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ORIGINAL ARTICLE

Weed vegetation ecology of arable land in Salalah, Southern Oman

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Abstract This paper applies multivariate statistical methods to a data set of weed relevés from arable fields in two different habitat types of coastal and mountainous escarpments in Southern Oman. The objectives were to test the effect of environmental gradients, crop plants and time on weed species composition, to rank the importance of these particular factors, and to describe the patterns of species composition and diversity associated with these factors. Through the application of TWINSPAN, DCA and CCA programs on data relating to 102 species recorded in 28 plots and farms distributed in the study area, six plant communities were identified: I- *Dichanthium micranthum*, II- *Cynodon dactylon–D. micranthum*, III- *Convolvulus arvensis*, IV- *C. dactylon–Sonchus oleraceus*, V- *Amaranthus viridis* and VI- *Suaeda aegyptiaca–Achyranthes aspera*. The ordination process (CCA) provided a sequence of plant communities and species diversity that correlated with some anthropogenic factors, physiographic variables and crop types. Therefore, length of time since farm construction, disturbance levels and altitude are the most important factors related to the occurrence of the species. The perennial species correlated with the more degraded mountain areas of new farm stands, whereas most of the annuals correlated with old lowland and less disturbed farms.

1. Introduction

The concept of a biotic community as a discrete ecological unit is somewhat vague but nonetheless useful because it allows ecologists to define accurately the vegetation with which they are concerned (Radosvich, 1984). A weed community and its environment when treated together as a functional system are known as an ecosystem. In this paper we look in particular at agricultural ecosystems, or agro-ecosystems. In agro-ecosystems species diversity, distribution and productivity are determined by the complementary relationships that develop among weeds, crops, and the environment they both share (Radosvich, 1984). Arable weed assemblages respond to crop type, sowing date and field history (Chancellor, 1985). Weed communities, consisting predominantly of annual plants, show a much higher degree of temporal dynamics than other vegetation types. These dynamics operate both on the scale of

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seasonal changes (Holzner, 1978; Lososová et al., 2003) and on a long-term scale that corresponds to the increasing intensification of agricultural production during the second half of the 20th century. Thus the gradients in the species composition of weed vegetation cannot be properly investigated without consideration of these broad temporal patterns (Lososová et al., 2004). Furthermore, data comparing weed assemblages within fields of single farms often show marked field-to-field variation, indicating that field history as well as local environment affect weed occurrence (Marshall and Arnold, 1994).

Despite its arid nature, Oman is home to various types of plant species. The richest floral areas are found along the coasts and in the mountains of Oman (Kürschner, 1986). The Dhofar area, in the south of the country, contains many afro-tropical and eremic faunistic species, including some endemics, and there is evidence that the region constituted a refuge during both mesic and xeric climatic phases prior to the present period of moist conditions. Rigorous conservation measures are needed to prevent the loss of this small ecologically unique area of Arabia (Sale, 1980; El-Sheikh, 2013).

Up to, 1978 many Jabalis (the Omani population in Dhofar) supplemented their pastoral lifestyle with the cultivation of grain and leguminous crops within circular stone enclosures (plots) as a protection from domestic stock. Subsequently, there has been a significant increase in the extent of cultivation on the Salalah coastal plain, where crops can be cultivated on a commercial scale with irrigation from underground water reserves. This, along with a variety of other factors, led to the cessation of cultivation in the mountainous regions (Sale, 1980). In recent years, however, the Omani government has constructed many experimental farms on the natural land of the mountains.

Regarding the publication of species checklists, the flora of Oman is still not well known, and needs further intensive investigation. So far, 1204 species of vascular plants are known, 750 of which are in Dhofar, reflecting the diversity of this region's habitats. Of these 1204 species, 100 are endemic or nearly endemic, 25 of which are located in the Northern mountains and 12 in central Oman with the remaining 63 are located in Dhofar, including two endemic genera-*Dhofaria* and *Cibirhiza*. Floristically, the plants of Dhofar have a stronger affinity with those of the island of Socotra and the drier regions of tropical NE Africa, rather than with those of Northern Oman. Scientists, however, are not well informed about the diversity of weed flora, and weed vegetation has also not received particular attention in Oman, with, generally, Omani species merely being included in regional floras and checklists, e.g. Mandaville (1978), Radcliffe-Smith (1980), Miller and Morris (1988) and El-Sheikh (2013). The present study is the first attempt to document the weed vegetation of Southern Oman. The study shows the value of this area, which constitutes about two third of the total flora of the country, and can be considered as a hot spot for endemic, native and naturalized species. In addition, in Oman, some species recorded in this area are considered to be troublesome weeds. The objectives of this study were to test the effects of environmental gradients, crop type and the length of time since the farm's construction on the composition of weed species, to rank the importance of these particular factors, and to describe the pattern of species composition and diversity that is associated with these factors.

2. Study area

The study area was a part of the Dhofar region, located in the Southwest of Oman (16° 90′–17° 15′ N and 54° 90′–54° 45′ E). The area consists of sparsely vegetated desert steppe but with a range of Limestone mountains along the Southern coast that is covered in a type of vegetation unique in Arabia. The mountains extend Eastwards, in a crescent-shape, for about 290 km from the border with Yemen (Fig. 1). The top of the range consists of a rolling plateau, rising to over 2100 m, dissected by deep wadis (El-Baz, 2002; El-Sheikh, 2013).

There are no permanent watercourses, however pools persist in the wadi beds and there are a series of spring-fed pools along the foot of the mountains. For three months every year, from June until mid-September, during the Khareef or SW monsoon, these South-facing escarpments are blanked in moisture-laden clouds and in consequence are covered by dense woodland. The clouds quickly disperse as they spill over the mountain ridges and so this unique area of woodland is restricted to a narrow belt some 240 km long but only extending from 3 to 30 km inland (Miller and Morris, 1988; El-Sheikh, 2013).

Meteorological data collected between 1987 and 1994 indicate that the highest temperatures occur in May and June with a mean of 32 °C. Using the notation of Walter (1973), all months except July and August are arid (Fig. 2). During the monsoon, the temperature drops with cloud cover, but relative humidity reaches its highest (97%) during July and August. The temperature rises again when the monsoon lifts in September. The lowest temperatures occur in January and February with means of 27–28 °C. The lowest relative humidity is 40% in February. The total annual rainfall on the coastal plain is between 45–154 mm with maximum values in July. The mountains, however, receive a substantial amount of their total annual rainfall during the monsoon months with between 200 and 500 mm of July and August, see Miller and Morris (1988) and El-Sheikh (2013).

Oman lacks truly fertile agricultural soils: its best soils are the alluvial soils washed down from the mountains in the interior and along the coast (El-Baz, 2002; El-Sheikh, 2013). Consequently, a large number of farms, irrigated using underground water, are located on the coastal plain. These farms grow coconut palms, banana, carica papaya, vegetables and fodder grasses. In the Dhofar Mountains, meanwhile, cultivation takes the form of enclosed plots associated with existing Jabali settlements, and experimental farms constructed by the Government. These farms cultivate grapes, Arabian coffee, orange and other citrus fruits, and vegetables.

