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ADVANCED MULTIVARIATE TECHNIQUES TO INVESTIGATE VEGETATION-ENVIRONMENTAL COMPLEX OF PINE FORESTS OF MOIST TEMPERATE AREAS OF PAKISTAN

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Abstract

Forty one stands of conifer forests of moist temperate areas, covering the natural limits of this forest type, in northern Pakistan were investigated. Multivariate techniques including cluster analysis (Ward's agglomerative method and TWINSPAN a divisive method) as well as ordination (DECORANA) were used to explore vegetation composition and structure of canopy trees and understorey (shrubs and herbs) vegetation and their relationship with the associated environmental factors. Classification of overstorey trees derived by TWINSPAN and Ward's methods showed some similarities in groups. Among the topographic variables, only elevation was found to be significant ($P < 0.01$) while edaphic variables showed no significant difference in group means. For understorey vegetation some similarities were also recorded between TWINSPAN and Ward's method. Among environmental variables elevation ($P < 0.001$), aspect ($P< 0.05$), canopy cover ($P < 0.001$) and soil pH ($P < 0.01$) were found to be significant.

In many cases relationship of axes in DCA stand ordination and environmental variables were also significantly correlated, however axis two of understorey ordination did not show any significant correlation with any environmental variables. Present study showed similarities between Ward's cluster analysis of tree vegetation and understorey vegetation data, despite a long history of anthropogenic disturbance in these areas.

Introduction

The present study deals with the quantitative analysis of the vegetation, prevailing in moist temperate belt of Himalayan region of Pakistan and Azad Kashmir. In Pakistan, the earlier ecological studies were generally observational. However, with the passage of time gradually quantitative principles were introduced and the vegetation description evolved to quantitative studies. The earlier studies generally appeared in 1950's were confined to visual description of the vegetation, and no attempts were made to recognize community types and to correlate them with the relevant environmental factors. Advanced multivariate techniques of ordination and cluster analysis had been routinely used in Europe and North. America since last several decades but in Pakistan such techniques were utilized in early 70's by Shaukat & Qadir in 1971 and Ahmed (1973, 1976), they performed a multivariate analysis of the vegetation of calcareous hills around Karachi, industrial area of karachi and Skardu respectively using polar ordination (Bray & Curtis, 1957). Again Shaukat *et al.*, (1976) employed agglomerative cluster analysis by group average linkage method in their study of the vegetation of Gadap area. Ahmed *et al.*, (1978) focused on multivariate approaches to the analysis of the vegetation complex and constructed three dimensional stand, species and environmental ordinations. Shaukat *et al.*, (1980) employed the same technique to construct the environmental and species ordinations and found significant correlations in vegetation with soil nutrients and moisture. Khan *et al.,* (1987) and Shaukat (1988) suggested a multivariate approach for vegetation sampling and pattern recognition at various scales while Shaukat & Uddin (1989a) compared various techniques of factor analysis using different kinds of factor rotation. In search of more effective multivariate techniques to expose the underlying relationships between phytosociological and environmental gradients, Shaukat & Uddin (1989b) employed canonical correlation analysis (CCA) and developed three new variants of CCA (models I, II and III) that circumvent certain problems in the implementation of CCA.. Uddin *et al*., (1995) developed Sweep-out component analysis (SCA) as an ordination model, providing an alternative method to principal component analysis (PCA). They showed that SCA is a much better option than PCA.

Shaukat (1994) conducted a multivariate analysis of the niches and guild structure of plant populations in a desert landscape using principal component analysis (PCA). For this purpose a computer program NICHE was developed in FORTRAN 77. Ahmed *et al.,* (1987) and Hussain *et al.,* (1994) described the vegetation of Chiltan in Baluchistan Swabi District and Khyber Pakhtoonkhwah by multivariate analysis. Shaukat *et al.,* (2005) compared correspondence analysis (CA), detrended correspondence analysis (DCA) and canonical correspondence analysis (CCA) techniques and concluded that CCA provides better interpretation of ecological data. Enright *et al.,* (2005) described the desert vegetation and vegetation-environment relationship in Kirther National Park, Sindh, Pakistan using classification (TWINSPAN) and ordination (nonmetric multidimensional scaling NMDS) techniques. Malik & Hussain (2006) used Divisive cluster analysis (TWINSPAN) and DCA ordination to analyze the vegetation communities of Lohibehr reserve forest and its surrounding area, Rawalpindi. Again Malik & Husain (2007) explored the invasion of *Broussoneta papyrifera* (exotic species) on the native scrub forest at the Himalayan foothills, Islamabad, using hierarchical agglomerative cluster analysis for species assemblage pattern and ordination techniques like Detrended correspondence analysis (DCA) and Canonical correspondence analysis (CCA) to established the relationship with the underlying environmental gradients. They also used Principal component analysis (PCA) and Factor analysis (FA) to identify set of environmental gradients.

Peer *et al.,* (2007) used TWINSPAN for the classification of steppe vegetation and CCA for examining relationships between the vegetation and selected environmental parameters. Wazir *et al.,* (2008), Saima *et al*., (2009) and Jabeen & Ahmed (2009) used DCA ordination and cluster analysis for the study of vegetation of Chapursan valley (Gilgit), Ayub and Ayubia national Parks respectively. Ahmed *et al*. (2009) evaluated the ecological aspects of roadside vegetation around Havalian City using multivariate techniques (DCA ordination, CCA ordination and CANOCO). Ahmed (2009) studied relation of herbaceous vegetation with edaphic factors of Margalla Hills National Park, Islamabad, using TWINSPAN and DCA ordination. Ali & Malik (2010) and Ahmed *et al*., (2010) assessed the plant communities of gardens and parks of Islamabad city and Motorway, using similar methods. Siddiqui *et al.,* (2010) used agglomerative cluster analysis and PCA ordination for quantitative vegetation description of moist temperate area of Pakistan. However, no multivariate analysis has yet been employed to investigate vegetation environmental complex of this area of Pakistan. Therefore divisive and agglomerative cluster analysis and detrended correspondence analysis (DCA) were chosen to expose the underlying pattern of vegetation of the entire moist temperate belt of Himalayan region of Pakistan.

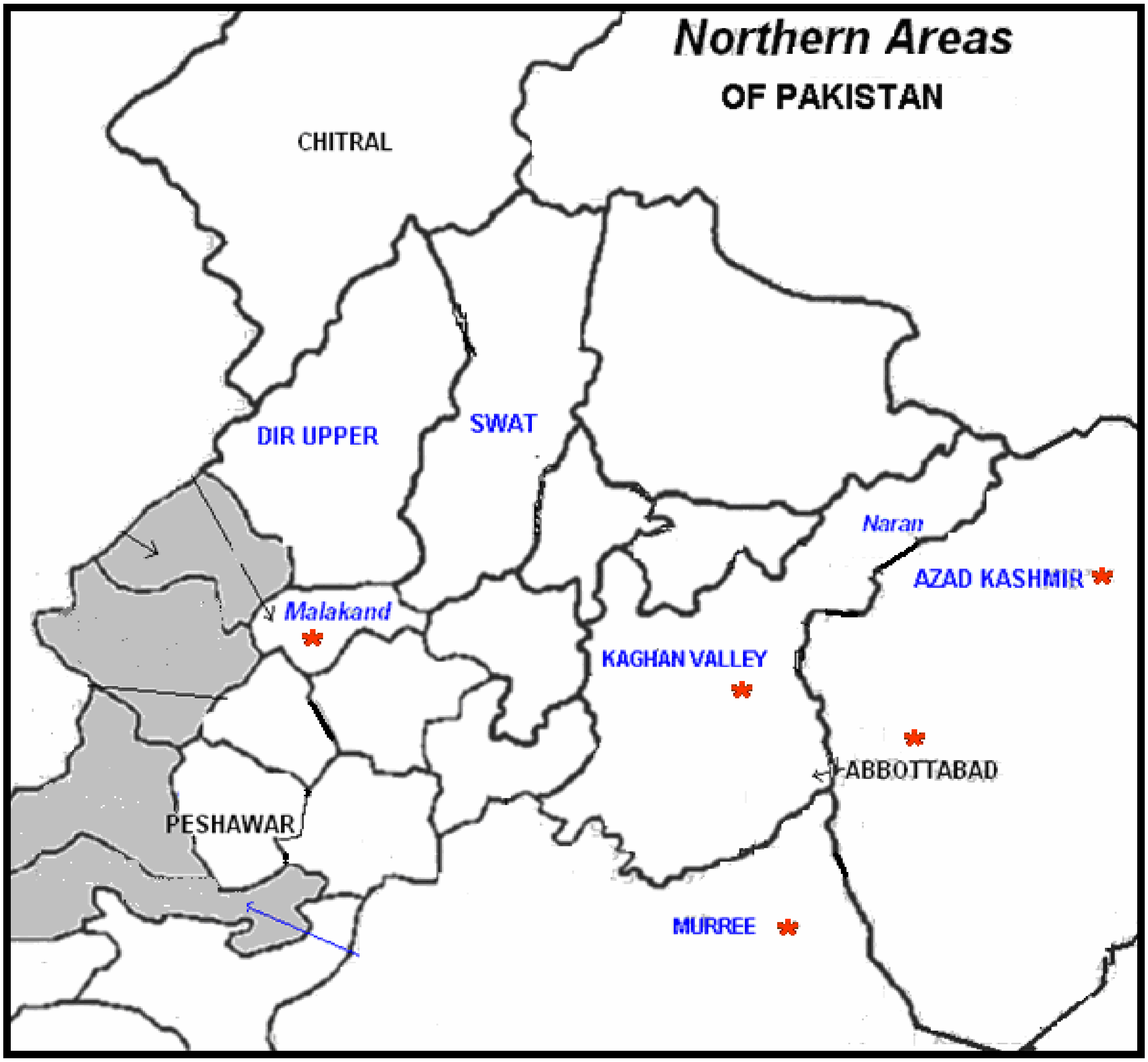


Fig.1 Asterisk showing the main locations where moist temperate forests were studied. Details of the sites and stands are given in Table 1.

Table 1 Summary of sampling sites and site characteristics of moist temperate area of Himalayan region of Pakistan.

