 97.2	**669.80** ± 383.8	877.0 ± 732	833.0	862.33 ± 519	804.04	2.87*
K	773.0 ± 90.1	2,420.0 ± 2,231	1,431.80 ± 1,436	572.71 ± 286	**538.2** ± 428	1,294.0 ± 1,238	**705.47** ± 634.0	**3,261.5** ± 3,602	1,727.0	**2,750.00** ± 2,697	1,130.04	2.05
Na	1,644.7 ± 519	1,650.0 ± 711	**1,646.80** ± 511	1,341.1 ± 836	**2,069.2** ± 795	1,278.7 ± 342	1,571.33 ± 794	1,068.5 ± 252	**1,009.0**	1,048.67 ± 181	1,519.57	0.88
Fe	**324.3** ± 346.2	**16,395** ± 2,2920	**6,752.60** ± 1,4452	1,227.3 ± 2,071	450.8 ± 358	3,224.7 ± 2,505	1,367.93 ± 2,163	331.0 ± 62.2	2,432.0	**1,031.33** ± 1,213	2,494.61	2.05
Mg	1,696.7 ± 299	2,898.0 ± 1,548	2,177.20 ± 1,037	1,615.9 ± 570	1,750.6 ± 519	**1,348.0** ± 997	1,607.20 ± 616	**3,580.0** ± 1,131	2,010.0	3,056.67 ± 1,208	1,920.17	2.81*
Mn	74.67 ± 59.1	92.00 ± 50.9	81.60 ± 49.8	49.00 ± 27.6	**28.4** ± 12.1	41.33 ± 35.6	40.60 ± 25.4	**144.0** ± 1.4	67.0	118.33 ± 44.4	59.65	3.64**

Table 4 continued

Landscape macro habitat	Lowland			Escarpment				Upland plateau			Total Mean	*F*-value
Microhabitat	Sandy sheets	Depr. channel	Mean	Wadi cliffs	Slope runnels	Depr.	Mean	Grooves	Grooves	Mean		
Community unit	VG I	VG II		VG III	VG IV	VG V		VG VI	VG VII			
Stand no.	10,13,14	1,15		8,11,12, 16,17,18,19	4,5,6,7,20	2,3,9		21,22	23			
G/P (%)	13	9	22	31	22	13	65	9	4	13		
DCA axis1	3.13 ± 0.71	1.45 ± 0.01	2.46 ± 1.0	2.85 ± 0.4	2.92 ± 0.20	0.40 ± 0.65	2.38 ± 1.0	2.94 ± 1.7	3.65	3.17 ± 1.2	2.50	8.96***
DCA axis2	0.46 ± 0.74	1.81 ± 0.02	0.99 ± 0.9	2.13 ± 0.26	1.98 ± 0.38	2.25 ± 0.20	2.10 ± 0.29	2.62 ± 0.7	6.25	3.83 ± 2.1	2.09	25.59***

G/P the percentage of the stands representing each vegetation group in relation to the total sampled stand. * $p \le 0.05$, ** $p \le 0.01$ and *** ≤ 0.001, according to one-way ANOVA. Max. and min. values are in *bold*

have a mosaic like pattern with dominant shrubby vegetation that have a well developed root system, capable of regeneration and that enables plants to survive period of burial (Kürschner 1986; El-Sheikh et al. 2010). The associated psammophytic species survive densely around these dominant shrubs which can make small phytogenic mounds, where aeolian of the fine particles deposits covered the land surface (i.e., wind protected areas). Therefore, these communities are characterized by high species dominance and moderate species diversity. In such cases, most of the plant cover is accounted by one or two dominant species that capable to use the available recourses, due to their high competitive capacities under environmental stress. Our results are similar to the effect of hummock formations on the reduction of species evenness and diversity, which also detected in Central Saudi Arabia, Kuwait and North Africa (Shaltout and Mady 1996; Shaltout and El-Ghareeb 1992; El-Sheikh et al. 2010; Wale et al. 2012). Moreover, these habitats have little substrate heterogeneity and low pronounced relies and dominated by pseudo-steppe vegetation (Baierle and Kürschner 1985).