3. Material and methods

3.1. Field sites

Twenty-eight 100 m by 100 m plots were used in this analysis. The samples were chosen to provide the most variability in the distribution of the weed vegetation in the common arable lands. Fifteen sample plots were selected from the farms on the coastal plain such as: 1- fodder grass (*Sorghum bicolor*, *Sorghum sudanense* and *Chloris gayana*) farms, which are characterized by soil intensively cultivated annually with perennial fodder crops but harvested after 7–9 months where the distur-

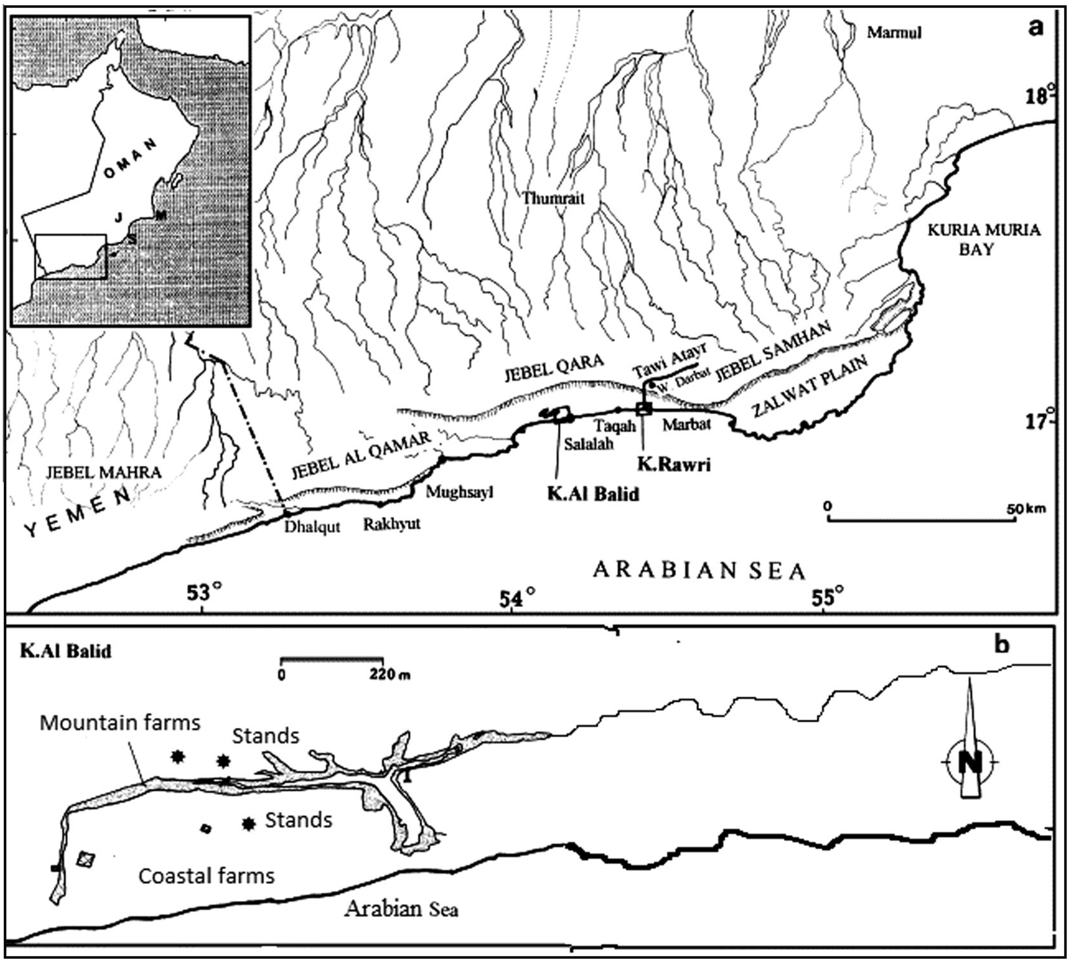

Figure 1 Map of Oman (inset) showing the study area of Salalah (Dhofar region). *The farms sampled.

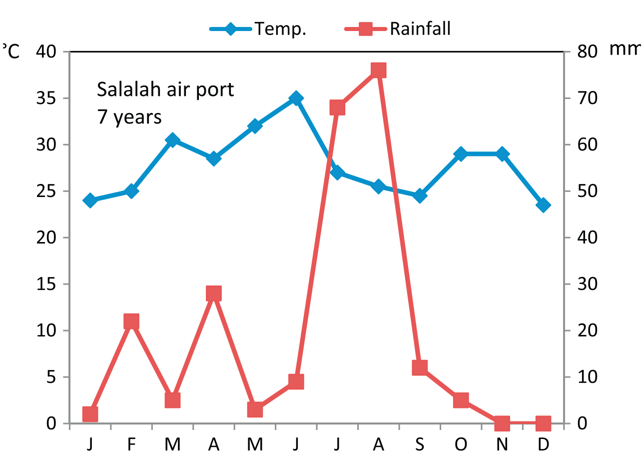

Figure 2 Average climate diagram (1987–1994) of Salalah using the notation of Walter (1973).

bance of tilling and management activities i.e. plowing, soil harrowing and fertilizing take place at the non-cultivation period and are ceased during their cultivation period; 2- banana (*Musa paradisiaca*) farms which are with perennial crop and characterized by soil cultivated only at the year of planting and disturbance by agricultural practices (e.g. weed hoeing and fertilizing) happens during growing period around the crop patches; and 3- abandoned farms which have lowest disturbance levels where human impact is ceased. On the other hand, in the mountains, sample plots consisted of farms of coffee (*Coffea arabica*), orange (*Citrus sinensis*), grape (*Vitis vinifera*) and abandoned orchard farms. These farms are characterized by no intensive soil cultivation and only at the year of crop plantation they were subjected to a relatively high level of tilling and managment activities (e.g. hoeing weeding, plowing, cutting, firing and mowing) during their growing peroid. These activities are carried out in patches around the crop plants and ceased in the abandoned orchard farms.

The environmental factors of the surveyed farms were recorded; including the time of farm construction, altitude (m), disturbance level and soil type with its compactness level according to Radcliffe-Smith (1980) and Information and Documentation Center (1995–2003). Disturbance was classified into three levels: high (level 1), medium (level 2) and low (level 3) as described by El-Sheikh (2005). At level 1, the sites were completely degraded because of clear cutting and other human impacts. At the medium level, the sites were relatively stable although there was evidence of moderate disturbance from human impacts. At low level, sites were relatively or completely protected. These disturbance categories are modified to cope with the agro-ecosystem as human disturbances including soil cultivation are normal phenomena in arable lands. Therefore, in agro-ecosystem the time, the type and the extent of human disturbances were recorded and evaluated together in each site according to their intensity levels which are classified into the same three levels mentioned above. The time of disturbance at level 1: the disturbance takes place between vegetation periods of crops only, i.e. in soil cultivated annually; at level 2: disturbance during the vegetation periods by tilling activity in patches around crop plants; and at level 3: human impact is ceased as in the abandoned farms. The type of disturbance at level 1: intensive as herbicides and firing can cause more degradation; level 2: non-intensive or medium due to tilling activities (e.g. weed hoeing, irrigation, fertilizing, and plowing); and level 3: human impact is ceased as in the abandoned farms. The extent of disturbance at level 1: disturbance on the total field surface, e.g. if crop is sprayed with herbicides on the total field surface which cause more degradation; level 2: disturbance on patches, as hoeing is in patches in farms; and level 3: human impact is ceased as in the abandoned farms. Soil compactness for each soil type was classified into three levels with level 1 indicating highly compacted soil, level 2 medium, and level 3 less compacted or loose alluvial soil according to the definitions in Bergmeier (2006). At level 1, the soil particles were dominated by the presence of gravels and hardpan outcrop 'bedded rocks' very near the surface where the ground was barren. At the medium level the soil particles were dominated by silty colluvial soil with medium particle sizes. The low level relates to loose sand-loamy substrate soil with less hardpan. The characteristics of these environmental factors are listed in Table 1. Plant species were listed and identified according to (Miller and Morris, 1988; Boulos, 1988; Boulos and Hadidi, 1994; Boulos, 1995; Chaudary and Akram, 1987; Chaudhary, 1999, 2001a,b; Al-Khulaidi and Kessler, 2001). The total weed cover was visually estimated as a percentage.

