Pak. J. Bot., 42(5): 3431-3440, 2010.

SPATIOTEMPORAL ASPECTS OF PLANT COMMUNITY STRUCTURE IN OPEN SCRUB RANGELANDS OF SUB-MOUNTAINOUS HIMALAYAN PLATEAUS

IFTIKHAR AHMAD[1], MUHAMMAD SAJID AQEEL AHMAD[1]*, MUMTAZ HUSSAIN[1], MUHAMMAD ASHRAF [1,2], M. YASIN ASHRAF[3] AND MANSOOR HAMEED[1]

[1]*Department of Botany, University of Agriculture, Faisalabad, Pakistan*
[2]*Department of Botany and Microbiology, King-Saud University, Riaydh, Saudi Arabia*
[3]*Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad, Pakistan*
**Corresponding Author: sajidakeel@yahoo.com*

Abstract

Six ecologically diverse study sites were studied for changes in the structure of open scrub-type plant community over space and time. Ecological data were recorded using Fixed Quadrat Sampling Method and analyzed by using *p*RDA technique. Results revealed that enough moisture, suitable temperature and availability of macronutrients during summer lead to the maximal complexity of all communities which was follows by autumn and spring. However, the reverse was true during winter. Similarly, the study of different sites also revealed significant variation in plant communities that seemed to be highly associated with the soils physico-chemical properties. For example, most of the species were found to be dominant in soils containing higher macronutrients with high field capacity (Khabeki, Khoora and Knotti Garden sites). Salt and drought tolerant species were dominant in saline soil with steep slopes and at higher elevation (Jallar site). In contrast, moisture loving species were closely associated with the springs and water channels (Knotti Garden and Dape Sharif sites). In conclusion, the spatio-temporal variations in plant communities of this area were found to be a result of the moisture contents, filed capacity, soil macro-nutrients and type and composition of the soil and elevation of selected sites.

Introduction

Different plant species had different habitat requirements. Therefore species distribution, richness, diversity and cover vary with variation in habitats especially with steepness of slopes (Uniyal *et al.*, 2006). Sometimes alien species causes disturbance in distribution of certain species as *Parthenium* weed (*Parthenium hysterophorus* L.) spread on waste lands (Shabbir & Bajwa, 2006). The population of many common medicinal plants growing in the wastelands might be rapidly declining due to fast and aggressive growth of *P. hysterophorus* as it replaces indigenous natural flora, including herbs utilized by people as a source of medicine. Abiotic components and plants spend their entire life cycles, closely related with each other. Species density for such under story plants was positively related to rainfall, negatively to seasonality where as positively but less consistently related to soil composition and fertility. Understory plant species composition also changes like ferns and many non-fern herbaceous families are absent from the driest sites (Gentry & Emmons, 1987; Wright, 1992).

Soone Valley is a source of rich biodiversity, however, presently the species richness have been reported to face a sharp decline in this area (Ahmad *et al.*, 2007). Increasing human interference, clear-cutting for agriculture and fuel wood, over-grazing and over-exploitation of resources for salt and other minerals, over-harvesting of plants species particularly for medicinal purposes, increased disturbances, soil degradation and increasing metal toxicity have been reported as the major threats to the vegetation of this area that have put a large number of species at the risk of extension (Ahmad *et al*., 2009). There are certain reports that if the prevailing threats to the biodiversity of this are not managed properly, a large proportion of biodiversity might become severely threatened or even extinct in near future (Ahmad *et al*., 2007).

Despite the factor that the biodiversity of this area is facing a steep decline, there is a little effort to preserve this area of rich biodiversity. In this regards, Punjab Wildlife Department is running different projects to monitor trends in the biodiversity. A number of sites including Khabeki, Uchali and Jhallr lakes, and Sodhi Wildlife Reserve have been declared protected area. Among these protected areas, Khabeki, Uchali and Jhallar lakes are also Ramsar sites. However, the protection of these reserves is questioned since poor local people violate laws and continue harvesting of fauna and flora that result in further decline of biodiversity. Other sites selected in this study including Khoora, Dape Sharif, Anga, Knotti Garden are also a rich source of biodiversity including a variety of medicinal plants. However, currently no effective conservation plan has been developed for these sites. Resultantly biodiversity in these sites is at sharp decline. Therefore, for the development of an effective plan for conservation of plant species, it is necessary to get the true picture of species during different seasons, information about habitat at different sites, ecological factors and the disturbing factors prevailing there in. In the present study we have reported the variations in the structure of natural plant communities located in the semi-arid regions of Pakistan. In addition, the relationship between vegetational diversity and moisture availability and concentrations of soil macro- and micro-nutrients has also been drawn. The information imparted in this manuscript can be used to develop effective conservation plan and decide whether the study site should be included among protected areas for conservation of biodiversity.