S. No.	Location and sites	Lati (N)	Longi (E)	Elev (m)	Slope (°)	Aspect	Canopy	Soil Comp.
1- Malakand Division								
1.	Kumrat	35° 54'	72° 14'	2400	R. Top	R. Top	Closed	165
2.	Pana Kot	35° 16'	71° 50'	2200	40	W	Closed	150
3.	Malam Jabba 1	35° 12'	72° 81'	2600	34	W	Moderate	175
4.	Malam Jabba 2	35° 20'	72° 40'	2350	30	N W	Open	200
5.	Miandam	35° 09'	72° 30'	2600	49	N	Moderate	150
2- Azad Kashmir								
6.	Keran, Dist. Neelam	34° 56'	73° 12'	1960	30	N E	Open	250
7.	Chikar, Dist. Baagh	34° 54'	73° 10'	1930	28	N W	Moderate	150
8.	Sudhan Gali 1,	34° 20'	73° 22'	2450	22	E	Moderate	200
9.	Sudhan Gali 2	34° 22'	73° 28'	2500	32	N	Partly closed	130
10.	Sudhan Gali 3	34° 19'	73° 25'	2420	38	West	Moderate	110

3- Muree, Rawalpindi Division								
11	Ghora Gali	33º 52'	73º 20'	2100	29	N	Moderate	150
12	Patreata 1	33º 50'	69º 56'	2300	40	S E	Closed	210
13	Patreata 2	33º 50'	69º 56'	2300	25	S W	Moderate	110
14	Patreata 3	33º 52'	69º 57'	2000	39	S	Moderate	150
15	Kashmir Point	34º 54'	73º 24'	2500	39	S	Closed	150
4- Abbot Abad, Hazara Division								
16.	Ghora Dhaka 1	34º 02'	73º 26'	2500	36	N E	Closed	130
17.	Ghora Dhaka 2	34º 04'	73º 24'	2500	32	S E	Closed	170
18.	Ghora Dhaka 3	34º 07'	73º 25'	2800	40	S W	Moderate	180
19.	Ghora Dhaka 4	34º 09'	73º 27'	2800	40	W	Closed	220
20.	Ghora Dhaka 5	34º 11'	73º 28'	2600	37	S W	Closed	170
21.	Khaira Gali	33º 57'	73º 23'	2730	42	S E	Closed	120
22.	Changla Gali 1	33º 59'	73º 23'	2650	47	W	Open	180
23.	Changla Gali 2	33º 59'	73º 23'	2670	35	S	Closed	150
24.	Kuzah Gali 1	34º 02'	73º 24'	2560	R. Top	R. Top	Moderate	210
25.	Kuzah Gali 2	34º 02'	73º 24'	2560	28	S E	Closed	210
26.	Nathia Gali 1	34º 54'	73º 46'	2640	35	S	Moderate	160
27.	Nathia Gali 2	34º 54'	73º 46'	2630	33	N W	Open	190
28.	Thandyani 1	34º 14'	73º 22'	2320	31	S	Moderate	140
29.	Thandyani 2	34º 14'	73º 22'	2300	38	S	Moderate	140
5- Kaghan Valley, District Mansehra								
30.	Paye	34º 47'	73º 30'	3100	38	S	Closed	250
31.	Sri	34º 47'	73º 30'	2900	39	N	Closed	90
32.	Shogran 1	34º 37'	73º 28'	2400	27	S W	Closed	170
33.	Shogran 2	34º 37'	73º 28'	2400	23	S	Closed	190
34.	Shogran 3	34º 37'	73º 28'	2500	33	S	Closed	150
35.	Paras	34º 41'	73º 35'	1600	20	N E	Closed	160
36.	Khanian	34º 47'	73º 32'	2000	35	E	Closed	195
37.	Shinu 1	34º 38'	73º 26'	1900	39	N W	Moderate	180
38.	Shinu 2	34º 38'	73º 26'	1650	43	W	Closed	120
39.	Naran	34º 53'	73º 39'	2500	R. Top	N W	Moderate	190
40.	Naran	34º 53'	73º 39'	2500	R. Top	N W	Moderate	170
41.	Lalazar (Naran)	34º 53'	73º 39'	3000	45	N W	Closed	150

Note: Lati. = Latitude, Longi.= Longitude, Elev.= Elevation, Soil comp.= Soil compaction, R. Top = Ridge top, E = East, W = West, N = North and S = South

Materials and Methods

Sampling was carried out in moist temperate conifer forests of Pakistan and Azad Kashmir throughout their natural limits. Details of site and sampling stands are described in Fig. 1. Though forests are disturbed but mature and least disturbed forests were selected for quantitative sampling. The criteria for the selection of a stand were:

1- That it should be dominated by conifer trees

2- There should be no recent sign of disturbance

3- Stand should cover at least five hectare area

Forty one stands were sampled by Point Centered Quarter (PCQ) Method (Cottam & Curtis, 1956) for quantitative study. At each stands twenty points were taken at every twenty meter intervals**.** The PCQ method has been recommended by Mueller-Dombois & Ellenberg (1974) and Kent & Coker (1992) for systematic and random sampling, particularly for tree vegetation. This method gives reliable overall density and relative density estimates (Greig-Smith, 1983). It is fast, reliable and requires little labour with relative ease of calculation and is readily applied in thick dense forest with uneven topography.

Aspects, elevation, soil compaction, slope angle, longitude and latitude of each stand were recorded, using GPS. Phytosociological attributes (importance value and relative frequency) were calculated, according to the method described by Mueller-Dombois & Ellenberg (1974). Importance Value Index (Brown & Curtis, 1952) was used to rank each species. A species list with a relative frequency for understorey (ground flora) plants (<10 cm dbh) is with the senior author, using a circular plot (1.5 m diameter) at each sampling point. Plants specimens which were unidentified in field were identified with the help of Flora of Pakistan (Stewart, 1972).

The multivariate analyses were performed using the package PC-ORD ver. 5.10 (McCune & Grace, 2002) on three data sets, each of forty one stands. The data sets are: (1) a data set of tree vegetation, (2) understorey vegetation, and (3) the corresponding environmental variables data set. Environmental variables are further classified into three groups i.e. topographic variables (elevation, slope and aspect), edaphic variables (soil compaction, pH, water holding capacity, salinity and conductivity) (organic matter of soil, and soil nutrients Ca, Mg, Na, K and total nitrogen). The data sets pertaining to tree and understorey vegetation were subjected to three different multivariate analyses, i.e. TWINSPAN (two-way indicator species analysis), a divisive, polythetic clustering. Ward's clustering (an agglomerative method) and DCA ordination. Importance values of tree species and relative frequency of understorey species were used in Matrix 1 for the multivariate analysis. Out of 87 understorey species occurring in 41 stands of study area, 31 species were selected for multivariate analysis (TWINSPAN, Ward's cluster analysis and DCA ordination) i.e. those species that were present in a minimum of three stands.

Environmental Variables

Four environmental variables (elevation, slope, aspect and soil compaction) are used in the second matrix for multivariate analysis. Environmental variable (aspect) assign numbers to use in matrix 2 for multivariate computation i.e. South = 1, North = 2, East = 3, West = 4 and Ridge top = 1.

Soil Analysis

Essential elements (N, P, K, Ca, Mg and Na) of soil are estimated following the method of Allen *et al.*, (1974). Organic matter of soil was determined by the method described by Dean (1974). Total dissolved salts, pH, Salinity and Conductivity were measured in the field with the portable instrument, Multiparameter meter, Model Sension, TM 105, U.K. Soil compaction was also estimated by portable soil compact meter while maximum water holding capacity was determined, following the method of Keen (1931).

ANOVA: (univariate analysis of variance)

Three main groups were recognized using Ward's clustering strategy. The individual environmental variables corresponding to the three groups were analyzed using univariate analysis of variance (ANOVA) to find if any of the environmental variables were significant.

Hotelling's T^2: (Multivariate Analysis Method)

The groups mean vectors of environmental variables were tested using Hotelling's T^2 statistics. Normality of the variables was checked (Liang, 2009) and they depicted normality or close to normality.

Results

Fig. 1 shows the location of sampling sites while Table 1 presents the characteristics of these sites. The vegetation studied occurred between 1600 m to 3100 m above the sea level. Significant correlations were found between vegetation composition and environmental variables on some occasions. Results obtained by the three multivariate techniques were more or less corresponded with each other. The groups derived from tree vegetation data and that obtained by understorey vegetation also disclosed close correspondence.

1- Classification
A- Tree Vegetation Data
(i)- Divisive, polythetic cluster analysis of stands (TWINSPAN)

The dendrogram based on TWINSPAN (divisive cluster analysis) is shown in Fig. 2 which also shows the negative and positive preferentials species at each clustering cycle. The stand numbers of those included in the cluster are also shown. The dendrogram shows seven clusters out of which two clusters have only one individual (stand).

Group I of TWINSPAN was pre-dominated by *Cedrus deodara* (average importance value = 76%) with *Juglans regia* and *Pinus wallichiana* as co-dominants. Group II was almost completely dominated by *Pinus wallichiana* (average importance value = 95.2%).

Cedrus deodara was dominated in group III attained 62.2 % average importance value while co-dominant species *Pinus wallichiana* occupied 32.4% average importance value. Group IV was dominated by *Abies pindrow* (average importance value = 44.25) and *Cedrus deodara* (average importance value = 31) with *Pinus wallichiana* as co-dominant. Group V was predominated by *Abies pindrow* (average importance value = 56) and *Pinus wallichiana* (average importance value = 26%). *Juglans regia* was also associated with this group (13% importance value). The dominance of group VI is shared by *Abies pindrow* (average importance value = 54.6%) and *Pinus wallichiana* (average importance value = 42.0 %), *Taxus wallichiana* is less abundant in this group comprises only 2.75% average importance value. Lastly, group VII exhibits dominance of *Abies pindrow* and *Picea smithiana* with 58.75% and 26.75% importance value respectively. *Pinus wallichiana* also occupies 14.5% importance value in group VII.

(iia) Agglomerative cluster analysis of stands (Ward's method)

The dendrogram resulting from cluster analysis for tree data using Ward's method is shown in Fig. 3. The dendrogram discloses three main groups at a squared Euclidean distance of $7x10^4$. Group I comprising of 12 stands, is characterized by the predominance of *Pinus wallichiana* (importance value = 81) with *Cedrus deodara* (importance value = 8.2) and *Abies pindrow* (importance value = 4.3). *Picea smithiana* is also prominent species in this group. Group II that includes 17 stands is the largest of the three groups. It is dominated by *Abies pindrow* (importance value = 62.3) with second dominant *Pinus wallichiana* (importance value = 26). *Picea smithiana* (importance value = 4.6) and *Cedrus deodara* (importance value = 3.5) are present with low importance value. Group III which comprises of 12 stands is predominated by *Cedrus deodara* (importance value = 78.0) while *Pinus wallichiana* is also conspicuous (importance value = 16.29). *Abies pindrow* has low abundance in this group.