3.2. Analysis

Two-Way INdicator SPecies ANalysis (TWINSPAN), as a classification technique and Detrended Correspondence Analysis (DCA) from CANOCO software 4.5, as an ordination method, were used to analyze the data from the cover estimates of 102 species in the 28 plots according to the computer programs of Hill (1979a,b) and Ter Braak and Smilauer (2002). The cover values of the indicator and associated species in relation to the environmental variables (time, altitude, disturbance, and soil compactness) were analyzed using Canonical Correspondence Analysis (CCA: CANOCO software 4.5) according to Ter Braak and Smilauer (2002).

The species richness (α-diversity) of the vegetation cluster was calculated as the average number of species stand^{-1}. Equitability or evenness of the relative importance values of the species was expressed according to the Shannon-Wiener index ($\hat{H} = -\Sigma$ pi log pi). Relative concentration of dominance was expressed by the Simpson index ($C = \Sigma \mathrm{pi}^2$): where (pi) is the relative importance value (i.e. relative cover) of the ith species (Pielou, 1975; Magurran, 1988). Dominance-diversity curves of the vegetation clusters were then drawn, where the abundance of each species is plotted on a logarithmic scale against the species rank in the sequence of species from the most to the least dominant species (Whittaker, 1965).

4. Results

One hundred and two species were recorded, representing 83 genera and 30 families (Table 2). Fifty-two species were annuals (51%) and 50 were perennials (49%). The largest families were Compositae (19%) and Gramineae (13%). Fig. 3 shows the life form spectrum and the phytogeographical distribution of weed species in the study area. Annual herbs were the most represented (46.1%), followed by shrubs (16.7%), perennial herbs (16.7%) and perennial grasses (8.8%). Considering the global floristic regions, 48 species were pluriregional (47% of the total species), 24 biregional (23.5%) and 30 monoregional (29.4%) including 6 endemics. The six endemic species were: *Dichanthium micranthum*, *Farsetia linearis*, *Maytenus dhofarensis*, *Phagnalon viridifolium*, *Teucrium mascatense* and *Tribulus omanense*.

Two major vegetation groups in mountain and lowland farms were identified at level 1 of the TWINSPAN analysis and these were then separated into six minor vegetation groups at level 3 of the analysis (Table 2; Fig. 4a,b and Fig. 5). The first three vegetation groups (I, II and III) were confined to the mountain farms while the other vegetation groups (IV, V and VI) were confined to the coastal plain farms. Their ordination along the first axis of the DCA and CCA showed that altitude, disturbance level, length of time since farm construction, soil compactness and types of agronomic activity all affected the composition of weed species in the study area. These vegetation groups were named according to the first and second dominant species as follows: (I) *D. micranthum*, (II) *Cynodon dactylon–D. micranthum*, (III) *Convolvulus arvensis*, (IV) *C. dactylon–Sonchus oleraceus*, (V) *Amaranthus viridis* and (VI) *Suaeda aegyptiacea–Achyranthes aspera*. The mountain groups (I, II and III) inhabited by the newly constructed farms of or-

Table 1 Characteristics of the environmental factors for 28 surveyed plots and farms in the study area (following Radcliffe-Smith 1980; Information and Documentation Center 1995–2003; El-Sheikh 2005; Bergmeier, 2006).

Character	Mountain farms				Coastal lowland farms		
	A. Coffee	Orange	Grape	Abandoned	Banana	Fodder	Abandoned
Mean time of Construction (year)	10	12	9	10	> 50	27	30
Mean Altitude (m)	1700	1650	1670	1650	15	25	18
Disturbance level	1	1	1	2	2	2	3
Compactness level	2	2	1	1	3	2	3
Soil substrate type	Silty colluvial	Silty colluvial	Chalk with bedded limestone	Pebbly colluvial limestone	Soft alluvial	Brown silty–clay	Soft sandy alluvial

ange, grape, and Arabian coffee and the abandoned arable land, were affected by high levels of disturbance and soil compactness. The lowland groups (IV, V and VI), meanwhile, inhabited by the traditional banana and fodder farms in the coastal lowlands and the abandoned arable land, exhibited relatively low levels of disturbance and loose alluvial soil (Fig. 4a,b and Fig. 5).

The correlation coefficients analysis showed that the first axis of CCA ordination was correlated positively with altitude, disturbance and soil compactness level (r = 0.84, 0.84 and

Table 2 Mean cover values (%) of the recorded species in the six vegetation groups derived after the application of TWINSPAN.

Species	Life form	Chorotype	Vegetation group					
			I	II	III	IV	V	VI
			Mountain groups			Coastal groups		
Total plots number			3	7	3	4	6	5
ACANTHACEAE								
Justicia odora	SH	SA	1.7					
AIZOACEAE								
Zaleya pentandra	PH	SA, TR, IT, ME			0.7	1.5		2.4
AMARANTHACEAE								
Aerva javanica	SH	TR				1		
Achyranthes aspera	PH	TR	2.3	9.6	3.0	2.0	1.3	30.4
Amaranthus hybridus	AH	AM, TE, TR				0.8	17.3	5.4
Amaranthus lividis	AH	COSM				5.0		2.0
Amaranthus viridis	AH	COSM			2.3	0.8	37	0.8
Digera muricata	AH	SA, EA			0.7			
ASCLEPIADACEAE								
Pergularia tomentosa	SH	SA, TR	0.7					
BORAGINACEAE								
Heliotropium bacciferum	SH	SA, TR						18.4
BURSERACEAE								
Commiphora habessinica	SH	SA, SU		0.2?				
CARYOPHYLLACEAE								
Cometes surattensis	AH	SA, IT				11.3		
Paronychia arabica	AH	SA, ME, SU				17.5		4
Spergularia diandra	AH	SA, ME, IT, TR			0.7			
Gypsophila bellidifolia	AH	SA				0.3		0.2
CELASTRACEAE								
Maytenus dhofarensis	SH	Endemic Oman	1.7					
CHENOPODIACEAE								
Atriplex dimorphostegia	AH	SA, IT			0.7	0.3		0.2
Atriplex lecucoclada	SH	SA, ME	0.7					
Atriplex sp.	AH		0.7					
Beta vulgaris	AH	ME, IT, ES						1.0
Chenopodium album	AH	COSM		0.7				
Chenopodium murale	AH	COSM				0.3	12	1.4
Suaeda aegyptiaca	AH	SA						37
CLEOMACEAE								
Gynandropsis gynadra	AH	SA, SU, IT				8.0		
COMPOSITAE								
Aster sp.	PH			0.9				
Atractylis carduus	AH	SA, ME, IT	1.7					
Carthamus tinctorius	AH	SA, IR, TR					1.2	
Conyza bonariensis	AH	TR, AM	14	1.0	0.7		0.8	0.4
Conyza stricta	PH	SA, TR, IT		0.6				
Conyza sp.	PH			0.7				
Echinops spinosissima	PH	SA, ME	2.3					
Eclipta prostrata	AH	TR		0.3		3.3		
Launaea procumbense	PH	SA, TR					1.0	1.8
Launaea nudicaulis	PH	SA, IT, SU		0.7		1.3	4.0	4.4
Matricaria aurea	AH	ME	0.7					
Osteospermum vaillantii	AH	SA, ME	0.7					
Phagnalon viridifolium	SH	South Arabia	0.7					

Table 2 (*continued*).