Material and Methods

Study sites: Six ecologically diverse study sites namely Khabeki (higher macronutrients and field capacity), Khoora (around cultivated area, fertile soil), Dape Sharif (water spring and water channels passing through the valley, soil with higher EC), Anga (high pH), Knotti Garden (macronutrients and water springs and water chennel) and Jallar (saline area with steep slopes) were studied during 2004-07 to analyze the changes in structure of plant community structure and distribution pattern of the vegetation of semi-arid rangelands. For this purpose, the study area was extensively surveyed and the available species at selected sites were enlisted. The details of plant community structure with dominant species have already been reported in one of our earlier publications (Ahmad *et al*., 2008).

Selection of study sites: The study sites were selected on the basis of location from Naushera, which is the centre of social and political activation of the area. Other factors for example, easiness of approach, extent of human disturbance, extent of grazing and habitat of important fauna and flora were also taken into consideration before selection of sites. The location of the study sites has been presented in Fig. 1.

Meteorological data: Meteorological data were recorded at Horticultural Research Station, Soone Valley for the entire study period. The data of rainfall, maximum and minimum temperature has already been reported in one of our previous publications (Ahmad *et al*., 2009).

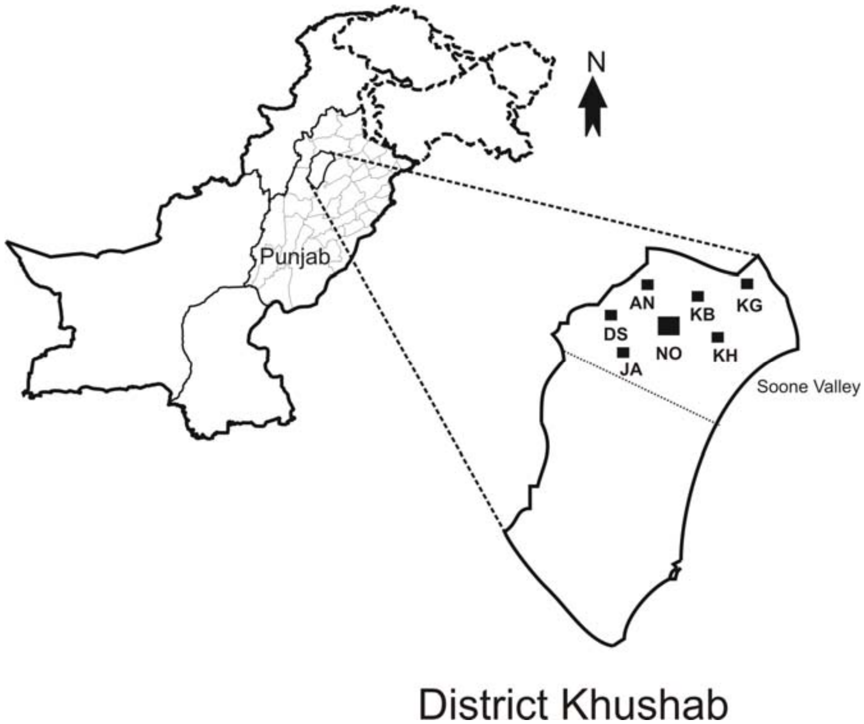

Fig. 1. Map of the study area showing the location of study sites. NO: Naushera; KB: Khabeki; KH: Khoora; DS: Dape Sharif, AN: Anga; and JA: Jallar.

Soil analysis: The soil samples were collected with a soil borer at a depth of 9 inches in three replicates from each quadrate. Soil texture was determined by using hygrometer method (Dewis & Freitas, 1970). Electrical conductivity pH and ions of saturation extracts were determined according to Rhoades (1982) and Jackson (1962). The results of the soil physico-chemical properties have already been presented in one of our previous publications (Ahmad *et al.*, 2008).