The escarpment habitat types are colonized by three community types (III, IV and V): *Acacia gerrardii–Panicum turgidum* (III) inhabits the main wadi channels of the escarpment cliffs, *Panicum turgidum* (IV) inhabits the narrow runnel of the escarpment slopes, and *Acacia ehrenbergiana–Lasiurus scindicus* (V) inhabits the deep depressions of the foothills in the escarpment. These are wadi and runnel communities of vein-like structure which represent a different size of the catchment areas and dominated by prominent component of the native range flora and scattered arboreal and scrubby-grass vegetation (i.e., extremely xeromorphic woodlands or pseudo-savannas of thorn woodlands). Deep wadi cliffs and deep depressions canyon are dominated by *Acacia* spp. which represents the climax stage of succession of the xerophytic vegetation in Arabia (Zohary 1973; Kürschner 1986; Shaltout and Mady 1996; Aref et al. 2003; El-Sheikh 2005; Kürschner and Neef 2011). The habitat types have alluvial fan, fluvial coarse sand, gravels with moderately drained soil and characterized by high organic matter content and low salinity, pH, and minerals. The soils are often derived from weathered calcareous formations by rugged relief, rapid runoff and pronounced water erosion (karstic rocks). Hence, the deriving heavy coarse sand particles from calcareous escarpment formations was fallen firstly in the deep wadis or gullies and rocky basin depressions, whereas the light fine sand particles will travel by wind to long distance and drops in the lower sand plain land of the park, which characterized by the fine soil particles. The coarse sand particles accumulate with large amounts of the plant debris, which shed at the soil surface of these deep depressions or deep canyon-like structure.