Pluchea arabica	SH	TR		0.3				
Pluchea dioscoridis	SH	SA, SU			0.7			
Senecio sp.	AH		2.7	7.1	1.7			
Sonchus asper	AH	ME						1.0
Sonchus oleraceus	AH	ME, IT, ES		7.6	5.0	40.0	25	2.2
Vernonia arabica	AH	COSM			0.7			
CONVOLVULACEAE								
Convolvulus arvensis	PH	SA, IT	2.3	0.6	63.3	22.5		
Convolvulus cephalopodus	PH	SA, IT	16.7					0.4
Convolvulus pilosellifolius	PH	SA, IT		0.2				
Cressa cretica	PH	ME, IT, TR			0.3?			
Ipomoea obscura	PH	TR	0.7	0.7				
CRUCIFERAE								
Diplotaxis harra	PH				0.3			
EUPHORBIACEAE								
Euphorbia geniculata	AH					5.5		
Euphorbia granulata	AH	SA, SM, SU		0.3			0.3	
Euphorbia hirta	AH	AM, TR	1.7	0.3	0.7	1.8	0.7	0.6
Euphorbia prostrata	AH	AM				0.3	0.5	
Euphorbia serpens	AH	AM					0.2	
Phyllanthus maderaspatensis	AH	SA, EA				1.3	1.2	1.4
Ricinus communis	SH	COSM			0.7			
GERANIACEAE								
Geranium mascatense	AH	SA, EA						1.0
LABIATAE								
Lantana petitiana	SH			0.3				
Ocimum forskolei	SH	SA, TR,EA				0.3		
Salvia deserti	AH	SA, ME	5.0	0.7				
Teucrium mascatense	AH	South Arabia	4.0		0.7			
LEGUMINOSAE								
Alhagi graecorum	SH	SA, ME, IT, SU				0.3		
Argyrolobium roseum	PF	SA, TR				0.3		
Astragalus vogelii	AF	SA, ME, TR		0.6				0.4
Indigofera oblongiflora	SH	SA, ME, TR				0.3		
Mililotus indicus	AF	SA, ME, IT			1.7			
Psoralea sp.	PF		1.7	22.9	8.0	38.0		
MALVACEAE								
Abutilon pannosum	SH	SA, EA, IT					4.2	2.0
MOLLUGINACEAE								
Glinus lotoides	AH	SA, TE, TR			1.7			
NYCTAGINACEAE								
Commicarpus helenae	PH	SA, IT, TR				0.3	1.0	1.3
OXALIDACEAE								
Oxalis corniculata	AH	COSM	3.3	12.1	18.3			
PORTULACEAE								
Portulaca oleracea	AH	COSM		0.7	0.7		9.2	
PRIMULACEAE								
Anagallis arvensis	AH	COSM		0.9	2.3		0.8	

Table 2 (*continued*).

RUTACEAE								
Haplophyllum tuberculatum	PH	ME, TE, SA, ES	0.3					
SAPINDACEAE								
Dodonaea angustifolia	SH	SA, TR		0.3				
SOLANACEAE								
Datura fastuosa	AH	TR, TE				0.5	1.2	2.4
Nicotiana gluca	SH	AM			0.7			
Physalis minima	AH	TR				19.3		
Solanum incanum	SH	SA, IT, EA	0.7	5.6		1.3		
Solanum nigrum	AH	COSM		3.9	1.3	33.3	1.0	1.6
Withania qaraitica	SH	ME, IT, TR,EA					2.2	0.3
TILIACEAE								
Corchorus olitorius	AH	TR				0.5		
Corchorus trilocularis	AH	SA, TR, AM, AU		0.3				
Grewia erythraea	PH	SA, IT, EA	1.7	2.1		0.5		1.0
UMBELLIFERAE								
Ammi majus	AH	ME, IT	3.0		0.7		0.3	
ZYGOPHYLLACEAE								
Tribulus omanense	AH	South Arabia					0.4	
CYPERACEAE								
Cyperus longus	PS	SA, ME, ES, IT				0.3		4.0
Cyperus rotundus	PS	COSM	1.7	21.0	26.7			
GRAMINEAE								
Cenchrus ciliaris	PG	SA, IT, TR						0.4
Chloris gayana	PG	TR				18.8	18.3	17.4
Cymbopogon parkeri	PG	SA, IT, EA	58.3	4.0				
Cynodon dactylon	PG	TR	1.7	56.9	58.3	60.8	24.2	20.0
Dactyloctenium aegyptium	AG	TR				1.8	8.6	
Dichanthium micranthum	PG	Endemic	85.0	54.3	1.7			
Digitaria sanguinalis	AG	TE						0.2
Echinochloa colona	AG	TR, TE, IT,EA				11.5	9.2	
Echinochloa crus-galli	AH	TR, TE, IT, EA						5.0
Panicum maximum	PG	TR, EA				23.8		12.0
Panicum repens	PG	ME, IT, AM						0.4
Setaria verticillata	AG			0.3	1.7	0.3	9.8	2.4
Sprobolus spicatus	PG	SA, IT, EA			0.7			0.6

Vegetation groups are: (I) *Dichanthium micranthum*, (II) *Cynodon dactylon–Dichanthium micranthum*, (III) *Convolvulus arvensis*, (IV) *Cynodon dactylon–Sonchus oleraceus*, (V) *Amaranthus viridis*, (VI) *Suaeda aegyptiacea–Achyranthes aspera*. Life forms are: SH: shrub, PH: perennial herb, PG: perennial grass, PF: perennial forb, PS: Perennial sedges, AH: annual herb, AG: annal grass, AF: annual forb. Chorotypes are: COSM: Cosmopolitan, SA: Saharo–Arabian, ME: Mediterranean, IT: Irano–Turanian, ES: Euro–Siberian, SU: Sudanian, TR: Tropical, EA: Eritro–Arabian, SM: Somalia–Masai, AU: Australian.

0.68, respectively), while being negatively correlated with the time of farm construction ($r = -0.72$). The second axis was correlated positively with the length of time since farm construction ($r = 0.57$) and negatively with disturbance level ($r = -0.41$) (Table 3). The CCA diagram (Fig. 5) shows that the length of time since farm construction, altitude and disturbance levels are the most important factors related to the distribution of species in the study area.

The *D. micranthum* cluster (I) that inhabited the orange farms had the highest numbers of shrubs (6), total natural wild species (20), endemics (4) and concentration of dominance ($C = 0.23$); but the lowest numbers of annual herbs (13), total weeds (6) and relative evenness ($\hat{H} = 0.89$). The *C. dactylon–D. micranthum* cluster (II) that inhabited the mixed farms had the highest number of perennial herbs (9) and total perennials (19); but the lowest number of genera (19). The *C. arvensis* cluster (III) in the abandoned farms was characterized by the highest values of total families (19), total genera (32) and species richness (10.7 spp stand^{-1}) (Table 4).