Ecological analysis of the vegetation: The plants were collected from their natural habitats at different sites in Soone Valley during all the four seasons (autumn, winter, spring and summer) for four consecutive years (2002-2006). For autumn, winter, spring and summer seasons the ecological data were recorded during last weeks of September, December, March and June respectively. The plants were identified with the help of flora of Pakistan. Specimens were mounted on herbarium sheets and were deposited in the Ecology Lab, Department of Botany, University of Agriculture, Faisalabad. Ecological data were recorded using random quadrate sampling method. Fifteen fixed quadrates of 1 m^2 for herbs and 5 m^2 for shrubs and trees were used at each site and all individual plants in the quadrates were counted. The data were used for the calculation of density, frequency, cover, relative density, relative frequency, relative coverage/dominance, importance value of species according to formulae given by Reynolds & Ludwig (1988).

Legend to the species used in Figures 2-5: 1. *Acacia farnesiana*; 2. *Acacia modesta*; 3. *Acacia nilotica*; 4. *Albizia lebbeck*; 5. *Dalbergia sissoo*; 6. *Olea ferruginea*; 7. *Prosopis glandulosa*; 8. *Salvadora oleoides*; 9. *Tamarix aphylla*; 10. *Ziziphus nummularia*; 11. *Ziziphus mauritiana*; 12. *Achyranthes aspera*; 13. *Adiantum capillus-veneris*; 14. *Alternanthera sessilis*; 15. *Sophora tementosa*; 16. *Barleria cristata*; 17. *Boerhavia procumbens*; 18. *Buxus papillosa* ; 19. *Cannabis sativa*; 20.*Capparis decidua*; 21.*Conyza ambigua*; 22. *Cynoglossum lanceolatum*; 23. *Datura metel*; 24. *Diclyptera bupleuroide*;

25. *Dodonaea viscosa*; 26. *Fagonia indica*; 27. *Heliotropium strigosum*; 28. *Justicia adhatoda*; 29. *Malvastrum coromandelianum*; 30. *Melilotus indica*; 31. *Medicago denticulata*; 32. *Mentha longifolia*; 33. *Nerium oleander*; 34. *Oxalis corniculata*; 35. *Peganum hermala*; 36. *Salvia virgata*; 37. *Sida cordifolia*; 38. *Solanum incanum*; 39. *Solanum nigrum*; 40. *Solanum surattense*; 41. *Tecomela undulata*; 42. *Tinospora malabarica*; 43. *Tribulus terristris*; 44 *Vicia sativa*; 45. *Withania coagulans;* 46. *Withania somnifera*; 47. *Cynodon dactylon*; 48. *Cyperus niveus*; 49. *Saccharum munja*; 50. *Saccharum spontaneum*; 51. *Parthenium hysterophorus*; 52. *Desmostachya bipinnata*.; 53. *Veronica arvensis.*

Statistical analysis: The Partial Canonical Correspondence Analysis (pCCA) technique was applied keeping seasons as a variable and sites as a co-variable and *vice versa*. The Multivariate Direct Gradient Model was fitted and all variables (nominal) were plotted on pCCA Axis 1 and 2. All species were arbitrarily grouped based on their clustering pattern for a particular season or site.

Results

The *pCCA* of relative density regarding seasons as environmental variables and sites as co-variables revealed highly significant results ($p<0.001$, eigen values 0.050) along axis I (Table 1). It was observed that the summer season had a significant effect on the distribution of species as compared to the all other seasons that lead to the grouping of the most of species (Group-I) around this season. However, some of the species (Group-II) were associated with autumn. In contrast, winter and spring seasons had relatively a little or no effect on relative distribution of species. Some of the species (Group-III) like *Sophora tomentosa* (15), *Withania somnifera* (46) and *Veronica arvensis* (53) showed equal distribution during summer and spring seasons. *S. munja* (49) showed a relatively different response as compared to all other species to seasonal variations and did not show any correlation with any specific season (Fig. 2a).