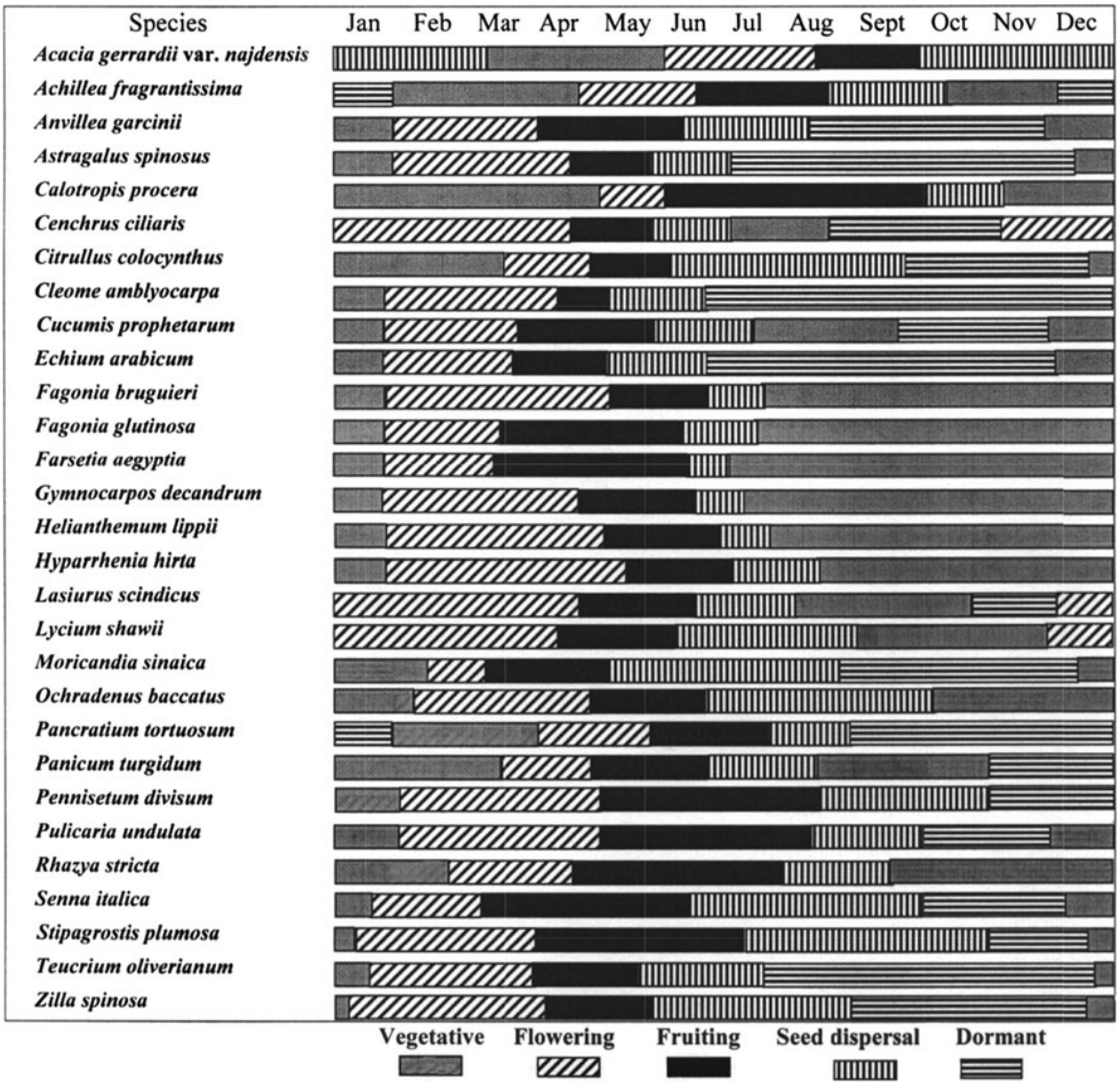


Fig. 6 Phenology of the common selected species in Thumamah Park

In addition, the community III which inhabits the deep main wadi channel of the escarpment cliffs has high plant cover, species richness, species relative evenness and lower species dominance. *Acacia gerrardii* dominates this wadi and is considered as one of the two large-trunked Acacias in Arabia that indicates high ground water sources (Mandaville 1990; Aref et al. 2003). This may explain the high species cover and attainment the final stage of pseudo-savannas climax. Moreover, the well established population of *Acacia gerrardii* plays a secondary role in the enhancement of the ecological niche conditions such as favorable microclimate under trees by providing a shelter or nourishment to other species, or even act as a key plant for many birds and animals and thereby increase the plant species diversity through the dispersal of their seeds and fruits (Baierle and Kürschner 1985; Kürschner 1986; Batanouny 1987; El-Sheikh 2005).

In general, the escarpment microhabitats are characterized by special type of "biotopes", which mostly formed by water erosion and formed deep and narrow canyon-like biotopes with the heterogeneity of the soil substrates. These represent protected gaps with small sized biotope, providing high amount of ecological niches for different species with good water supply that can hardly be found in the rest of the Park and therefore the species diversity increase in these habitats (Baierle and Kürschner 1985). For these reasons and since most of the runnels, wadis and drainage systems being major component in the landscape, the area has an ecological key functional role for the whole park and its surroundings (Alday et al. 2011; Wale et al. 2012). It is an important regeneration center and acts as distribution center or nucleus area for regeneration of plants and animals for the whole area.

The communities inhabiting the upland plateau are dominated by *Helianthemum lippii* (VI) and *Helianthemum kahiricum* (VII). Within both clusters, vegetation is restricted to the small fissures or grooves in colline rock of the upland plateau. These communities are representing habitat types characterized by high salinity, pH and clay contents and lower values of plant cover and species diversity (i.e., xerodrymlum community with poor species productivity and diversity). These habitat types are characteristic to the highest altitude of our study area. These vegetation groups are adapted to low nutrient availability, narrower local distribution in the grooves or fissures between rocks and represent the earlier stages of xerarch succession "xerosere". As described by Alatar et al. (2012), Wale et al. (2012), these communities are characterized by their low productivity.

The correlation analysis indicates that species richness, evenness and turnover are correlated positively with total plant cover and negatively with pH and Mn, whereas species dominance correlated positively with the coarse sand and negatively with total plant cover. Similar correlations were reported in Pysek et al. (2004) and El-Sheikh et al. (2012) in late stage of succession of the desert vegetation. Because many different life forms, the tree, shrub and grass species have different functional behavior. The interspecific competition increases at the medium and later successional stages than in the early stages, which in typical plots, most of the species cover was accounted for by one or two species. Meanwhile, the species dominance increases and species richness decreases at the first stage of succession (Fynn et al. 2011; El-Sheikh et al. 2012). Our results are coincided with those of Qinfeng (2004) who pointed out that a continuing trend towards the increasing species richness and plant cover with time after protection from disturbance. He concluded that it would take between 30 and 50 years for the desert perennial vegetation to recover fully from the effects of prolonged grazing and other large-scale human disturbances.