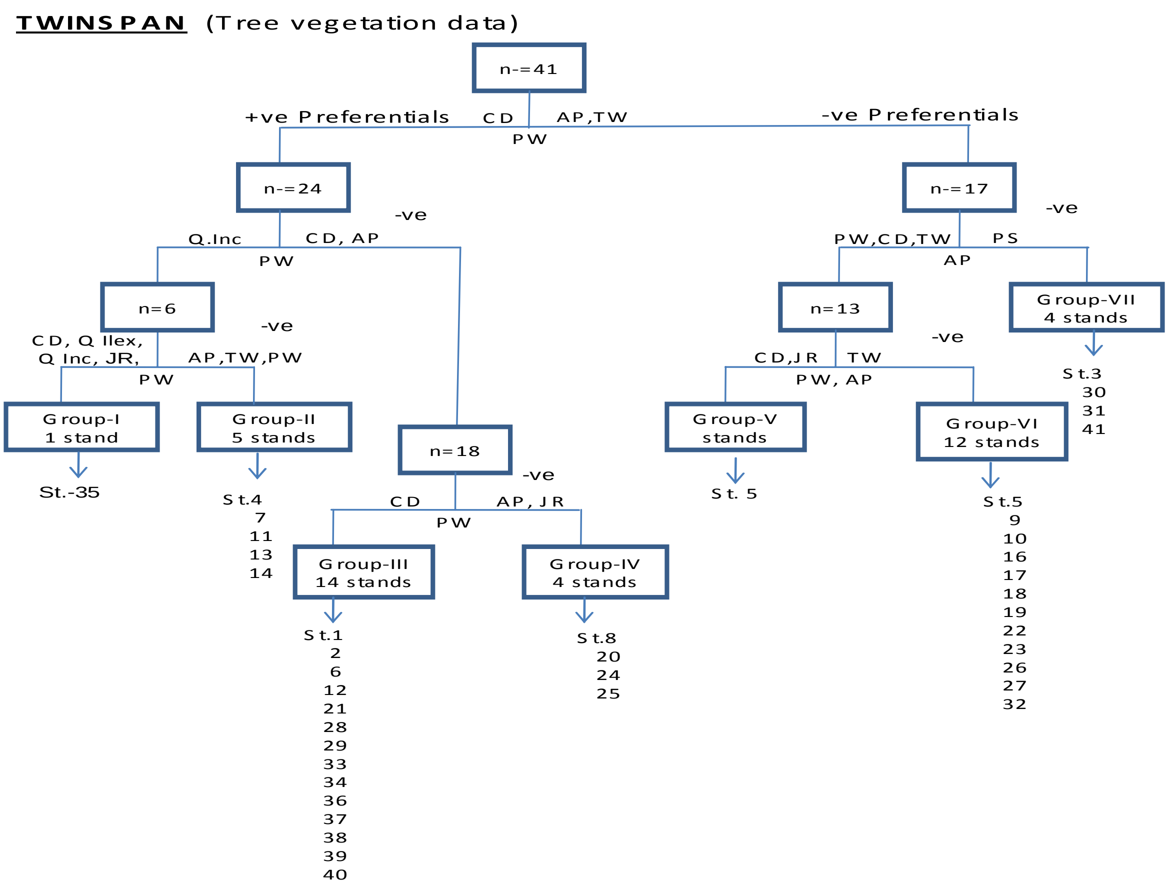


Fig. 2. Results of TWINSPAN cluster analysis. Stands belonging to each group and the +ve and –ve preferential species are indicated. For species symbols refer to Fig. 11.

Environmental characteristics of groups: With respect to environmental variables the three groups (based on Ward's cluster analysis) show some variability. Group I is characterized by medium elevation, higher rating of aspect, medium salinity and conductivity levels, medium Ca levels, low K level but high soil nitrogen level. Group II is characterized by higher elevation, greater slope, low aspect rating, higher salinity and conductivity, low Ca level but high K level and low N content of soil. Group III is associated with low elevation, medium slope, medium aspect rating, low salinity and conductivity, high Ca, medium K level and N content of soil.

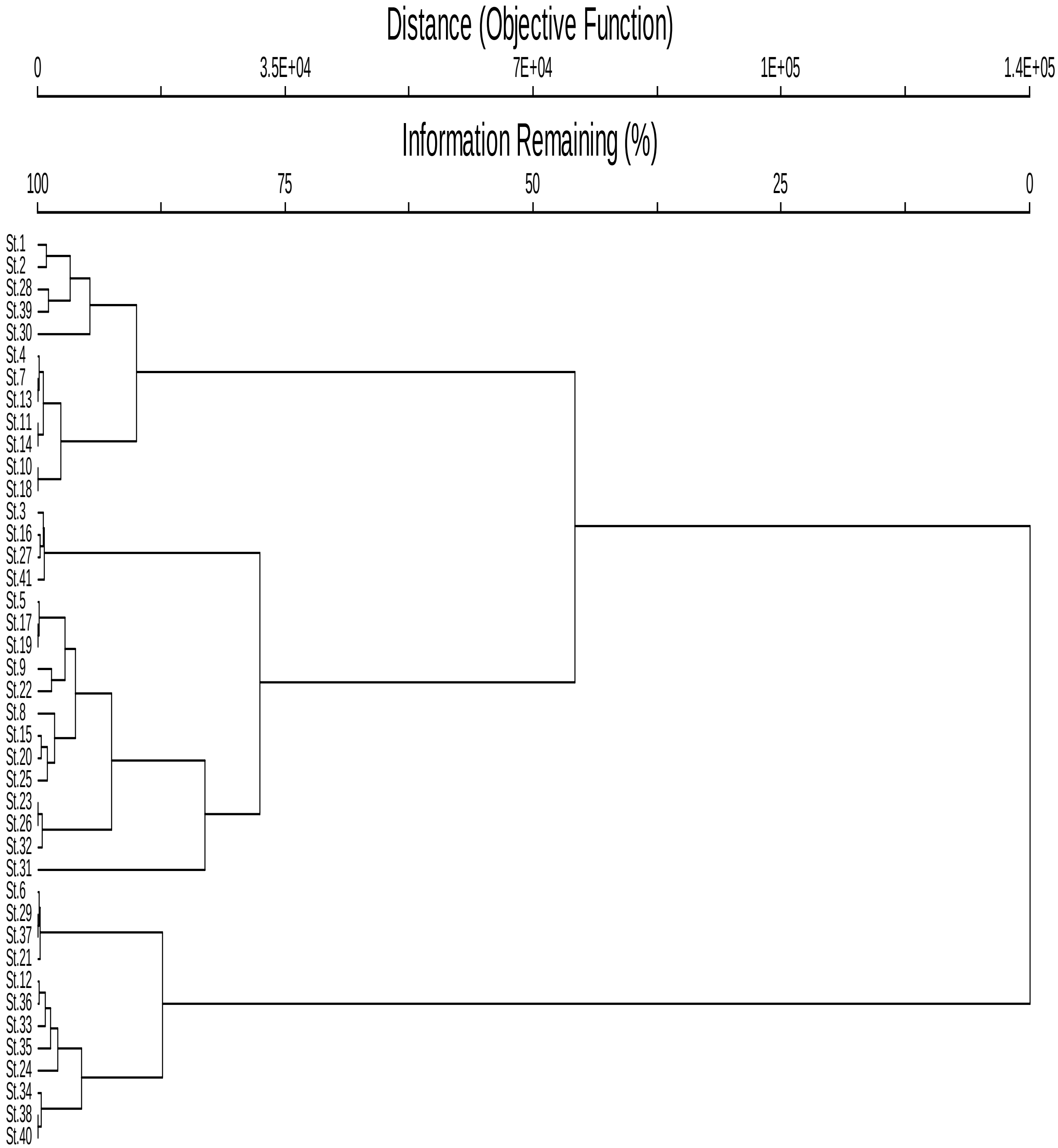


Fig. 3. Dendrogram obtained from Ward's agglomerative cluster analysis of tree data of 41 stands of moist temperate forest of Pakistan. Stand numbers are shown at the base.

Univariate analysis of variance (ANOVA)

Three main groups were also recognized using Ward's clustering strategy. The individual environmental variables corresponding to the three groups were analyzed using univariate analysis of variance (ANOVA). Among the topographic variables, elevation was found to be significant (F= 7.5; P< 0.01) while slope and aspect were found non-significant (F= 1.7 and F= 2.2 respectively, both n.s.). Among the five edaphic variables *i*.e. soil compaction, soil pH, water holding capacity, salinity and conductivity all showed non-significant differences in group means (F= 0.4, F= 0.01, F= 0.4, F= 2.1 and F= 1.4 respectively, all n.s.). Similarly among the organic matters and all the five nutrient levels i.e., Ca, Mg, Na, K and total N all showed non-significant differences in group means (F= 0.1, F= 0.7, F= 0.6, F= 0.5, F= 0.2 & F= 1.0 respectively, all n.s.).

Multivariate comparison of environmental variables of groups derived from Ward's cluster analysis, using tree data set: (Hotelling's T^2 test)

To compare the groups derived from Ward's method of cluster analysis on the basis of mean vectors of environmental variables, Hotelling's T^2 was used. Three sets of variables described in material and method were compared between pairs of groups with respect to the first set of variable (topographic) when the comparison was performed between groups I and II they showed a significant difference ($F= 3.4$, $df_1 = 3$, $df_2 = 25$, $P < 0.05$). The mean vectors for groups 1 and 3 were found to be non-significant ($F= 1.43$, $df_1 = 3$, $df_2 = 20$, n.s.), while groups 2 and 3 showed a significant difference in the mean vectors ($F= 5.8$, $df_1 = 3$, $df_2 = 25$, $P < 0.01$). Using the mean vectors for the groups pertaining to edaphic variable, the comparison of groups 1 and 2 revealed no significant difference ($F= 0.9$, $df_1 = 5$, $df_2 = 23$, n.s.). Groups 1 and 3 were also non-significant in this respect ($F= 0.462$, $df_1 = 5$, $df_2 = 18$, n.s.). Similarly, group II and III yielded no significant difference ($F= 0.487$, $df_1 = 5$, $df_2 = 23$, n.s.). Comparison of mean vectors relevant to nutrients for groups 1 and 2, groups 1 and 3 and group II and III disclosed that the groups did not differ significantly with regard to nutrient concentrations in the soils.