The effect of sites on species distribution was more evident ($p<0.001$, eigen value 0.308, Table 1) as compared to seasons. It was observed that most of the stress tolerant and highly competitive species were abundant in stressed soils with high pH and salinity, and lower moisture availability. However, moderately stress tolerant species such as *Solanum surattense* (40), *Salvia virgata* (36) and *Melilotus indica* (30) were more associated with soils of high pH (Anga site). Stress sensitive and moisture loving species of group II, III and IV were associated with high mineral and moisture containing sites (Khabeki, Knotti Garden and Dape Sharif respectively). Some sensitive species of group V were more distributed in moisture containing sites (Khoora and Dape Sharif). Species in group VII and VIII showed relatively less effect of sites on their distribution. However, these seem to be a little associated with moisture containing soils (Dape and Knotti Garden) [Fig. 2b].

In contrast to relative distribution of species, the effect of seasons on relative frequency of species was more prominent ($p<0.001$, eigen values, 0.071; Table 2). Most of the species were more frequent during summer (Group-I). However, some species as *Boerhavia procumbens*, *Cynoglossum lanceolatum*, *Heliotropium strigosum* and *Malvastrum coromandelianum* were frequent during autumn. Summer and spring seasons had a similar effect on the species occurrence of group-III, whereas species of Group-IV showed almost equal effect of summer, spring and winter seasons. Species in Group-V formed a distinct group between summer and autumn that indicated equal effect of both seasons on their distribution (Fig. 3a).

Table 1. Summary of the partial CCA of the vegetation data for relative density and environmental data for seasons and sites.

Parameters and data	Axes		Total inertia	F-ratio	*P* value
	1	2			
Relative density (Seasons | Sites)					
Eigenvalues	0.050	0.032	0.776	3.165	0.0040***
Sum of all canonical Eigenvalues	0.095				
Relative density (Sites | Seasons)					
Eigenvalues	0.308	0.070	0.776	12.448	0.0020***
Sum of all canonical Eigenvalues	0.489				

Table 2. Summary of the partial CCA of the vegetation data for relative frequency and environmental data for seasons and sites.

Parameters and data	Axes		Total inertia	F-ratio	*P* value
	1	2			
Relative frequency (Seasons | Sites)					
Eigenvalues	0.071	0.050	1.032	3.053	0.0020***
Sum of all canonical Eigenvalues	0.138				
Relative frequency (Sites | Seasons)					
Eigenvalues	0.248	0.111	1.032	5.816	0.0020***
Sum of all canonical Eigenvalues	0.609				