The *C. dactylon–S. oleraceus* cluster (IV), inhabiting the fodder farms, had a high number of annual herbs (20), total annuals (23), total species (40), total cover (337.3), total weeds (21) and relative evenness ($\hat{H} = 1.17$); but the lowest number of endemic species, concentration of dominance ($C = 0.09$). The *A. viridis* cluster (V), which occupied banana farms, had a low number of perennial herbs (4), shrubs (2), total perenni-

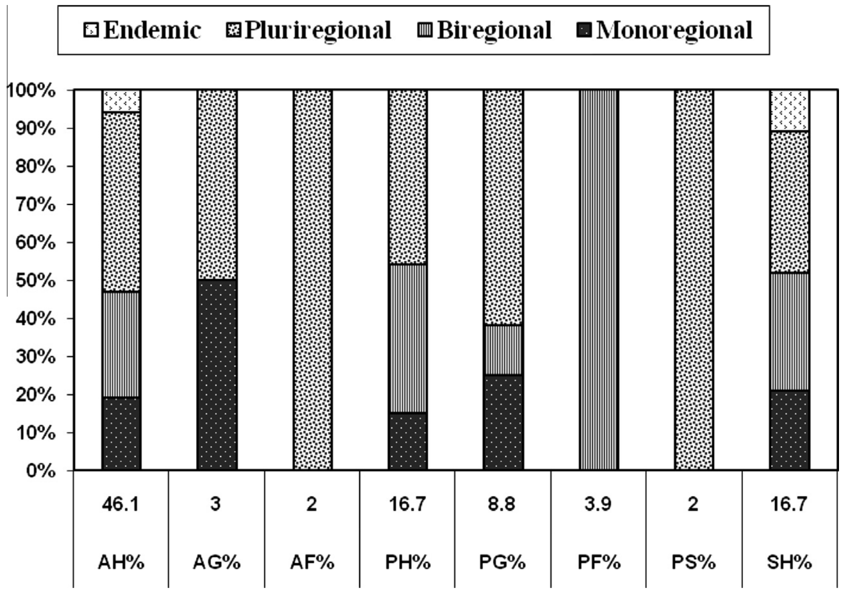

Figure 3 Diagram of the life form spectra and chorotype of the arable weeds in Salalah farms. Life forms are: AH: annual herb, AG: annal grass, AF: annual forb, PH: perennial herb, PG: perennial grass, PF: perennial forb, PS: Perennial sedge, SH: shrub.

als (8), total natural species (10), total families (14), total species (29) and species richness (4.8 spp stand^{-1}). The *Suaeda aegyptiaca–A. aspera* cluster (VI) in the abandoned farms had a high number of perennial grasses (6) and a low level of cover (187.8) (Table 4).

The dominance diversity curves of the mountain clusters (I, II and III) were steeper than those of the lowland communities (IV, V and VI) (Fig. 6). They also had the highest *C* values of the relative concentration of dominance (0.23, 0.16, and 0.20, respectively). Moreover, the first two dominant species contributed the highest values of total cover (143.0%) in cluster (I), (111.2%) in cluster (II), and (121.6%) in cluster (III) (Table 4). On the other hand, less steep curves were obtained for the lowland communities (cluster IV, V, VI). These had the lowest *C* values of the relative concentration of dominance (0.09, 0.10, and 0.10, respectively).

5. Discussion

The cultivated fields in the present study contained 102 species, representing approximately 10% of the 1204 species of vascular plants known from Oman, and 14% of the 750 species recorded from Dhofar (Radcliffe-Smith, 1980; Miller and Morris, 1988). This number includes 40 weedy species of widespread distribution most likely as a result of contaminated crop seeds (39.2% of the total species) (Chaudary and Akram, 1987; Boulos, 1988; Al-Khulaidi and Kessler, 2001). It is remarkable that some alien species successfully invaded the irrigated agricultural habitats in the fodder grass farms such as: *Gynandropsis gynandra*, *Euphorbia serpens* and *Abutilon pannosum*. *Euphorbia prostrata*, *Euphorbia hirta* and *C. gayana* occurred in irrigation ditches and were well established in shadier parts of groves (Bor, 1968). In addition, 60% of the total species were native species, with endemic species as the relics of the original natural vegetation. The present study indicated the presence of six endemic species, which is 6% of the 100 species of the total endemics known from Oman and 10% of the 60 species of the total endemic recorded from Dhofar. The endemics species are *Maytenus dhofarensis*, *Phagnalon viridifolium*, *Farsetia linearis*, *Teucrium mascatense*, *Tribulus omanense* and *D. micranthum*.

The origin of the Dhofar weeds, therefore, can be summarized as follows: (1) plants considered as remnants of the original vegetation, (2) immigrants from adjacent natural vegetation, (3) introduced and alien plants (Bergmeier, 2006; Liira et al., 2008). The 30 families reported in the study area constitute about 40% of the total families listed in Dhofar (76 families), while also constituting some 80 genera. The generic index approximates 1.3 i.e. "large number of genera in proportion to that of the species". This generic index value is in accordance with the study of Radcliffe-Smith (1980) in the Dhofar region. Therophytes represent the main floristic element in the cultivated land. Many of these have a short life cycle, which enable them to cope with the instability of the agro-ecosystems in which they occur (Shaltout and El-Fahar, 1991; Bergmeier, 2006).

The pluriregional categories of Saharo–Arabian, Irano–Turanian, Tropical, Eritro–Arabian and Mediterranean are represented by relatively high number of species in most life forms compared with the other floristic elements. This high value of pluriregional species in the Dhofar area may be due to: (1) the flora ranges from severe xerophytism to fertile stretches, (2) the geological gradient that ranges from the mountains to the low coastal plain and lateral wadis, (3) the vegetation composed of relics of the regional natural vegetation pool and weedy species, (4) the fact that the Dhofar area is located on the boundary between the Holaractic kingdom and the Palaeotropic kingdom (Zohary, 1973) and (5) the fact that the Dhofar area is strongly influenced by the adjacent regions of Yemen and Ethiopia to the West, peninsular India to the East, and the deserts of North Africa and North–West India to the North (Radcliffe-Smith, 1980; Miller and Morris, 1988). The fact that some of the endemic species are important components of the vegetation in terms of numbers of individuals