(iib) Agglomerative cluster analysis of species (Ward's method)

The results of Cluster analysis of tree species (Fig. 4) shows good agreement with the results of cluster analysis of stands. *Pinus wallichiana* which is broadly distributed in moist temperate area forms an isolated individual in the dendrogram. *Cedrus deodara*, a dry temperate species (found between elevations of 1600 to 2700 m) also shows somewhat isolated position in the dendrogram but it is connected with a small cluster of species because it has wide ecological amplitude, distributed in moist temperate, dry temperate and sub-alpine regions. *Abies pindrow* forms a group with other moist temperate species i.e. *Taxus wallichiana*, *Quercus ilex, Quercus incana and Juglans regia*. *Picea smithiana* is a dry temperate species associated with *Abies pindrow* group in the dendrogram.

B-Understorey Vegetation Data

(i) Divisive, polythetic cluster analysis of stand (e.g. TWINSPAN)

The dendrogram based on TWINSPAN (divisive cluster analysis) is shown in Fig. 5 which also shows the negative and positive preferentials species at each clustering cycle. The stand numbers of the set of stands included in the cluster are also shown. The two way ordered table shows five clusters (groups) out of which cluster I has only one individual (stand), cluster II have two individuals (stands), cluster III have nine individuals (stands), cluster IV have twenty four individuals (stands) and cluster V have five individuals (stands).

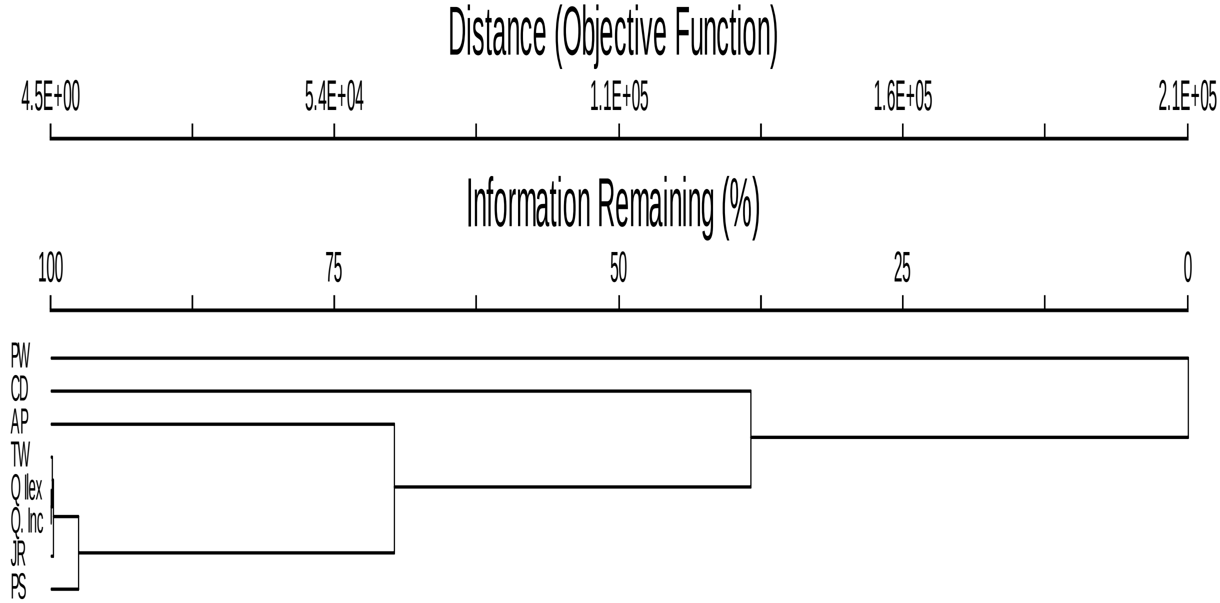


Fig. 4. Dendrogram derived from cluster analysis of tree species by Ward's method using tree vegetation data of 41 stands. AP, *Abies pindrow*; CD, *Cedrus deodara*; JR, *Juglans regia*; PW, *Pinus wallichiana*; PS, *Picea smithiana*; Q. Ilex, *Quercus ilex*; Q. Inc, *Quercus incana* ; TW, *Taxus wallichiana*.

Group I of TWINSPAN comprised of one stand, pre-dominated by *Cymbopogon jawarancusa* (average relative frequency = 50%). Group II was dominated by *Aristida adscensionis* (average relative frequency = 48%) with three other co-dominant species i.e. *Echinophs niveus, Cedrus deodara* and *Abies pindrow* (average relative frequency = 14.5, 12.5 and 12.5 respectively).

None of the species attained dominance in Group III but some species occurred in this group with moderate abundance i.e. *Pinus wallichiana* seedlings, *Cedrus deodara* seedlings, *Cymbopogon jawarancusa, Thymus linearis, Rubus ellipticus, Rosa brunoni* and *Cotoneaster microphylla* (average relative frequency = 9.2, 8, 6.33, 6.11, 4.67, 4.11 and 3.63 % respectively). Some species had low abundance, including *Duchesnea indica, Podophylum emodi, Adiantum venustam* and *Pteris cretica* (average relative frequency = 2.33, 1.67, 1.22 and 1.02). Remaining species of this group have less than 1 relative frequency, listed according to their abundance *Echinophs niveus, Rosa wabbiana, Aristida adscensionis, Berberis lyceum, Acer caesium, Hedera nepalensis* and *Rubus biflorus*. Group IV was dominated by *Pinus wallichiana* (average relative frequency = 11.54), *Acer caesium* (average relative frequency = 11.38), *Abies pindrow* (average relative frequency = 10.21) with *Pteris cretica* as co-dominant (average relative frequency = 8.34). Some species are associated in this group with low relative frequency i.e. *Rosa wabbiana, Rosa brunoni, Cedrus deodara* (seedlings), *Rubus ellipticus, Rubus biflorus, Thymus linearis, Adiantum venustam* and *Andropogon lancifolius* with average relative frequency 3.71, 3.52, 3.42, 2.71, 2.34, 2.25, 2.25 and 2 % respectively.

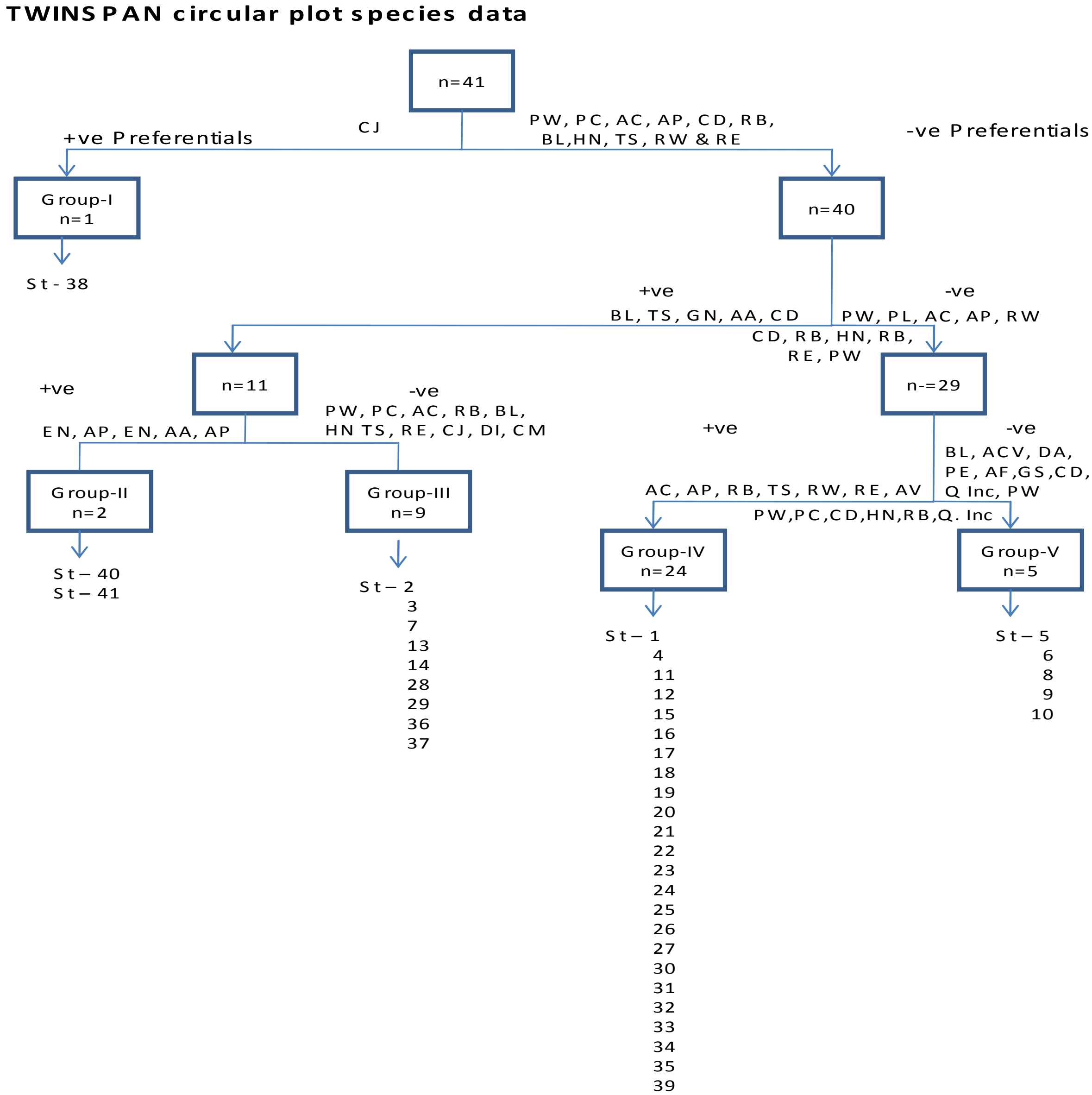


Fig. 5. Results of TWINSPAN classification of understorey vegetation (41 stands) of moist temperate areas of Pakistan. Stand numbers belonging to groups and the +ve and –ve preferential species are shown.