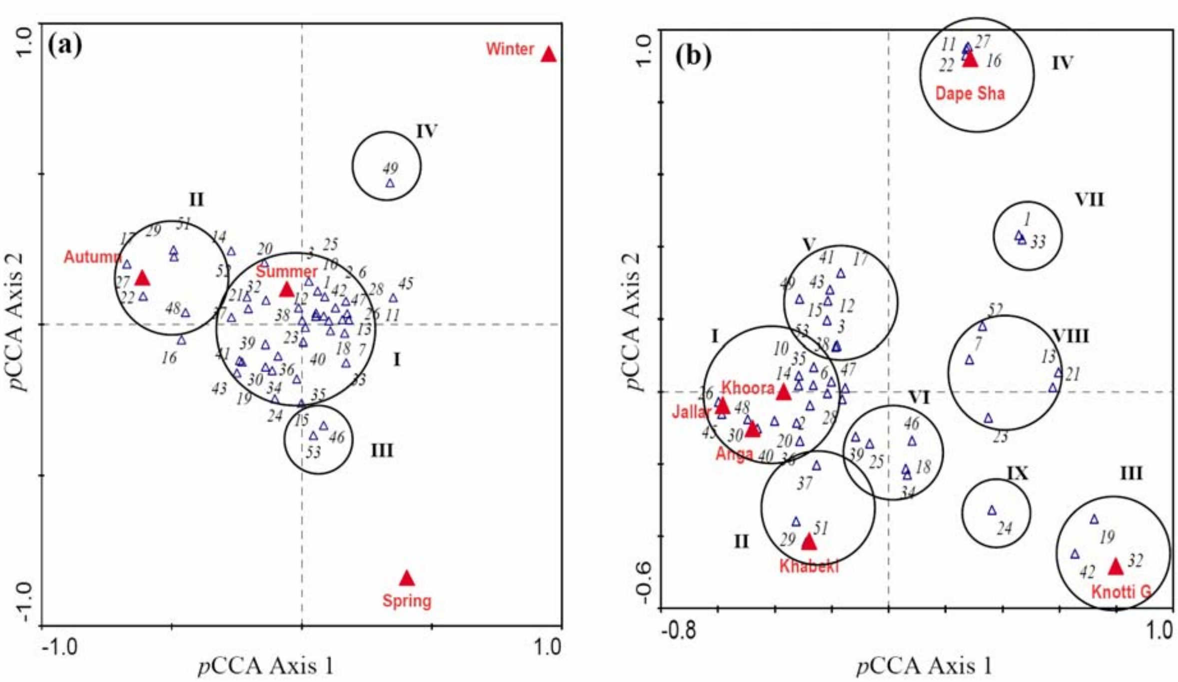

Fig. 2. Partial CCA ordination biplot showing the effect of seasons (a) and sites (b) on relative density of vegetation from Soone Valley of Salt Range.

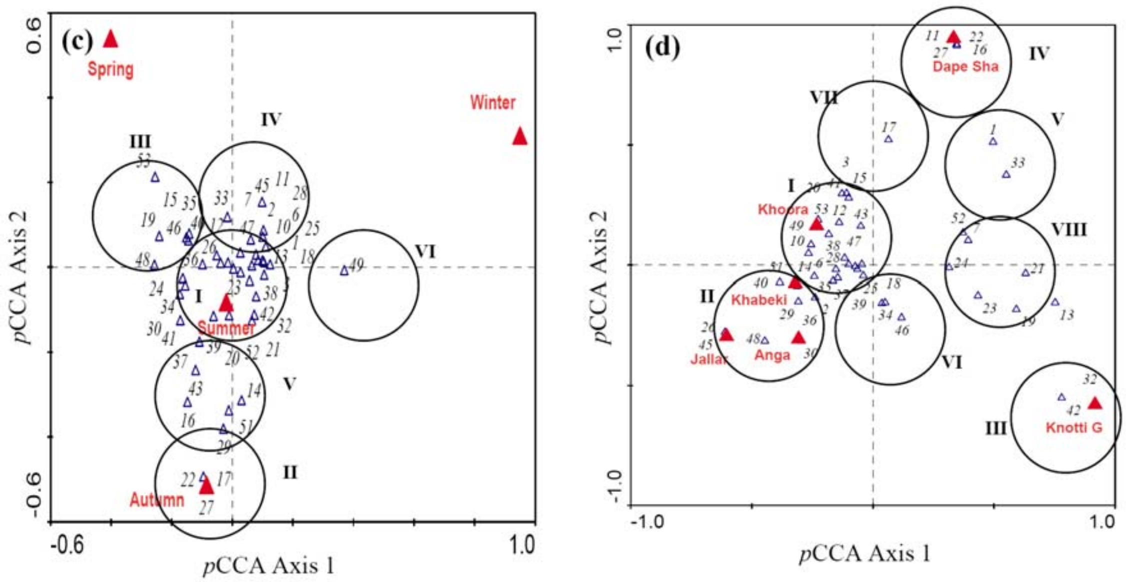

Fig. 3. Partial CCA ordination biplot showing the effect of seasons (a) and sites (b) on Relative frequency of vegetation from Soone Valley of Salt Range.

Table 3. Summary of the partial CCA of the vegetation data for relative cover and environmental data for seasons and sites.

Parameters and data	Axes 1	Axes 2	Total inertia	F-ratio	*P* value
Relative cover (Seasons | Sites)					
Eigenvalues	0.032	0.028	0.616	2.768	0.0140***
Sum of all canonical Eigenvalues	0.077				
Relative cover (Sites | Seasons)					
Eigenvalues	0.252	0.065	0.616	13.568	0.0020***
Sum of all canonical Eigenvalues	0.398				

The species occurrence showed a wide variation on all the sites studied ($p<0.001$, eigen value 0.248). *pCCA* ordination biplot showed almost similar trend to that of species distribution for sites with some variations. For example, the species of (Group-II) formed a relatively separate group as compared to that for species distribution. In this case, high pH and mineral (Khabeki and Anga) and salt contents (Jallar site) seemed to be the determinant factors for species occurrence. In addition, *Cannabis sativa* showed relatively less correlation with high mineral and moisture containing soils of Knotti Garden and shifted to the separate Group-VIII. Similarly, *Diclyptera bupleuroide* was also grouped within Group-VIII which was found in fertile soils. However some species (Group-VI) that were adaptable to a variety of environmental conditions were equally associated with stressed soils of Khoora, Anga, Khabeki and Knotti Garden (Fig. 3b).