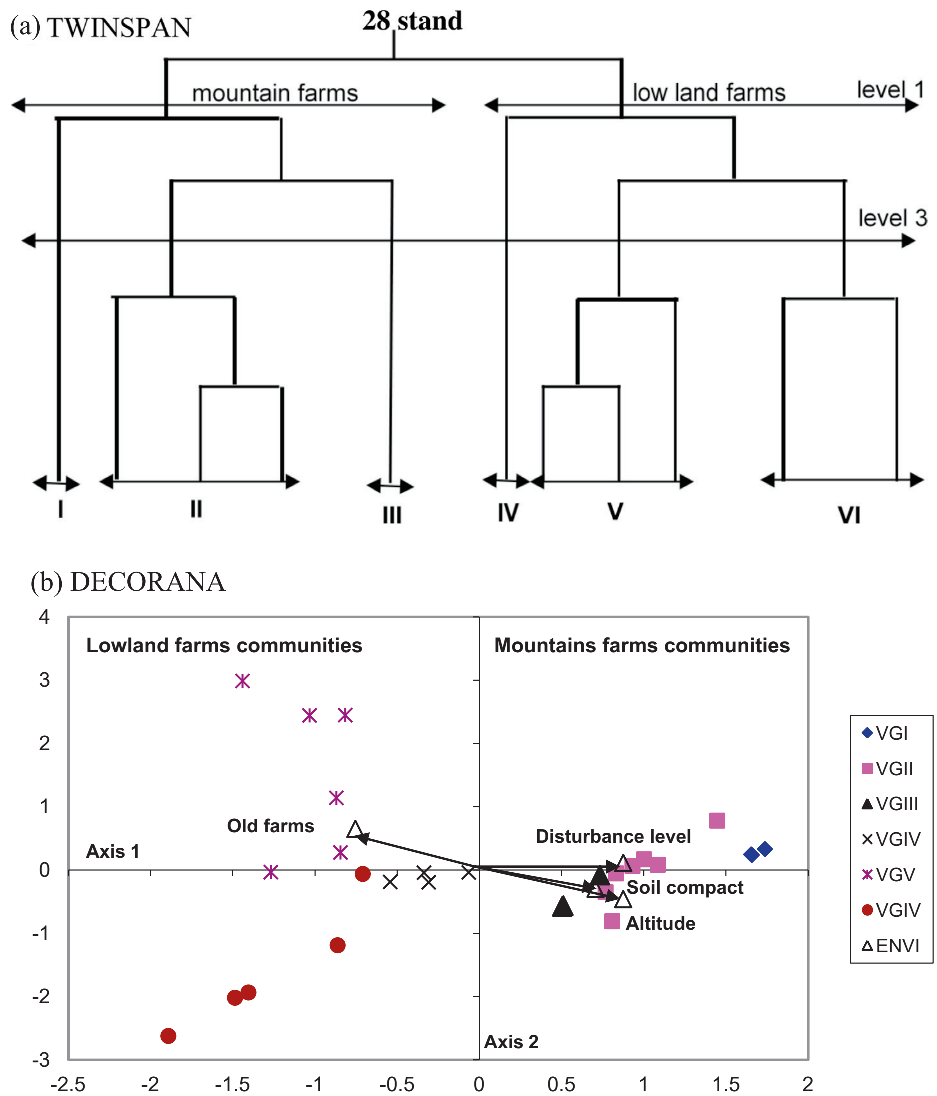

Figure 4 Relation between the six vegetation groups of "Lowland farm communities" and "Mountain farm communities" resulting from the application of TWINSPAN (a) and DCA technique (b). I: *Dichanthium micranthum*, II: *Cynodon dactylon–Dichanthium micranthum*, III: *Convolvulus arvensis*, IV: *Cynodon dactylon–Sonchus oleraceus*, V: *Amaranthus viridis*, VI: *Suaeda aegyptiaca–Achyranthes aspera*.

might be because they are being maintained by a favorable climate, the influence of which might formerly have extended over a wider area, and consequently they might have been more widely distributed in the past than they are now.

The structure of weed vegetation in Dhofar is mainly determined by the management of agricultural crops, competition, the presence of native species that depend on the disturbance, stress level, altitude, soil depth and topography. Mountain clusters that inhabit the newly arable land (i.e. land that has become arable in the past 5–15 years) are characterized by the highest disturbance level, soil compactness level, total natural species (including endemics), and total shrubs, but the lowest number of weeds and species diversity and evenness. On the other hand, the lowland clusters inhabiting the older traditional arable land (fodder and banana crops) along the coastal plain of Dhofar are characterized by high numbers of weeds and species diversity, but the lowest number of natural species including endemics. These old lowland farms are characterized by regular agricultural practices (e.g. irrigation, fertilization and plowing). In regularly disturbed habitats, the weed community tends to consist of short-lived obligate or facultative annual plants (Grime, 1979; Shaltout and El-Halawany, 1992; Shaltout et al., 1992; El-Sheikh, 2005; Bergmeier, 2006; El-Sheikh, 2013).

The correlation coefficients between the environmental factors and the axes of CCA ordination suggest that the separation of the species along the first axis is strongly influenced (positive correlated) by the altitude, disturbance and compactness levels. The length of time since the construction of the farm, however, correlated negatively with the first axis. The CCA diagram (Fig. 5b) shows that the length of time since the farm construction, altitude and disturbance levels are the most important factors related to the distribution of species in the study area. The perennials of both natural and semi-natural species of mountain clusters (I, II and III) (e.g. *Cymbopogon parkeri*, *D. micranthum*, *Solanum incanum*, and *Conyza*

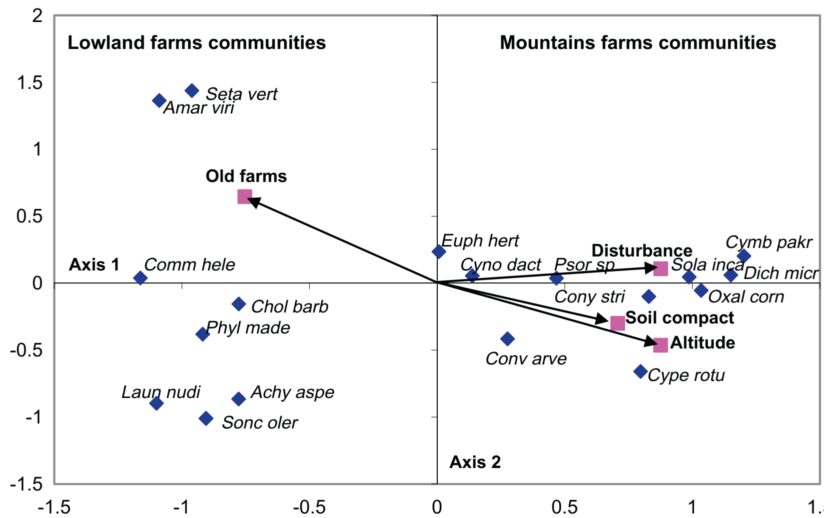

Figure 5 CCA biplot with environmental variables (arrows) and ordination of abundant species of "Lowland farm communities" and "Mountain farm communities". The abundant species are represented by the first four letters of the genus and species name. For the complete names of species see Table 2.

Table 3 Significant simple linear coefficients of the environmental factors with CCA axes: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***} \leqslant 0.001$.

Environmental Factor	Axis 1	Axis 2	Axis 3	Axis 4
Time of Construction	-0.72^{***}	0.57^{**}	−0.05	−0.07
Altitude	0.84^{***}	0.09	0.01	−0.36
Disturbance level	0.84^{***}	-0.41^{*}	−0.05	0.09
Compactness level	0.68^{***}	−0.26	-0.55^{**}	0.02

stricta) coincided with the more degraded disturbed areas of new farm stands, whereas most of the annual weeds in the lowland clusters (IV, V and VI) (e.g. *A. viridis*, *Setaria verticeillata* and *S. oleraceus*) correlated with old lowland and less disturbed farms. Similar correlations were reported in Lososová et al. (2004). There is a clear distinction, therefore, between thermophilous weed communities at low altitudes with loose soil and communities in moderate and wetter areas at higher altitudes and with nearly hardpan soils.

The results indicated that the *D. micranthum* cluster, inhabiting the newly arable mountain orange farms generally located on disturbed sites of originally pristine "natural" vegetation has a high number of natural species including endemics as well as a high number of shrubs and a high concentration of the dominance, but the lowest number of annual weed species and relative evenness. These features may reflect the fact that wild species react in different ways when their habitats are disturbed by human. Some species flourish under disturbance such as mowing, irrigation, plowing and other tillage practices (e.g. *Convolvulus cephalopodus*, *Salvia deserti*, *Echinops spinosissima*, *Oxalis corniculata*, *Cymbopogon parkeri*, *D. micranthum*). In a natural plant community, any disturbance in the ecosystem tends to result in a change in the structure of the plant community (El-Sheikh, 2013). Those plants which are susceptible to a particular kind of disturbance decrease in number or even disappear (Chaudary and Akram, 1987; Bergmeier, 2006).