Altitude is correlated with the increase of salinity, silt, Na, Mg, Mn and had low species diversity. Because the increasing salinity and minerals content, usually resulted from rock erosion, where the direct action of wind and heating effect of the sun which increases the evaporation rates from exposed fissures soil, hence the water table decrease and salinity and minerals become concentrated. Correspondingly, our results show that species richness decreased markedly, with increased dosage of fertile soil, agree with the general trend and therefore, upland plateau are restricted by dwarf "xerosere" plant community (Kürschner 1986; Batanouny 1987; El-Sheikh and Abbadi 2004; Wale et al. 2012).

In general, the Park vegetation in the present study has higher species cover and species diversity indices than the vegetation of the other regions (see Table 5). Moreover, the study of Zahran and Younes (1990) on a fully protected area in the region of Khamis Mushait with the mean annual rainfall of 242 mm year^{-1} indicated that the total cover was 96 % inside the protected area and 45 % in the free grazing areas. In the region of Abha, the mean annual rainfall is 332 mm year^{-1}, whereby Abulfatih et al. (1989) reported an increase of phytomass that reached 267 % after 5 years of protection. The increase of species richness and total plant cover was mainly due to emergence of palatable herbs and grasses, which was usually decreased in response to heavy grazing before fencing the Park (Hajara 1993; Shaltout et al. 1996; Assaeed 1997; Havstad et al. 1999; Floyd et al. 2003; Qinfeng 2004; El-Sheikh et al. 2006; Wale et al. 2012).

A variation of plant phenology in space and time explains the phenological diversity among perennial plant species in Thumamah Nature Park. Beside the importance of environmental factors in such phenological diversity, it

Table 5 Comparison between the species diversity indices of vegetation of the present study and that of the raudhas (depressions) in Arriyadh and coastal lowland in the eastern region of Saudi Arabia

Diversity variables	Present study 2012	Shaltout and Mady 1996	Shaltout et al. 1996	
	Protected Thumamah Park (stand size 10 × 10 m)	Unprotected raudhas near the study area (stand size 10 × 10 m)	Protected Coastal vegetation (stand size 20 × 20 m)	Unprotected Coastal vegetation (stand size 20 × 20 m)
Species cover m 100 m^{-1}	147.6	54	66.5	39.7
Total species no (Υ-diversity)	119	107	68	61
Species richness (α-diversity) spp. stand^{-1}	21.0	3.3	18.9	14.2
Species turnover (β-diversity) Υ α^{-1}	3.1	3.10	3.96	5.1
Relative evenness ($\hat{H}$) Shannon-Wiener index	0.99	0.39	0.82	0.62
Conc. of dominance (C) Simpson index	0.21	0.56	0.28	0.38