The partial *CCA* for relative cover data (seasons as environmental variables and sites as co-variables) also revealed highly significant results ($p<0.001$, eigen value 0.032) along axis I (Table 3). Overall, the seasonal effects on species cover were very much similar to that of species distribution. Summer season showed the most prominent effect on species cover as compared to other seasons (Fig. 4a, Group-I). It was interesting to note that density and cover values were strongly correlated for the species in Group-II during autumn and hence were clustered in the same group. On the other hand spring and summer seasons showed a very little or no effect on species cover. Similarly, some species like *Veronica arvensis* (Group IV) and *Diclyptera bupleuroide* and *Withania coagulans* (Group III) did not show any effect of seasons on their cover values.

Table 4. Summary of the partial CCA of the vegetation data for importance value and environmental data for seasons and sites.

Parameters and data	Axes		Total inertia	F-ratio	*P* value
	1	2			
Importance value (Seasons | Sites)					
Eigenvalues	0.055	0.044	0.878	2.995	0.0020***
Sum of all canonical Eigenvalues	0.114				
Importance value (Sites | Seasons)					
Eigenvalues	0.277	0.087	0.878	8.594	0.0020 ***
Sum of all canonical Eigenvalues	0.543				

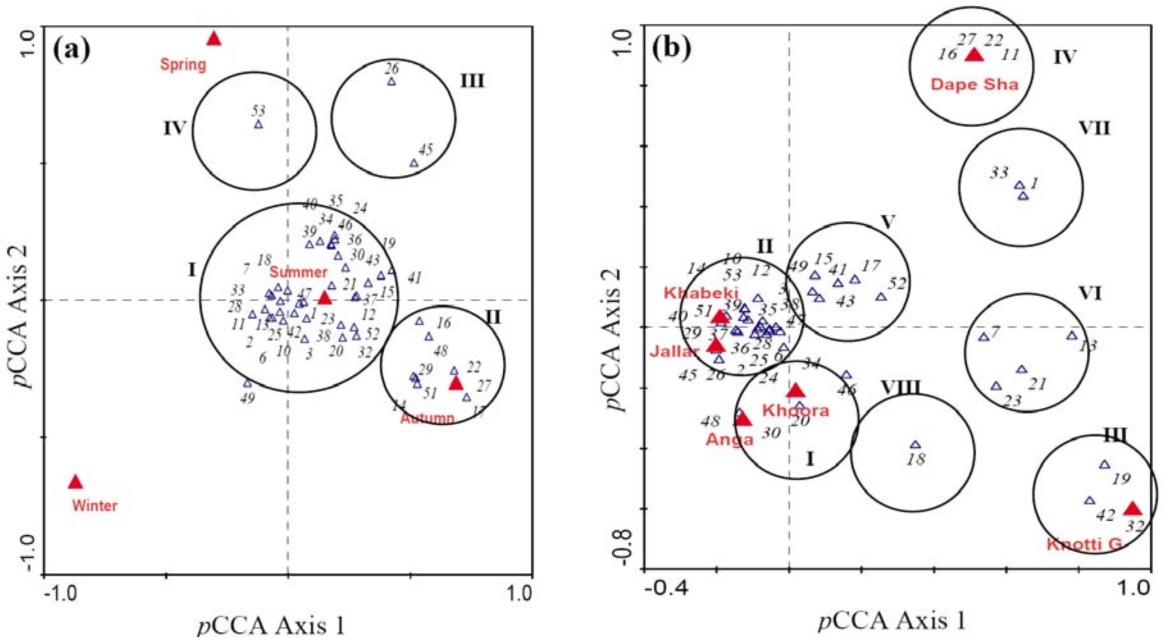

Fig. 4. Partial CCA ordination biplot showing the effect of seasons (a) and sites (b) on Relative cover of vegetation from Soone Valley of Salt Range.