The *C. arvensis* cluster that inhabits the neglected farms had a high number of genera, species richness and a comparable number of native and weed species. This may be because weeds may invade newly disturbed habitats, but they are usually replaced by wild colonizers if the disturbance is ceased. Therefore, once agricultural operations cease, the systematic replacement of early and intermediate seral stages occurs through time until the original community appears (Horn, 1974; Wet and Harland, 1975; Radosvich, 1984; Chaudary and Akram, 1987). Moreover, the high number of genera and species richness of this community suggests a high degree of heterogeneity within the farms (e.g. moisture, gaps, agriculture practices and soil depth). These factors are collectively considered to represent an intermediate habitat that is suitable for many species. Some of these species prefer the rocky pastures, semi-wet meadows and woodlands, while other species occupy a wide range of human-made, more or less nitrophytic habitats (Biondi et al., 2006; Bergmeier, 2006; Liira et al., 2008; El-Sheikh, 2013).

The *C. dactylon*–*S. oleraceus* cluster that inhabits the fodder farms had a high number of annual weeds and relative species evenness. This may be because these farms are characterized by the lowest level of the disturbance during the growth period of the fodder until annual fodder harvest (i.e. less stress on the annual weeds at their establishment period, therefore enhancement of their diversity). The time of disturbance is annual as tilling management activities, e.g. plowing, soil harrowing and fertilizing take place only after fodder harvest. Therefore, fodder farms have been greatly influenced on the decreasing proportion of perennial weeds and increasing proportion of annual weeds; and the species composition will be changed (Pál et al., 2013). As many of

Table 4 Mean of community varibles of the six vegetation groups of the arable land of the Dhofar area, identified after the application of TWINSPAN: (I) *Dichanthium micranthum*, (II) *Cynodon dactylon–Dichanthium micranthum*, (III) *Convolvulus arvensis*, (IV) *Cynodon dactylon–Sonchus oleraceus*, (V) *Amaranthus viridis*, and (VI) *Suaeda aegyptiacea–Achyranthes aspera*.

Variable	Vegetation group					
	I	II	III	IV	V	VI
Life form						
Annual herbs	13.0	13.0	18.0	**20.0**	18.0	17.0
Annual grasses	–	1.0	1.0	3.0	3.0	3.0
Annual forbs	–	1.0	1.0	–	–	1.0
Total annuals	13.0	15.0	20.0	**23.0**	21.0	21.0
Perennials herbs	6.0	**9.0**	5.0	6.0	4.0	7.0
Perennial grasses	3.0	3.0	3.0	3.0	2.0	**6.0**
Perennial forbs	1.0	1.0	1.0	2.0	–	–
Perennial sedges	1.0	1.0	1.0	1.0	–	1.0
Shrubs	**6.0**	5.0	3.0	5.0	2.0	3.0
Total perennials	17.0	**19.0**	13.0	17.0	8.0	17.0
Total weeds	6.0	14.0	17.0	**21.0**	18.0	20.0
Total naturals 'native'	**20.0**	19.0	12.0	19.0	10.0	17.0
Total endemics	**4.0**	1.0	3.0	–	1.0	1.0
Diversity indices						
Number of families	18.0	18.0	**19.0**	17.0	14.0	16.0
Number of genera	28.0	19.0	**32.0**	24.0	24.0	22.0
Number of species	30.0	34.0	32.0	**40.0**	29.0	38.0
Plant cover (%)	219.4	218.9	208.1	**337.3**	193.2	187.8
Cover of first two dominant species (%)	143.0	111.2	121.6	100.0	62.0	67.0
Species richness (spp/stand)	10.0	4.9	**10.7**	10.0	4.8	7.6
Concentration of dominance (*C*)	**0.23**	0.16	0.20	0.09	0.10	0.10
Relative eveness ($\hat{H}$)	0.89	0.99	0.91	**1.17**	1.12	1.17

annuals have a short life cycle, sometimes only a few weeks, which enable them to cope with the instability of the fodder agro-ecosystems in which they occur. Moreover, annual weedy species are characterized by anemochores which result in a higher level of seed dispersal across a greater area (El-Sheikh, 2005; Liira et al., 2008). Grasses are among the important fodder plants in Oman which compete with the grassy weeds. These grassy weeds need the same nutrients as the fodder grasses which leads to increased competition than with non-grass weeds. In addition, competition between grassy weeds and fodder grasses is more intense because their roots occupy the same soil strata and possess a more general habit of fodder growth (Baker, 1974; Holm, 1978; Radosvich, 1984; Chaudary and Akram, 1987).

The *Amaranthus viridus* cluster in the banana fields exhibited a low number of perennials, shrubs and species diversity. This may be because the banana plants have crowded large leaves that prevent sunlight from reaching inside the farm and consequently affect weed growth (El-Kady et al., 1999). The planting of the banana and their culms, however, still leaves sufficient space to allow the growth of some shading annual weeds (Grime, 1979; Bergmeier, 2006; Liira et al., 2008).

The *Suaeda aegyptiaca–A. aspera* cluster in the old abandoned arable land had the highest number of perennial grasses. This may be due to the cessation of agriculture practices in these old abandoned arable sites which help for secondary succession proceeds. Therefore, secondary succession is toward more advanced seral stages, till reaching a stable stage of the original community. This in turn encourages the growth of perennial rhizomatous grasses that might be considered to be the remnants of the original vegetation. This habitat is considered as semi-natural and is characterized by low species cover because there is a lower level of competition between species (Chaudary and Akram, 1987; El-sheikh, 2005; El-Sheikh et al., 2006; Bergmeier, 2006). The evolutionary dynamism of vegetation linked to abandonment is most evident in the spreading of high grasses that invade neglected fields (Biondi et al., 2006). Furthermore, the presence of some halophytes in this community (e.g. *Suaeda aegyptiaca*, *Atriplex dimorphostegia*, *Cressa cretica*) may be due to the relatively high soil salinity that characterizes the abandoned farms. The old abandoned farms in the coastal plain have poor drainage that results in water-logging and high salinity. Edapho-hygrophilous and semi-mesophilous species tend to be found under these conditions (Bergmeier, 2006).

The dominance diversity curves for the plant communities of the mountainous farms (*D. micranthum*, *C. dactylon–D. micranthum* and *C. arvensis*) are steeper and are characterized by high values of the relative concentration of dominance and low species richness. Hence, they are more profitable for approximating the geometric series of the niche-pre-emption that characterizes communities with low diversity (Whittaker, 1965; Whittaker, 1972; Pielou, 1975). This means that these communities inhabiting the arable land on the mountains show less weed diversity. The behavior of these communities is controlled by the length of time since the farm construction (between 5 and 12 years), high disturbance, more soil compactness and concentration of dominance of some wild species at high altitudes. The curves representing the plant communities of the coastal plain farms (*C. dactylon-S. oleraceus*, *A. viridis* and *Suaeda aegyptiaca-A. aspera*) approach a sigmoid distribution with a moderate slope throughout. This kind of distribution approximates the log normal distribution, consequently there are many weed species of intermediate