These species have very poor abundance in this group *Hedera nepalensis, Echinophs niveus, Picea smithiana* seedlings, *Sinapis arvensis*, *Indigofera hebepatela*, *Aristida adscensionis*, *Cymbopogon jawarancusa*, *Duchesnea indica* and *Dicanthium annulatum* with average relative frequency of 1.75, 1.67, 1.29, 1.29, 1.22, 1.21, 1.21, 1.21 and 1.0 respectively. The following species have less than 1 average relative frequency i-e *Plantago asciatica, Ranunculus muricatus, Berberis lyceum, Cotoneaster microphylla, Quercus incana, Taxus wallichiana* seedlings, *Podophylum emodi* and *Gloriosa superba.* Group V was predominated by *Pinus wallichiana* (seedlings) (average relative frequency = 18.6) and *Adiantum capillus veneris* (average relative frequency = 11%). *Pteris cretica* was also co-dominant with this group (10% average relative frequency).*Cedrus deodara, Podophylum emodi, Dicanthium annulatum, Asplenium filix foemina, Gloriosoa superba* and *Rubus biflorus* are also associated with this group with 8.4, 6.4, 4.8, 3.8, 2.6 and 2.0

average relative frequencies respectively. *Berberis lycium*, *Hedera nepalensis* and *Abies pindrow* seedlings exhibit have poor abundance i.e. 1.2, 1.2 and 1.0 average relative frequency respectively.

(iia) Agglomerative cluster analysis of Stands :(understorey vegetation data)

The dendrogram resulting from understorey vegetation data using Ward's method is shown in Fig. 6. The dendrogram discloses three main groups at a squared Euclidean distance of $7x10^4$. Group I comprising of 20 stands, is characterized by the predominance of *Pinus wallichiana* seedlings (relative frequency = 10.8) with *Cedrus deodara* (relative frequency = 9).Other widely distributed species found in this group are *Rosa brunoni, Thymus linearis, Adiantum capillus veneris, Abies pindrow* seedlings, *Rubus ellipticus, Podophylum emodi, Cotoneaster microphylla* and *Rubus biflorus, Duchesnea indica* and *Rosa webbiana* their importance value are = 4.7, 2.8, 2.75, 2.7, 2.1, 2.4, 2.5,1.9, 2.3 and 1.9 respectively). *Picea smithiana* is also prominent species in this group. Group II that includes 18 stands. It is dominated by *Acer caesium*, *Abies pindrow* seedlings, and *Pinus wallichiana* seedlings (relative frequency = 15.2, 12.3 and 11.4 respectively). Other associated species are *Pteris cretica, Thymus linearis, Rosa webbiana,* Rubus *ellipticus, Adiantum venustam, Echinopes niveus, Rubus biflorus* and *Cedrus deodara seedlings* (relative frequency = 6.44, 3, 3.3, 3.6, 2.2, 2.2, 2.4 and 2.3 respectively). Group III which comprises of 2 stands is predominated by *Cymbopogon jawarancusa* and *Rubus biflorus*, (relative frequency = 43 and 4.5) while *Acer caesium, Hedera nepalensis* and *Aristida adscensionis* are also conspicuous (relative frequency = 2.5, 2.5 and 2.5 respectively).

Environmental characteristics of groups: With respect to environmental variables the three groups derived from Ward's cluster analysis using understorey species data showed some variability. Topographically, group I is characterized by medium elevation, low slope angle and medium aspect rating while group II exhibits high elevation, medium slope and low aspect value. Group III is characterized by low elevation, steep slopes and high aspect rating. With respect to edaphic variables, group I showed medium soil compaction, water holding capacity and salinity but low conductivity and pH. Group II represent soils with high compaction, salinity and conductivity but medium pH and water holding capacity. On the other hand, group III is characterized by relatively high water holding capacity and pH (still acidic), and low soil compaction, salinity and conductivity. Group I shows medium organic matter, Ca, Mg, Na but high in nitrogen. Group II exhibits relatively lower organic matter and Na, high in Ca and K while having medium Mg and soil nitrogen. In comparison group III is high in organic matter and Mg but low in Ca and total nitrogen.

Univariate analysis of variance (ANOVA)

Three main groups were recognized using Ward's clustering strategy. The individual environmental variables corresponding to the three groups were analyzed using univariate analysis of variance (ANOVA). Among the topographic variables, elevation was found to be highly significant ($F= 21.017$; $P< 0.001$) while aspect was also significant ($F= 3.95$; $P< 0.05$). Canopy cover gave a significant F- ratio ($F= 7.12$; $P< 0.01$). However, slope and soil compaction were found non-significant ($F= 1.89$, $F= 0.4$, both n.s.). Among the edaphic variables only soil pH showed a significant F value ($F= 6.046$; $P< 0.01$). Other edaphic variables including water holding capacity, salinity, conductivity and total dissolved salts were found non-significant (F= 0.100, F= 1.458, F= 2.824 & F= 1.20 respectively, all n.s.). among the six nutrient levels organic matters, Ca, Mg, Na, K and N all showed non-significant differences in group means significant (F= 0.056, F= 1.74, F= 0.89, F= 1.18, F= 2.47 & F= 0.008 respectively, all n.s.).

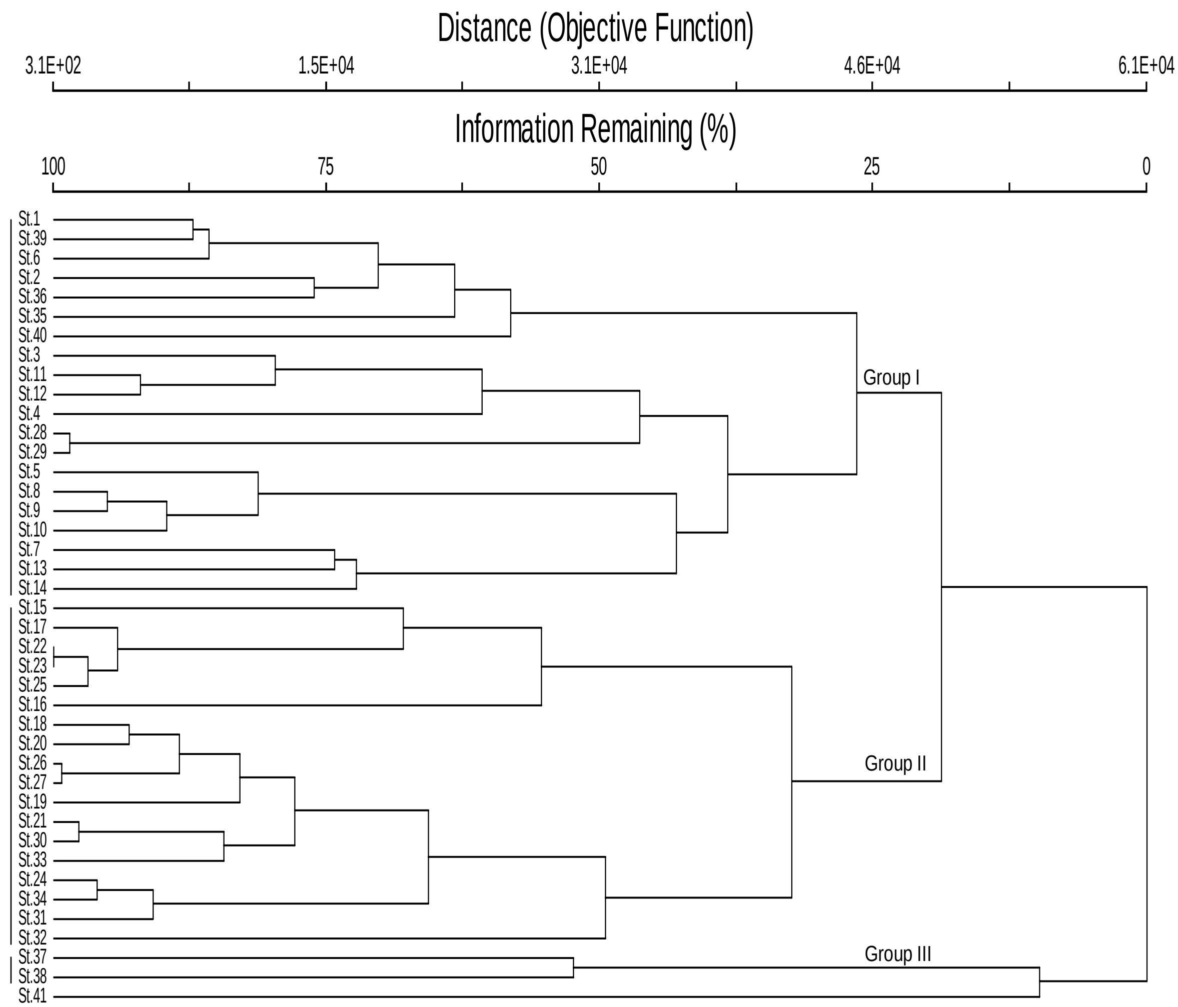


Fig. 6. Dendrogram derived from Ward's cluster analysis based on understorey vegetation of 41 stands of moist temperate areas of Pakistan. Stands numbers are given at the base of the dendrogram.

Multivariate comparison of environmental variables of groups derived from Cluster analysis, using understory vegetation data set: (Hotelling's T^2 test)

To compare the groups derived from Ward's method of cluster analysis on the basis of mean vectors of environmental variables, Hotelling's T^2 was used. The mean vectors of three sets of variable were compared between pairs of groups with respect to the first set of variable (topographic) when the comparison was performed between groups 1 and 2 showed a significant difference (F= 10.4, df_1 = 3, df_2 = 34, P< 0.001) (see Table 2.10). The mean vectors for groups 1 and 3 were found to be non-significant (F= 2.41, df_1 = 3, df_2 = 18, n.s.), while groups 2 and 3 showed a significant difference in the mean vectors (F= 19.4, df_1 = 3, df_2 = 16, P< 0.001). Using the mean vectors for the groups pertaining to edaphic variable, the comparison of groups 1 and 2 a significant difference was obtained ($F= 3.55$, $df_1 = 5$, $df_2 = 32$, $P< 0.05$). Group 1 and 3 were non-significant in this respect ($F= 0.995$, $df_1 = 5$, $df_2 = 16$, n.s.). Similarly, group 2 and 3 yielded no significant difference ($F= 0.3003$, $df_1 = 5$, $df_2 = 14$, n.s.). Comparison of mean vectors relevant to nutrients for group 1 and 2, groups 1 and 3 and group 2 and 3 disclosed that the groups did not differ significantly with regard to nutrient concentrations in the soils.