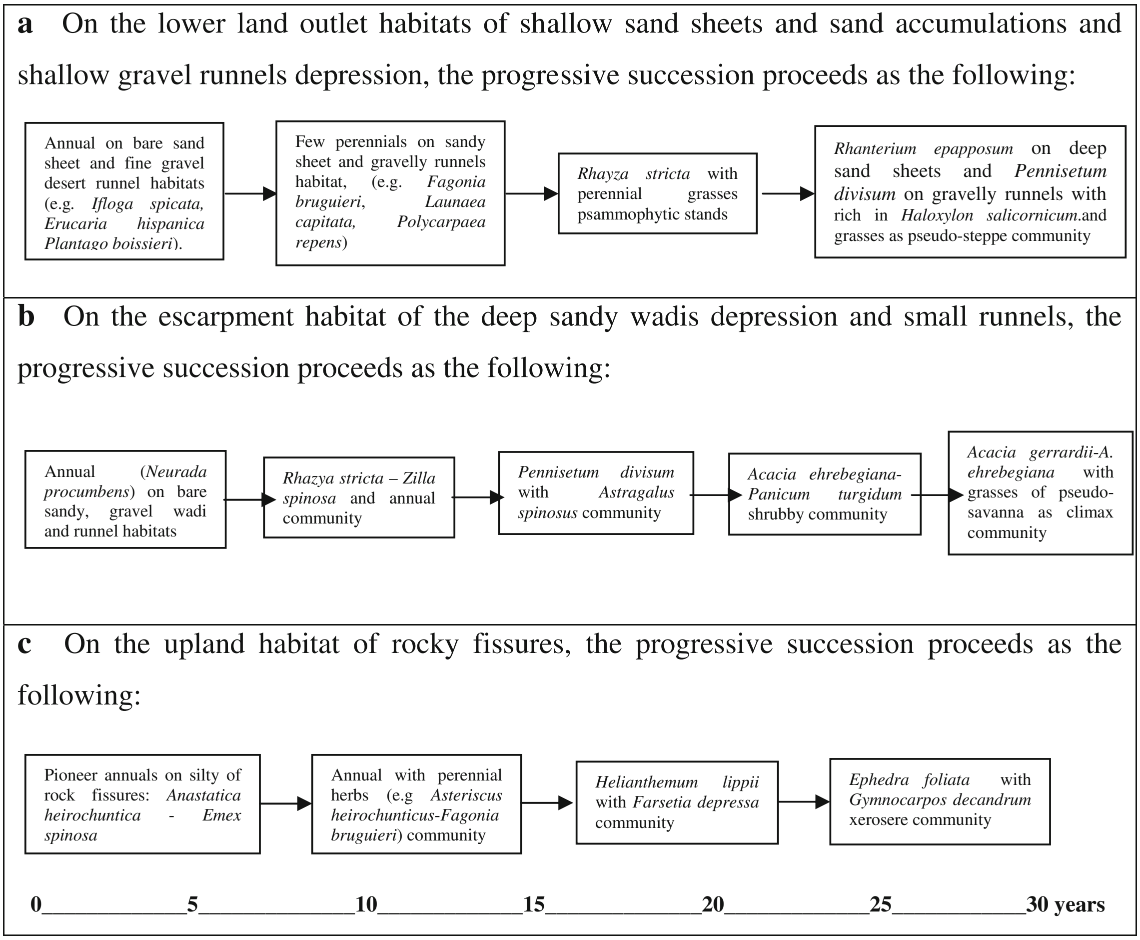


Fig. 7 The hypothesis of the main processes involved in the progressive succession of Thumamah Nature Park vegetation during the prolonged conservation of 30 years **a**–**c**

may be a product of competition among plants for pollination activities (Stone et al. 1998). The phenological diversity around the year results from variable biotic and abiotic factors, particularly, the plant life forms, rainfall events and temperature (Marques et al. 2004; Hegazy et al. 2012). This is considered as important reproductive and adaptive plant strategies in arid deserts (Ward 2009). All study species exhibited a unimodal peak for flowering and fruiting around the year.

The phenological behavior of *Ochradenus baccatus* in the study area demonstrated unimodal flowering–fruiting peak covered spring and summer seasons. This contrasts the species behavior in another arid region, wadi Degla in Egypt, where many individuals of the species flower over most of the year with two major peaks (bimodal) in spring and autumn (Hegazy et al. 2012). This behavior was reported also in Ein Gedi, Palastine (Wolfe and Burns 2001). Topographic features, historical and geographical changes in rainfall are important drivers that cause complex phenological changes among species and communities (Penuelas et al. 2004). Soil type plays a role in water availability for plants and may produce various phenological niches under same environmental variables (Hegazy et al. 2012). The species having accidental flowerings during autumn, e.g., *Ochradenus baccatus*, *Zilla spinosa* and *Lycium shawii* do not reach into fruiting stage or produce viable seeds. In this case flowers function as photosynthetic organs rather than reproductive organs (Kassas 1966).

When a park is fenced against human impacts, the success of the initial revegetation treatment provides a starting species pool for the subsequent succession. Once this pool is established, other processes come into play including species assembly rules, rates of species colonization and extinction and both positive and negative species interactions; all of which interact to produce species turnover and vegetation structure change. Therefore by following the course of succession those spatial and temporal changes in the vegetation structure and species patterns that determine the outcome of succession can be identified (Walker and del Moral 2009; Alday et al. 2011). Hence, as succession proceeds, there is an opportunity to study the dynamics of vegetation development in these disturbed ecosystems (Alday et al. 2010, 2011). The plant succession has a practical importance for future ecological restoration and theoretical importance for understanding the fundamental ecological theory and the initial phases of vegetation establishment (Robbins and Mathews 2009).