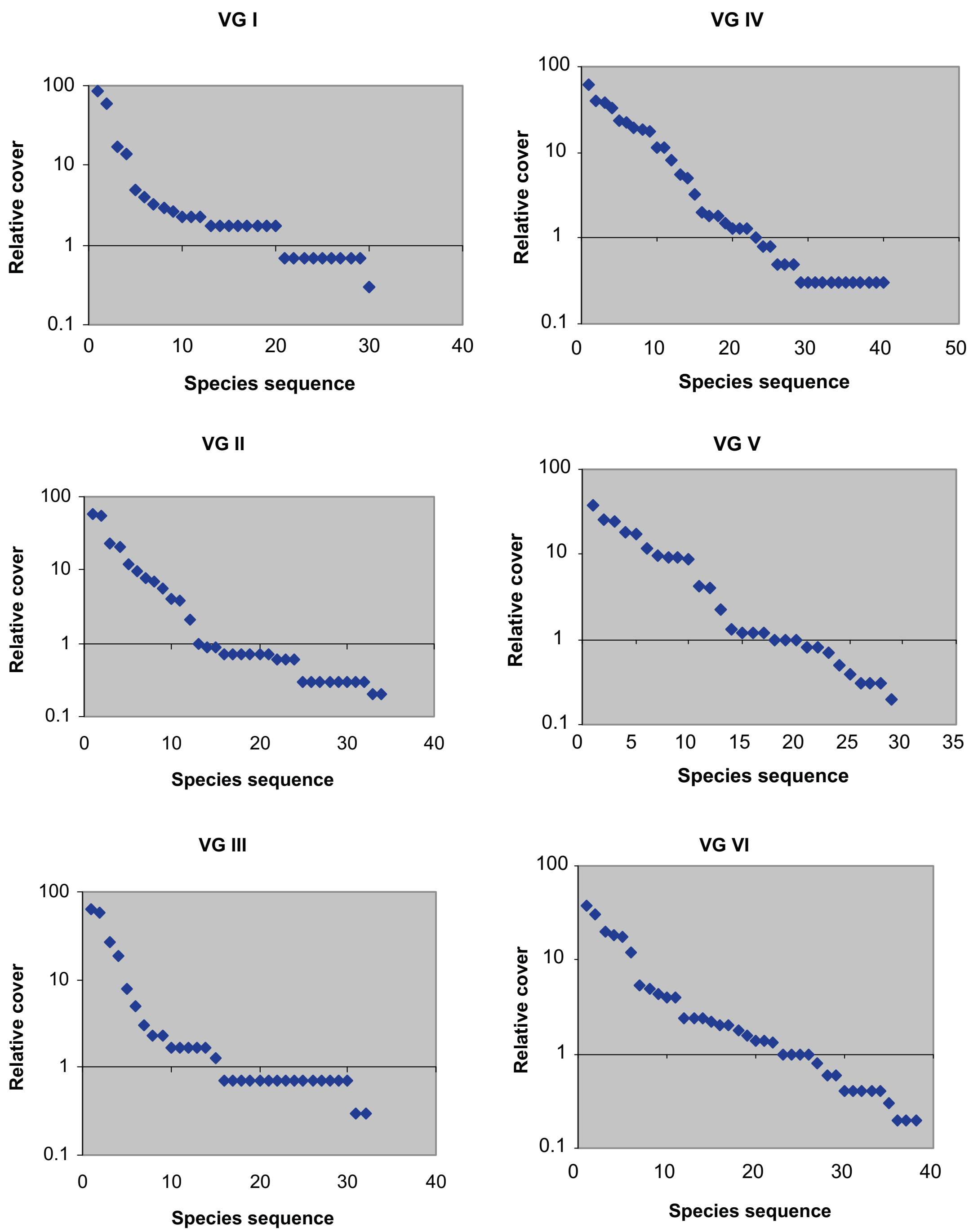

Figure 6 Dominance-diversity curves of the six plant communities inhabiting the arable lands of Salalah.

abundance values and few common species (El-Sheikh et al., 2006). The high species diversity of these communities may be due to the spatial and temporal disturbance that characterizes the old farms. High levels of species diversity may be caused by local differentiation in soil properties around individual plants, since heterogeneity of environments allows the satisfaction of the requirements of diverse species within a community (Mellinger and McNaughton, 1975; Whittaker and Levin, 1977; El-Sheikh et al., 2006).

Therefore, altitude also influences the diversity of weed vegetation. Unexpectedly, species richness increases with the altitude of the neglected farms, which is in contrast with the decreasing patterns that are more commonly found in the mountain weed vegetation of the study area. The higher numbers of species per relevé plot at higher altitudes in neglected farms is probably due to a lower degree of agricultural intensification in less productive upland areas. Similar relationships have been found in the study of urban and weed vegetation in Central Europe (Pysek, 1993; Lososová et al., 2004). Altitude and associated environmental factors do not only influence species composition and diversity, but also a proportion of dominant life forms of weed vegetation, therophytes and shrubs. The proportional changes from therophytes to shrubs along the altitudinal gradient, revealed in this study, suggest that at higher altitudes weed communities contain more species of adjacent vegetation, e.g. meadows and pastures, while the performance of ecologically specialized annual weeds decreases (Lososová et al., 2004). The present study also demonstrated that alien weeds and neophytes showed a remarkable concentration of occurrences at lower altitudes, see Kowarik (1990) and Sukopp (2002). In addition, the higher altitude sites are associated with specific climatic conditions, which are related with more precipitation, low temperature and base status of soil (i.e. near hardpan). Hence, significant changes in weed species composition were associated with a complex gradient of increasing altitude and precipitation, and with decreasing temperature and base status of the soil (Lososová et al., 2004; Cimalová and Lososová, 2009; Silc et al., 2009; Pinke et al., 2012; Pál et al., 2013).

Soil compactness variable showed correlations with species richness and the cover values of the species. Moreover, soil compactness is related to high clay and organic matter content which exhibited significant differences between mountain and lowland farms. These results suggest the effective role of soil compactness in the weed community structure and diversity. The present findings agree with those of Fried et al. (2008), Andreasen and Skovgaard (2009), Gomaa (2012) and Pinke et al. (2012) and indicated the importance of soil texture, salinity and organic matter in the composition and species richness of weed communities. Organic matter content as a pivotal soil fertility factor can affect phytodiversity; and soil texture may affect productivity through the influence on water holding capacity, infiltration rate, moisture availability for plants and consequently plant nutrition (Sperry and Hacke, 2002; Zhang et al., 2010; Gomaa, 2012).

6. Conclusion

Six plant communities of weed vegetation were identified in the arable land of Salalah, Southern of Oman: I- *D. micranthum*, II- *C. dactylon*–*D. micranthum*, III- *C. arvensis*, IV- *C. dactylon*–*S. oleraceus*, V- *A. viridis* and VI- *Suaeda aegyptiaca*–*A. aspera*.

The composition and diversity of weed vegetation in Dhofar are affected by many environmental gradients. In Dhofar, the arable lands include two broad categories strongly differing in agricultural management, further referred to as old and new farms. The old arable lowlands with low agricultural management was applied during the period of growth, while more recently mountain farms were subjected to hoeing weeding or tilling and high disturbance level. Therefore, the effect of variable crop was less pronounced than the effect of altitude, mechanical disturbances, soil compactness degree and the length of time since the farm construction. A similar conclusion was attained by Lososová et al. (2004).

The study highlights the significance of the study area which harbors about two third of the total flora of the country and is considered as a hot spot of endemic, native and naturalized species. Dhofar, like other areas of Oman, is developing rapidly, and this development has the potential to put the natural ecosystem under stress through increased human activities such as farming, cutting for firewood, housing, road construction, and overgrazing; and this would lead to the loss of endemic and rare native species. One of the important features of a cloud forest is that a large proportion of total precipitation is filtered by the very presence of vegetation. Once the vegetation is degraded, it becomes more difficult to re-establish due to the reduced level of filtered precipitation. Over-use of the Dhofar cloud forest would seriously threaten this diverse ecosystem (Miller and Morris, 1988; Ghazanfar, 1998; El-Sheikh, 2013). In addition, in Oman, some species recorded from this area are considered to be troublesome as they are invasive and weedy with rapid distribution; and the natural vegetation will be replaced by weeds and ruderal in few years. For these reasons, these mountains warrant designation as a natural reserve.

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