(iib) Agglomerative cluster analysis of circular plot species data :(understorey vegetation data)

The dendrogram (Fig. 7) derived from agglomerative Cluster analysis of understorey vegetation shows two distinct groups. Group I consists of four species i.e., *Pinus wallichiana* seedlings, *Abies pindrow* seedlings, *Pteris cretica* and *Acer caesium* (seedlings) whereas group II consists of three sub groups that comprise of a total of twenty five species. *Cymbopogon jawarancusa* and *Aristida adscensionis* did not merge with any group and occurred as isolated individuals (species). Group I is correlated with high moisture and high altitude between 6000 to 8000 feet. Group IIa can be correlated with relatively lower soil moisture regime. Altitude of group IIa is 7000 to 8000 feet. Group IIb seems to be associated with specific microclimatic conditions with high soil moisture regime. Group IIc is characterized by varied degree of disturbance primarily due to anthropogenic factors. *Cymbopogon jawarancusa* and *Aristida adscensionis* indicate the presence of human settlements in the nearby areas and these plants are perhaps escapes from the adjacent agricultural lands.

2- Ordination

DCA Ordination of Tree species DCA

Correlation between tree vegetation and environmental variables (elevation, slope, aspect and soil compaction) of different stands is evaluated by DCA ordination.

(i) Stand ordination

The DCA stand ordinations on axes 1 and 2, axes 1 and 3 and axes 2 and 3 are shown in Fig. 8 (Species): An examination of the distribution pattern of stands in two dimensions shows a V shape distribution of stands though the configuration on axes 1 and 2 depicts a dense area of the location of stands whereas on axis 1 and 3 stands show inverted V shape distribution.

When the three main groups (I, II and III) derived from the cluster analysis by Ward's method were superimposed on DCA ordination (axes 1 and 2) and (axes 1 and 3) and no overlapping of groups was seen in all three groups. The three groups separated out clearly in DCA ordination of axes 1 and 2, and axes 1 and 3. However, the three groups separated out clearly (with only one exception) in the DCA ordination on axes 2 and 3 i.e. only one stand (31) was located in group I instead of group II. Interestingly, the ordinations of axes 1 and 3 and axes 2 and 3 exhibit an almost continuous distribution of stands across the ordination planes.

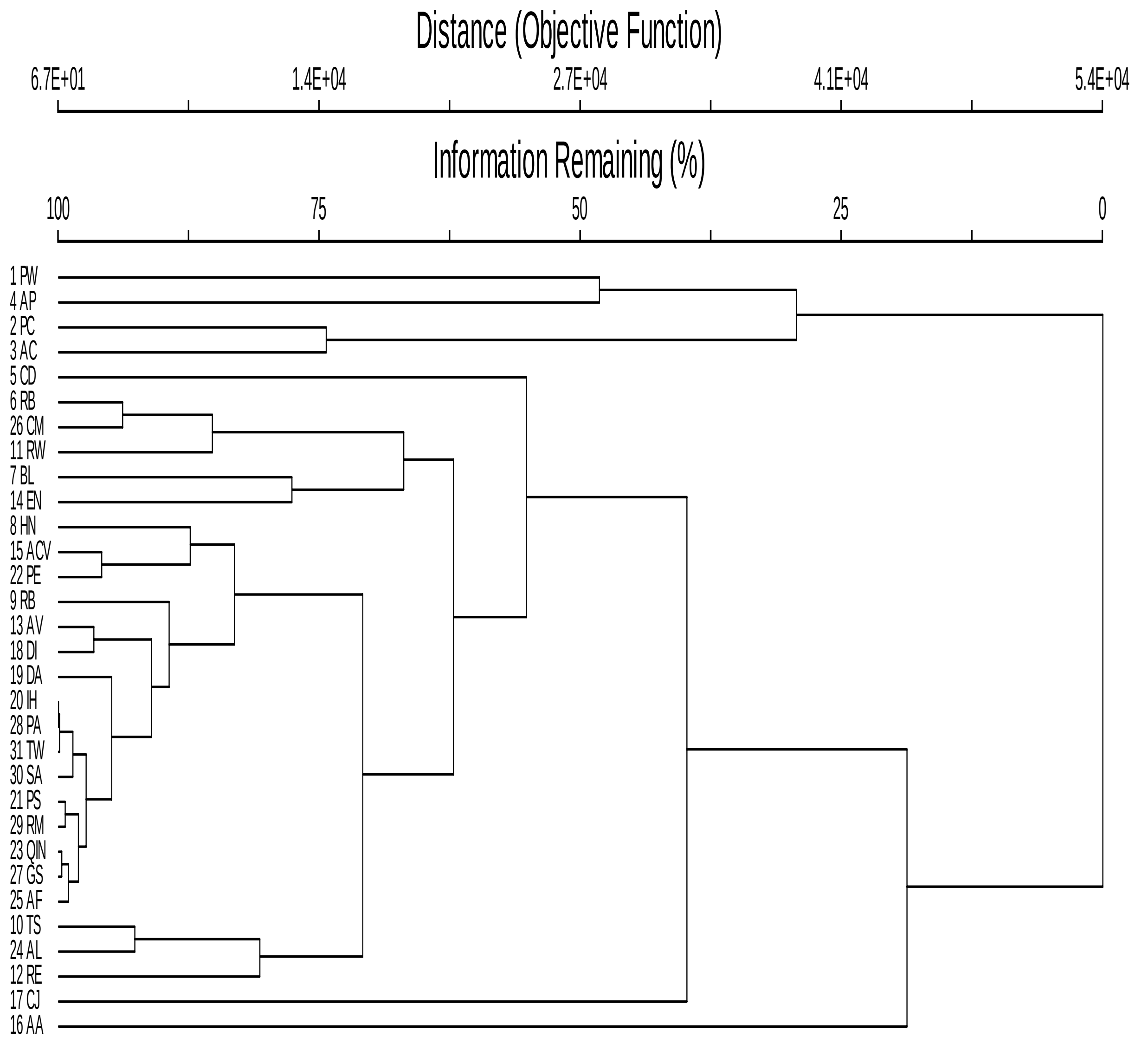


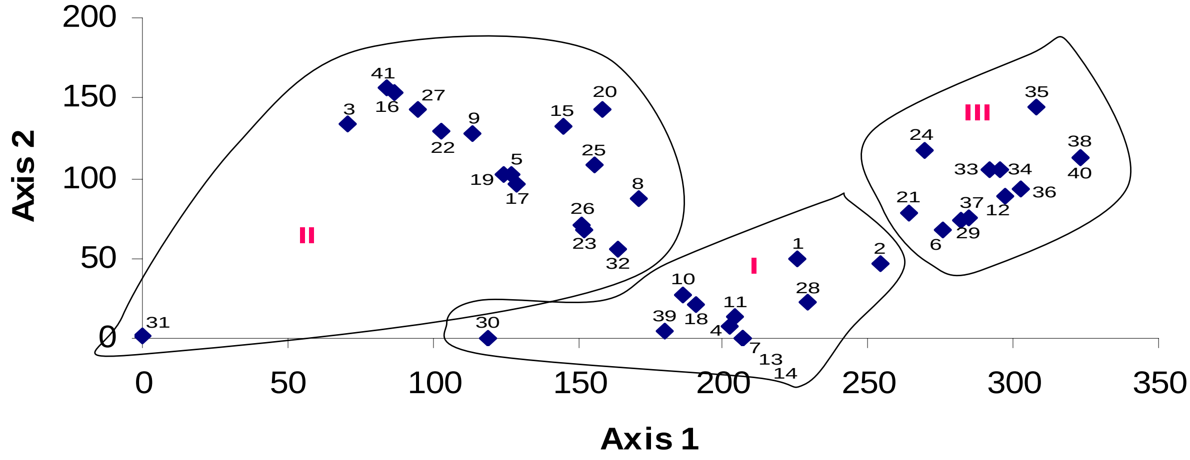
Fig. 7. Dendrogram derived from Ward's cluster analysis using understorey species data of 41 stands of moist temperate forests of Pakistan. For species symbols refer to Figure 11.

Three main groups are separated on the basis of highest importance value. All 12 stands in group I are dominated by *Pinus wallichiana*. Group II is designated as *Abies pindrow* dominating group with few exceptions. Group II is the largest group, consisting of seventeen stands in which thirteen stands are dominated by *Abies pindrow*. Group III is dominated by *Cedrus deodara*, all twelve stands are dominated by *Cedrus deodara.*

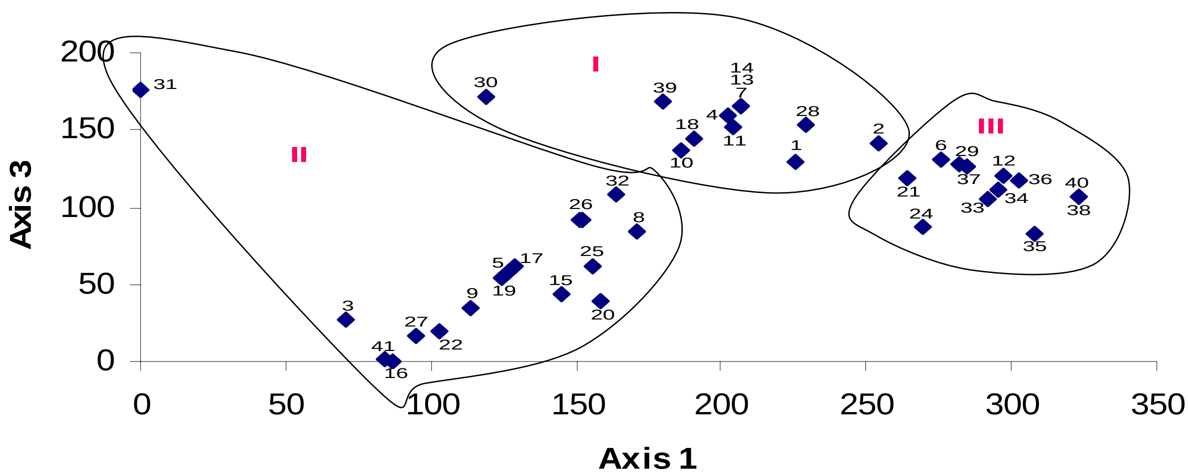
Stand 7 Chikkar and Stand 13 Patriata 2 of group I are the monospecific stands of *Pinus wallichiana*. Stand 1 Kumrat, Stand 2 Panahkot and Stand 28 Thandyani are occupied by *Cedrus deodara* as co-dominant species. *Abies pindrow* occupied second position in Stand 4 Malam Jabba 2, Stand 10 Suddhan Gali 3 and Stand 18 Ghora Dhaka 3. *Albizia chinensis* in Stand 14 Patriata 3 and *Pyrus pashia* (angiospermic species) in Stand 11 Ghora Gali occurred with second position. *Picea smithiana* is second dominant species in Stand 30 Sripaye and Stand 39 Naran river belt.