As compared to seasons, the spatial effects were more evident on species cover as it showed highly significant variations along axis I ($p<0.001$; eigen value 0.252; Table 3). It was observed that most of the species (Group-II) had relatively more cover at soils with high field capacity (Khabeki and Jallar sites). Species (Group-I) were more associated with the fertile soils of Khoora where as species which can tolerate high pH had relatively more cover values at Anga site. The cover values of the most of the water loving species (Group III and IV) were associated with springs and water channels (at Knotti Garden and Dape Sharif sites). However, species of Group-V and Group-VIII had some association with mineral containing fertile soils (of Khabeki and Khoora respectively). Similarly species of Group-VI and VII are also moderately water loving therefore had some association with soils of spring and water channels (Knotti Garden and Dape Sharif, respectively) (Fig. 4b).

The importance values of the species also significantly varied during all the four seasons and at 6 sites ($p<0.001$, eigen value 0.055; Table 4). Species in Group-I, II, III and IV had maximal importance values during summer and autumn. On the other hand, winter and spring had no effect of importance values of species. Some species like *Alternanthera sessilis* and *Barleria cristata* had importance values associated equally with summer and autumn. On the other hand, *Saccharum munja* did not show a specific association with any season (Fig. 5a).

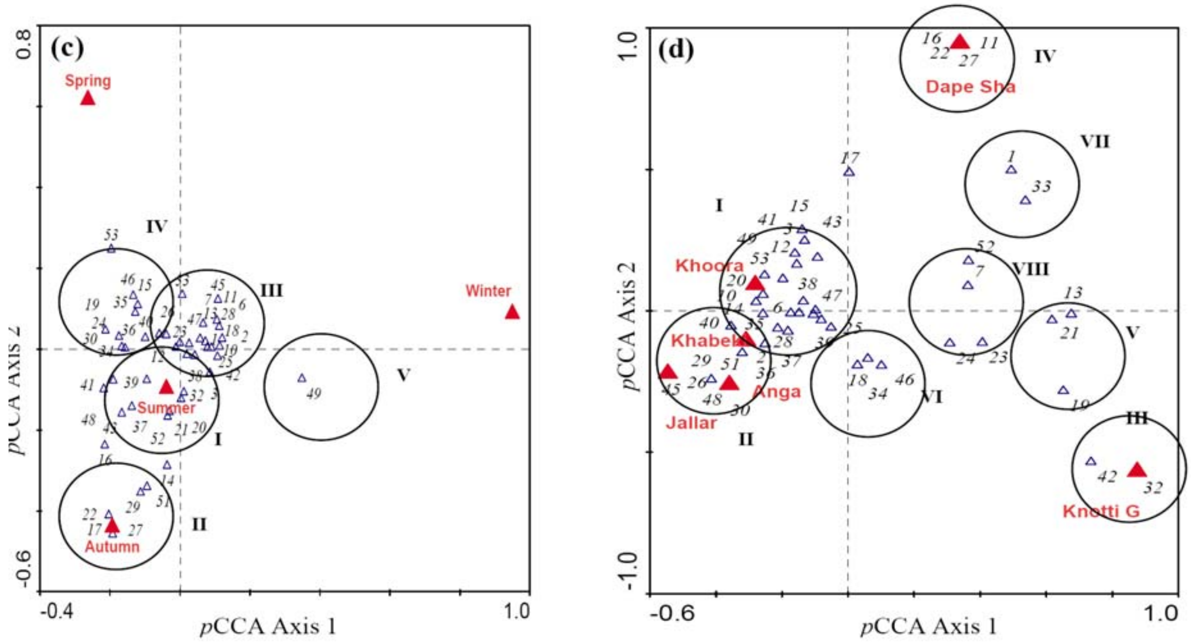

Fig. 5. Partial CCA ordination biplot showing the effect of seasons (a) and sites (b) on Importance value of vegetation from Soone Valley of Salt Range.

Similar to that of the data for species density, frequency and cover values, the importance value also showed highly significant variations for sites ($p<0.001$, eigen value 0.27; Table 4). Species (Group-I) had maximum importance values at fertile soils (Khoora site). Species in Group-II had more affiliation for importance values with the soil containing high mineral content (Khabeki), high pH (Anga) and high field capacity (Jallar sites). On the other hand, water loving species of Group-III and Group-IV showed more effect of spring and in soils of high moisture contents (Knotti Garden and Dape Sharif respectively). However, species of Group-VI, VII and IV showed relatively less or no effect of sites on their importance value as they did not show association with any specific site (Fig. 5b).