We can hypothesized the main processes involved the progressive succession of Thumamah Nature Park vegetation during the prolonged conservation of 30 years (Fig. 7a–c): On the bare sand sheets and fine gravel runnels of the lowland, annuals are established first followed by perennial herbs and grasses of psammophytic species dominated by *Rhazya stricta*. Finally, *Rhanterium epapposum* on deep sand sheets and *Pennisetum divisum* on gravel runnels colonize the lowlands in association with *Haloxylon salicornicum* and grasses as pseudo-steppe succession community (Fig. 7a). The progressive succession in the escarpment habitats “wadi and runnels” proceeds from pioneer annual herbs, e.g., *Neurada procumbens* community, then perennial herbs and shrubs of *Rhazya stricta–Zilla spinosa* community appear and modify the substrate before the next succession stages of *Acacia ehrenbergiana–Panicum turgidum* shrubby community and finally to pseudo-savanna as a diverse climax community of *Acacia gerrardii–Acacia ehrenbergiana* (Fig. 7b). In the upland plateau, *Anastatica heirochuntica–Emex spinosa* of pioneer annuals community establishes first and followed by annual and perennial herbs of *Asteriscus heirochunticus–Fagonia bruguieri* community. Then *Helianthemum lippii* and *Farsetia depressa* community are established with *Ephedra foliata* and *Gymnocarpos decandrum* as a dwarf xerosere community (Fig. 7c).

In conclusion, the community types representing common stages of the progressive succession reflect the relationship between altitude, edaphic factors and the type of vegetation type in each habitat type. The simultaneous invasion of both early and late succession species and their successful establishment depends on the specific nutrient and water availability, and the life cycles of the taxa. The findings of this study highlight that desert vegetation under exclusion of anthropogenic effects and mixed prevailing environmental conditions may enhance establishment of diverse plant communities. Plant populations showed interspecific variations in their relative timing of phenological phases with varied flowering/fruiting activity periods.

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Appendix

Synoptic table of the vegetation groups in Thumamah Park after identifying by TWINSPAN: VG I-*Rhanterium epapposum–Rhazya stricta*, VG II-*Pennisetum divisum–Haloxylon salicornicum*, VG III-*Acacia gerrardii–Panicum turgidum*, VG IV-*Panicum turgidum*, VG V-*Acacia ehrenbergiana–Lasiurus scindicus*, VG VI-*Helianthemum lippii* and VII-*Helianthemum kahiricum*