Thirteen stands of Group II are dominated by *Abies pindrow* whereas in four Stands it is second dominant species. *Pinus wallichiana* was found as a dominant species in three stands (stand 23 Changla gali, stand 26 Nathia gali and stand 32 Shogran), where as in stand 31 Sripaye *Picea smithiana* is the first dominant species. *Taxus wallichiana*

Stand distribution on axis 1 & 2.



(b) Stand distribution on axis 1 & 3.



(c) Stand distribution on axis 2 & 3.

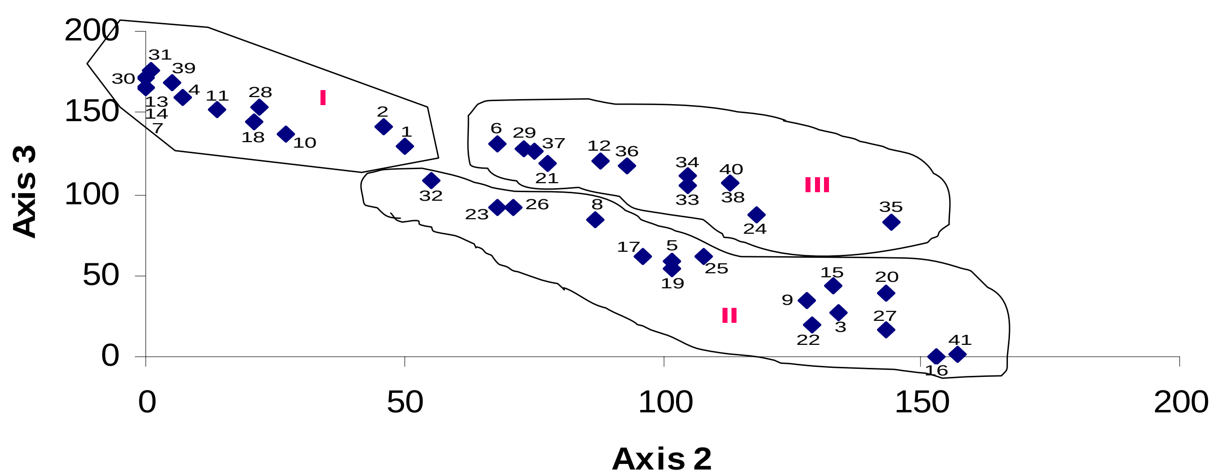


Fig. 8. Two-dimensional DCA ordination of stands, using tree species data of 41 stands of moist temperate areas of Pakistan. (a) Ordination of axis 1 & 2, (b) Ordination of axis 1 & 3, while (c) Ordination of axis 2 & 3.

specifically associated with the *Abies pindrow* on second or third position in Group II (Stand No. 16, 17, 19, 22 and 23. *Taxus wallichiana* was found in only stand 11 of Group I whereas it is absent in Group III with *Cedrus deodara*. In Group III seven stands (stand 6, 12, 29, 33, 36 and 37) were occupied by *Pinus wallichiana* as a second dominant species whereas in stand 24 *Abies Pindrow,* in stand 34 *Picea smithiana* and in stand 35 *Juglans regia* occupied second position. Stand 38 and 40 are the monospecific deodar forest. *Picea smithiana* is distributed in all three Groups regardless of first and second dominant species. *Picea smithiana* found as a dominant species in only in stand 31 which is far from the other species of the group. *Juglans regia* was mainly found in Group II with *Abies pindrow* in stands No. 22, 15 and 20 but it also found in stand 33 of Group III and totally absent in Group I. Mean elevation of Group I is 2368 meter that is suitable for the growth of Pinus *wallichiana*, mean elevation of Group II is 2618 meter suitable for *Abies pindrow* and Group III *Cedrus deodara* grows on the elevation of 2208 meter. Mean elevation of three groups show that the *Abies pindrow* prefers to grow on high altitude. *Pinus wallichiana* dominated stands found on the elevation of 1930 m to 3100 m, *Abies pindrow* dominated stands found on the elevation of 2400 m to 3000 m while *Cedrus deodara* dominating stands found on 1600 m to 2730 m elevation. Mean slope angle of Group I is 29º, Group II is 36º and Group III is 30º which indicates the slope requirement of trees. *Pinus wallichiana* groups were prefers to grow on south or south-west facing exposure. Not a single stand of *Pinus wallichiana* was found on east facing exposure and very rare stands found on north or north-west facing aspect. Out of seventeen stands of *Abies pindrow* only one stand found on east facing exposure and other stands distributed on all exposures, indicates that it does not prefer to grow on east facing exposure. Group III dominated by *Cedrus deodara* grow on all exposures almost equally, it shows exposure do not take part on the growth of *Cedrus deodara*. Out of twelve stands of *Pinus wallichiana* eight stands found in moderate canopy, one in open and three in closed canopy. Eleven stands of *Abies pindrow* show closed canopy, four moderate and two open canopies. *Cedrus deodara* groups show maximum closed canopies (seven stands), four stands show moderate and one show open.

(ii) Tree species ordination

The two dimensional DCA species ordination on first two axes (axis 1 and axis 2) Fig. 9 shows essentially a continuous distribution. Cluster analysis of species also did not yield any clear-cut grouping because of chaining effect except for one group of four species. However, the only group of cluster analysis could not be superimposed on the ordination. The DCA ordination on axis 1 and 2 shows the three important species *Picea smithiana*, *Taxus wallichiana*, and *Abies pindrow* to the left of the ordination. *Pinus wallichiana* and *Juglans regia* occupy the middle position of the ordination plane while *Quercus ilex*, *Q. incana* and *Cedrus deodara* are located to the right of the ordination configuration. The DCA ordination on axes 1 and 3 essentially repeats the pattern depicted by ordination of axis 1 and 3 showing continuity in the distribution of species in the ordination plane. However, the plot on axis 2 and 3 showed a distribution pattern of species rather different from that of DCA ordinations on axes 1 and 2 and that of 1 and 3.The plot of axes 2 an 3 shows *Pinus wallichian*a to the extreme left followed by *Taxus wallichiana, Cedrus deodara* and *Picea smithiana*, *Abies pindrow* and *Quercus incana* in the middle-left. Two species *Quercus ilex* and *Juglans regia* are situated in the right side of the ordination plane. If we consider the isolated clusters of single species in the dendrogram as groups, then these groups can roughly be traced in the two-dimensional (axes 2 and 3) DCA ordination of species.

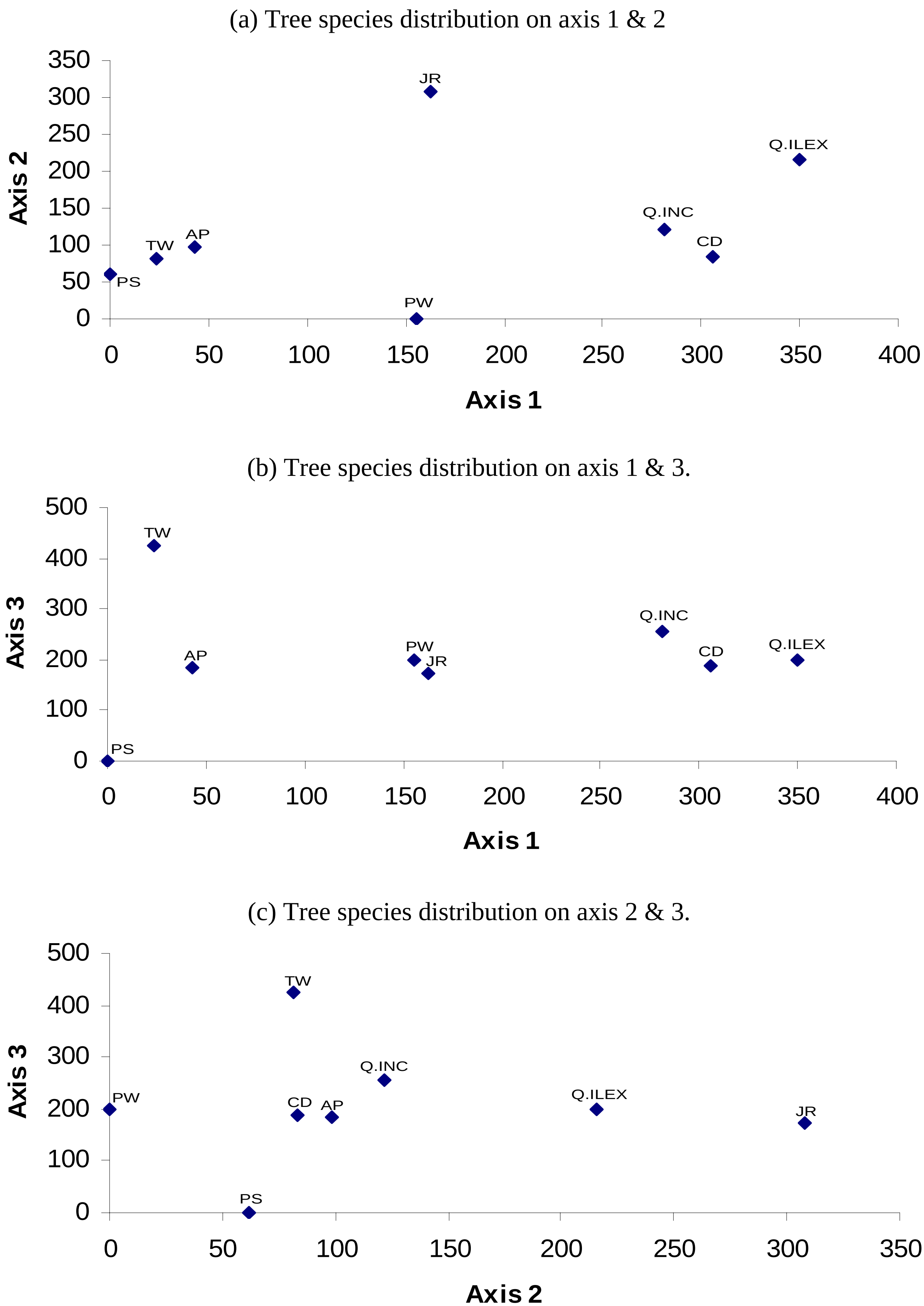


Fig. 9. Two-dimensional DCA ordination of species of 41 stands of moist temperate areas of Pakistan. (a) Ordination of axis 1 & 2, (b) Ordination of axis 1 & 3, while (c) Ordination of axis 2 & 3.