Discussion

The primary determinants of plant growth and distribution are the environmental factors including the soil moisture (Skarpe, 1990; Michael *et al.,* 2002), types, mineral nutrient composition and topography (Sharma *et al*., 1983; Cole *et al*., 1987, Dalsted, 1988; Austin & Heylgens, 1989; Smitheman & Perry, 1990). These factors were also found to be an important component for the determination of vegetation structure during different seasons and sites in this study. For example, the higher distribution of most of the species in summer and autumn seemed to be correlated with suitable temperature and availability of moisture during these seasons (Skarpe, 1990; Zaman, 1997; Ahmad *et al.,* 2008). Another reason of clustering of species around summer can be the higher availability of macronutrients (Ahmad *et al*., 2008) which are essential for optimal growth of plants (Skarpe, 1990; Madan *et al*., 2007). In addition, elevated temperature has been reported to enhance shrub production and reduce the occurrence of nonvascular plants (Chapin, 1995) that were also evident in this study. On the other hand, association of only few species with spring could be mainly due to severe cold temperature and low water availability during winter. Only trees and few shrubs had little association with winter as these shrubs and trees were found during all seasons (Varghese & Murthy, 2006).

Most of the salt tolerant species such as *Fagonia indica* and *W. cogulans* had more distribution at saline area of Jallar site. In addition, this area also had high field capacity which help in maintaining more moisture even during the periods of low rainfall. On the other hand, most of the herbs and shrubs were distributed at fertile area around cultivated lands (Khoora site). In addition, some salt sensitive species were associated with soils containing higher macronutrients and field capacity (Khabeki site) (Ahmad *et al.*, 2008). Some species like *Canabis sativa, M. longifolia* and *Tinospora malabarica* were observed to be mostly found at soils with high moisture and mineral contents therefore were entirely associated with the areas of water springs and water channels (of Knotti Garden). These species are mostly abundant at high moisture containing sites. Moreover enough macronutrients availability of this site also help the growth of such type of vegetation (Knotti Garden) (Ahmad *et al.*, 2008) which is essential for maximum growth of herbs (Madan *et al.*, 2007).

Generally sites with higher contents of macronutrients and high field capacity (Khabeki and Khoora) had higher species frequency. Salt and drought tolerant species were associated around saline area and steep slopes of Jallar site that generally had high salt and low soil moisture contents. On the other hand, moisture loving and moderately moisture requiring species were associated equally with the water springs and water channel containing sites (Knotti Garden and Dape Sharif). Due to the presence of enough moisture, suitable temperature and macronutrients, species had the maximum plant cover during summer followed by autumn and spring and the minimum in winter.

Among the sites, most of the species showed the maximum plant cover at sites with enough availability of nutrient, moisture and suitable temperature (Khabeki site followed by Khoora site) (Madan *et al.*, 2007), salt and drought tolerant species showed maximum cover at saline area (Jallar site) and water loving species at soils with water springs and channels (Knotti Garden and Dape Sharif). Most of the species showed higher importance values around summer and few during autumn whereas spring and winter had least association with importance values.

The sites, dominated by excellent nutrient status, macronutrients, moisture holding capacity and other favorable environmental factors (Khabeki, Khoora and Anga) showed high importance values for most of the species. Moisture loving plants had higher importance value at sites having better water reservoirs (Dape Sharif and Knotti Garden) whereas salt and drought tolerant species at saline area and steep slopes (Jallar site).The spatial variations might be due to the soil type, composition of soil, elevation of selected sites, moisture contents of soil, nature of disturbance like grazing pressure, human interference and distance of study site from population area etc.

Overall, plant community structure showed significant variations during all seasons and at all sites studied. All parameters studies were significantly affected by summer and autumn seasons whereas, spring and winter seasons showed a little or no effect. On the other hand, soil mineral and moisture contents, pH and ECe seemed to be major determining factor for distribution of most of the species in this area. In addition, grazers, human influences and disturbance also seemed to be determinant factors for these changes especially during the periods of suppressed plant growth and high energy requirements by local population in winter. There is a dire need to develop an effective conservation plan based on this study to conserve the native flora of medicinal importance.

Acknowledgement

The authors greatly acknowledge the technical and linguistic assistance provided by Prof. Dr. Michael W. Palmer, Botany Department, Oklahoma State University, 04 LSE, Stillwater, OK 74078, USA during study and preparation of this manuscript.

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(Received for publication 30 December 2009)