Spp. no.	Species	Life form	Choro-type	I II II IV V VI VII
				1111 1 111 121 222
				03451468812957607239123
39	*Echinops erinaceus* Kit-Tan	Ch	IT	------312233223-------2
2	*Acacia gerrardii* Zoh.	Ph	SA	------5554554-4--------
18	*Calligonum comosum* L'Her.	Ph	SA-IT	-------5---------------
20	*Carthamus oxyacantha* M. Bieb.	Th	IT	----------4---1--------
71	*Lycium shawii* Roem. & Schult.	Ph	SA-SM	-------5-355--5--------
101	*Savignya parviflora* (Del.) Webb	Th	SA	-------2---3--1--------
119	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Ph	SH-SM	-------5---------------
13	*Astragalus spinosa* (Forssk.) Muschl.	Ch	IT	-------2-3------2------
29	*Convolvulus buschiricus* Bornm.	Ch	SA	-----------3----2------
33	*Cucumis prophetarum* L.	He	SA	------2-----1----------
34	*Cynondon dactylon* (L.) Pers.	He	TR	-------122-3--3--------
85	*Pergularia tomentosa* L.	Ch	SH-SM	------4--------2-------
104	*Scorzonera musillii* Vel.	He	IT	------212-2---1-2------
113	*Teucrium oliverianum* Ging. ex Benth.	He	SA	-----------21----------
9	*Artemisia monosperma* Del.	Ch	SA	------33----53---------
19	*Calotropis procera* (Ait.) Ait.f.	Ph	SH-SM	------4-----4-2--------
32	*Cuscuta planiflora* Tenore	Th	AM	-------1---21-111------
54	*Gastrocotyle hispida* (Forssk.) Bunge	Th	SA-IT	--------------11-------
63	*Horwoodia dicksoniae* Turril	Th	SA	------1------1–2-------
64	*Ifloga spicata* (Forssk.) Sch.- Bip.	Th	SA	----------------5------
76	*Monsonia nivea* (Decne.) Decne. ex Webb.	Th	SH-SM	-------------1–1-------
80	*Pancratium tortuosum* Herb.	He	Med	----------------2------
102	*Schimpera arabica* Hochst. & Steudel	Th	SA	-------1-----1–2-------
103	*Sclerocephalus arabicus* Boiss.	Th	SA	-----------3–222-------
106	*Senna italica* Miller	Ch	SH-SM	------------1---2------
11	*Astenatherum forsskalii* Vahl	Ch	SA-IT	-----1--1---11-1-------
49	*Farsetia aegyptiaca* Turra	Ch	SH-SM	---2-1223-342-442------
73	*Medicago laciniata* (L.) Mill.	Th	SA	-----12-------2-2------
81	*Panicum turgidum* Forssk.	Ch	SA-SM	----244442545455-------
25	*Citrullus colocynthis* (L.) Schrader	He	SA	----334-222-----2------
48	*Fagonia glutinosa* Del.	Ch	SA	-----1--1–2----2-------
75	*Moltkiopsis ciliata* (Forssk.)I.M. John.	Ch	SA	----2-2---21----1------
7	*Aristida adscensionis* L.	He	Med-IT-SA	-----1-------1–2-------
15	*Bassia eriophora* (Schrader) Asch.	Th	SA-SM	----2------------------
16	*Blepharis ciliaris* (L.) B.L. Burtt.	Th	SA-IT	----21-2----1-222------
26	*Cleome amblyocarpa* Barr. & Murb.	Th	SA-SM	-----2----------1------
42	*Ephedra alata* Decne.	Ph	SH-SM	----23----------1------
45	*Erodium laciniatum* (Cav.) Willd.	Th	Med	----3--1-----1---------
51	*Farsetia stylosa* R.Br.	Ch	SH-SM	----312--2--11---------
60	*Heliotropium arbainense* Fresen.	Ch	SA	-----2------1-2--------
69	*Launaea angustifolia* Boiss.	Th	SA	-----1---------1-------
114	*Tribulus macropterus* Boiss.	He	SH-SM	----2-----------1------
115	*Tribulus terrestris* L.	Th	EU-Med-IT	----2---1-----1-2------
78	*Neurada procumbens* L.	Th	SA	2---5--2222331–5-------
91	*Polycarpaea repens* (Forssk.) Asch.. & Sch.	He	SH-SM	2----111112--1-12------
31	*Convolvulus oxyphyllus* ssp. *oxycladus* Rech. f.	Ch	SA	2----------------------
83	*Pennisetum divisum* (Gmel.) Henr.	Ch	SA	52245---4-5----1-------
96	*Rhazya stricta* Decne	Ch	SA	53345----4-------------
111	*Stipagrostis plumosa* (L.) Munro ex T. Anders.	He	SA-IT	222----1--------2------
36	*Deverra triradiata* (Hochst.) Aschers	Ch	SA	5-----34–34------------
46	*Erucaria hispanica* Druce	Th	Med	-22-21-12–111421-------
95	*Rhanterium epapposum* Oliv.	Ch	SA	555--221--554-354------
56	*Haloxylon sallicornicum* (Moq.) Bunge	Ch	SH-SM	5225422435-5-3442-2-1--

continued

22 *Centaurea pseudosinaica* Czerp.	Th	SA	------21-23---1------2-
43 *Ephedra foliata* Boiss. ex C.A. May	Ph	SH-SM	------222-54--4-4----5-
21 *Cenchrus ciliaris* L.	Ch	SA	----3--13--21-22-2---2-
62 *Heliotropium bacciferum* Forssk.	Ch	SA-SM	1---4-12233--22-2—222--
88 *Plantago boissieri* Hausskn. & Bornm.	Th	SA	-11-5--21--------2-----
118 *Zilla spinosa* (L.) Prantl.	Th	SA	---4—3-22543-3--32-----
79 *Ochradenus baccatus* Del.	Ph	TR AF	----2--35—4------2-----
47 *Fagonia bruguieri* DC.	Ch	SA	---12--2----1-52----2-3
97 *Rumex vesicarius* L.	Th	SA	----212-3---213223—22--
17 *Calendula arvensis* L.	Th	Med-IT	------1111----1-----12-
50 *Farsetia burtoniae* Oliver	Ch	SH-SM	-------2---2---------3-
70 *Leontodon laciniatus* (Bertol) Widder	Th	SA-IT	-----152---------4-----
82 *Paronychia arabica* (L.) DC.	Th	SA	-----------1---2---2--
77 *Moricandia sinaica* (Boiss.) Boiss.	Ch	SA	-----5--------------3-3
89 *Plantago ovata* Forssk.	Th	SA-IT	-------2--2-----2—21-2-
8 *Arnebia hispidissima* (Lehm.) DC.	Th	SA-SM	---------1--------1----
41 *Emex spinosa* (L.) Campd.	Th	Med	1------2-221-1--225-1--
65 *Lasiurus scindicus* Henr.	He	SA-SM	---45--233-------255---
84 *Periploca aphylla* Decne	Ph	TR AF	----------5------4-----
59 *Helianthemum lippii* (L.) Doum.- Cours.	Ch	SA-SM	-12----2----1-1-2---25-
14 *Atractylis mernephethae* Asch. Schweinf.	Th	SA	-22---------------11---
61 *Heliotropium aegyptiacum* Lam.	Ch	SA	---2--1------------2---
66 *Launaea capitata* (Spreng.) Dandy	Th	SA	111--------------3-----
87 *Plantago amplexicaulis* Cav.	Th	SA	-----------2--3—4-2----
5 *Anisosciadium lanatum* Boiss.	Th	SA	-------1------11-4-----
28 *Convolvulus austro-aegyptiacus* **Abdallah & Sa'ad**	He	SA	------------12----3----
55 *Gymnocarpos decander* Forssk.	Ch	SA	---------------1----1--
72 *Malva parviflora* L.	Th	Med-IT	---------2-21-11-3-222-
1 *Acacia ehrenbergiana* Hayne	Ph	SH-SM	------------5----45----
3 *Althaea ludwigii* L.	Th	SA	---------2-------1-24--
4 *Anastatica heirochuntica* L.	Th	SA	---------------1-3-252-
6 *Anvillea garcinii* (Burm.f.) DC.	Ch	SA	--------------2—2113--
30 *Convolvulus pilosellifolius* Desr.	He	IT	-----------------2-1---
67 *Launaea mucronata* (Forssk.) Muschl.	Th	SA	------------------21---
68 *Launaea nudicaulis* (L.) Hook.f.	Ch	SA	--------1--------3----1
94 *Pulicaria undulata* (L.) C.A. May	Ch	SH-SM	---2-------------3-----
112 *Tamarix aphylla* (L.) Karst.	Ph	SH-SM	------------------4----
117 *Trigonella stellata* Forssk.	Th	SA	-----------------3-2---
12 *Astragalus schimperi* Boiss.	Th	SA	--------------------2--
27 *Cleome rupicola* Vicary	Ch	SH-SM	---------------1-----2-
38 *Diplotaxis harra* (Forssk.) Boiss.	Ch	SH-SM	---------------1----2--
52 *Farsetia depressa* Kotschy	Ch	SH-SM	---------------1----22-
74 *Microchloa kunthii* Desv.	He	SA	---------------------2-
105 *Senecio glaucus* L.	Th	SA-IT	--------------1------2-
10 *Asteriscus heirochunticus* (Michon) Wiklund	Th	SA	---------------1------2
44 *Erodium glaucophyllum* (L.) L'Her	He	SA	----------------------3
58 *Helianthemum kahiricum* Del.	Ch	SA	----------------------4

The cover levels are coded as follows: 1, ≤ 10 %; 2, 10–20 %; 3, 20–30 %; 4, 30–40 %; 5, 40–50 %; 6, 50–60 %; 7, 60–70 %; 8, 70–80 %; 9, ≥ 90 %. The life forms are: *Th* therophyte, *Ch* chamaephyte, *Ph* phanerophyte, *He* hemicryptophyte. The chorotypes are: *IT* Irano-Turanian, *SA-IT* Saharo-Arabian–Irano-Turanian, *SH-SM* Sahelian-Somali Masai, *TR* tropical, *SA* Saharo-Arabian, *SA-SM* Saharo-Arabian-Somali Masai, *TR AF* tropical African, *TR AM* tropical American, *Med-IT* Mediterranean–Irano-Turanian, *EU-Med-IT* Euro-Siberian–Mediterranean–Irano-Turanian, *Med* Mediterranean, *Med-IT-SA* Mediterranean–Irano-Turanian–Saharo-Arabian, *Cosm* cosmopolitan, *TR AF-SA* Tropical Africa–Saharo-Arabian

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