Relationship (correlation coefficient) of 3 ordination axes with environmental variables

Ordination axis 1 was found positively correlated with elevation (P<0.001), slope (P<0.05), electrical conductivity (P<0.05) and weakly correlated with salinity (P<0.1). Ordination axis 2 was found weakly correlated only with water holding capacity (P<0.1). Axis 3 was moderately correlated with elevation (P<0.05) and showed a weak correlation with Na^+ (P<0.1). The other environmental variables did not show significant correlation with DCA ordination axes. It could be due to long history of anthropogenic disturbance.

DCA Ordination of Understorey Species

(i) Stands ordination

The DCA stand ordinations on axes 1 and 2, axes 1 and 3 and axes 2 and 3 are shown in Fig.10. An examination of the distribution pattern of stands in two dimensions shows a continuous distribution of stands though the configuration on axes 1 and 2 depicts a dense area of the location of stands. When the three main groups derived from the cluster analysis by Ward's method were superimposed on DCA ordination (axes 1 and 2) some overlapping of groups I and II was seen. However, the three obvious groups separated out (with only two exceptions) in the DCA ordination on axes 1 and 3. The three similar groups also separated out in DCA ordination of axes 2 and 3. Interestingly, the ordinations of axes 1 and 3 and axes 2 and 3 exhibit an almost continuous distribution of stands across the ordination planes.

Ordination on axes 1 and 2 show that stands located to the extreme left side are dominated by *Adiantum spp.*, *Polygala spp. Punica granatum*, *Duchesnea indica* and *seedlings of Abies pindrow* and *Pinus wallichiana.* The stands located to the extreme right are dominated by *Cymbopogon jawarancusa*, *Echinophs niveus* and *Aristida adscensionis.* The central part of the 2-D ordination where the overlapping of the groups 1 and 2 of cluster analysis occurs are dominated by a wide variety of species including *Rubus* spp., *Thymus linearis* , *Andropogon lancifolius*, *Pinus wallichiana* (seedlings), *Podophylum emodi* , *Acer caesium* (seedlings), *Pteris cretica, Dicanthium annulatum* **,** *Berberis lyceum* and *Sinapis arvensis*. The stands situated centrally in lower middle part of axes 2 are principally composed of *Rosa brunoni*, *Campanula tenuissima*, *Indigofera gerardiana* and *Berberis lyceum.* The trend of change in dominance across the ordination plane (axes 1 and 2) is more or less repeated in the ordination based on axes 1 and 3. Perusal of species dominance in the stand ordination on axes 2 and 3, where the groups (of cluster analysis) are separated horizontally, shows that the stands in upper portion of ordination (corresponding to group I) are dominated by *Cedrus deodara* (seedlings), *Rubus spp.*, *Ribes alpestre*, *Echinophs niveus*, *Argemone mexicana, Rosa spp.*, *Quercus spp.* (seedlings), *Thymus linearis*, *Dicanthium annulatum* and *Pteris cretica.* In the group III located below group I, the dominant species are *Dicanthium annulatum* and *Pteridium equalinum*.

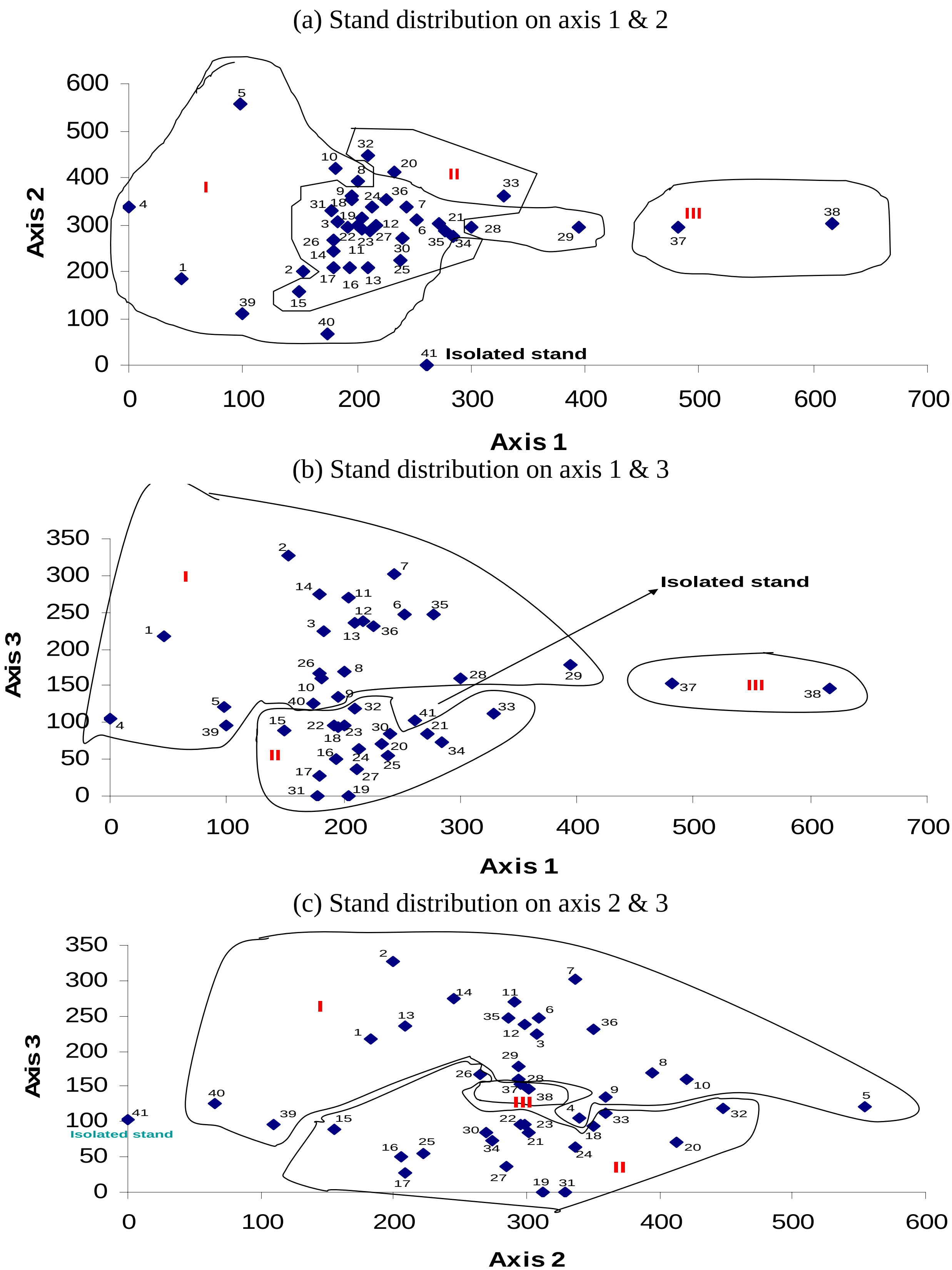


Fig. 10. Two-dimensional DCA stand ordination of understorey vegetation of 41 stands of moist temperate areas of Pakistan. (a) Ordination of axis 1 & 2, (b) Ordination of axis 1 & 3, while (c) Ordination of axis 2 & 3.

On the other hand, group II located horizontally in the lower part of ordination (axes 2 and 3) is dominated by species like *Pinus wallichiana* (seedlings), *Abies pindrow* (seedlings), *Acer caesium* (seedlings), *Taxus wallichiana* (seedlings), *Sinapis arvensis* , *Hedera nepalensis*, *Indigofera hebepatela*, *Andropogon lancifolius*, *Ranunculus muricatus* , *Aristida cyanantha* , *Adiantum venustam*, *Picea smithiana* (seedlings), *Rosa wabbiana* , *Sonchus asper* , *Quercus spp.* (seedlings) and *Chrysopogon echinulatus*.

ii) Understorey species ordination

The two-dimensional species ordinations of axes 1 and 2, axes 1 and 3 and axes 2 and 3, all show more or less continuous distribution pattern, though few groups can be recognized. (Fig. 11). When the groups obtained from cluster analysis by Ward's method were superimposed on the DCA ordination (Axes 1 and 2) neat separation of groups could not be achieved but the groups boundaries overlapped in the ordination plane. However some similarities can be seen in the results of cluster analysis and ordination. As an example *Cymbopogon jawaranucosa* occur as an isolated species in the dendrogram as well as in the ordination. *Rubus ellipticus*, *Thymus linearis* and *Andropogon lancifolius* (groups) occur in the middle left of the ordination. The large group in the dendrogram , that include *Rubus biflorus*, *Adiantum venustam*, *Duchesnea indica*, *Dicanthium annulatum***,** *Indigofera hebepatela*, *Plantago asciatica* , *Taxus wallichiana*, *Sinapis arvensis* , *Picea smithiana*, *Ranunculus muricatus*, *Quercus incana*, *Gloriosa superba* and *Asplenium filix* (Group 4) are distributed as a loose group in the central part of the ordination. Another group *Rosa brunoni*, *Cotoneaster microphylla*, *Rosa wabbiana*, *Berberis lyceum* and *Echinophs niveus* (group 2) occurs as a group covering the extreme upper left to upper middle part of the ordination plane. A group of three species *Hedera nepalensis*, *Adiantum capillus veneris* and *Podophylum emodi* (group 3) occurs in the lower left to upper middle position of the ordination plane.

In the DCA species ordination (axis 1 and axis 3) again *Cymbopogon jawarancusa* remain isolated with the rest of the species. Group 1 occurs as a loose group in the central part of the dense area of species distribution on axes 1 and 2. Group 2 occurs as a diffused group in the lower left of the ordination plane. Group 3 form a compact cluster in the central portion of the dense part of the 2-dimensional configuration. Group 4 constituted by 12 species forms a diffused cluster mainly in the central part of the vertical axis. The species belonging to group 5 are located in the middle to lower right of the clustered area of ordination plane.

The distribution pattern of species in the species ordination pertaining to axes 2 and 3 gives a different picture compared to those of axes 1 and 2 and that of axes 2 and 3. Here group 1 is located centrally on axis 2 and lower middle part of axis 3. On the other hand, member species of group 2 are located on the right side of the ordination plane. Group 3 form an elongated group on the left side at the central portion of axis 3. Group 4 forms a diffused group covering a major portion of the ordination plane. The species belonging to group 5 occupy more or less the lower part of central portion of the ordination configuration.

Species symbols refer to: PW= *Pinus wallichiana* A.B.Jackson, PC= *Pteris cretica.* L mant, AC= *Acer caesium* Wall ex brandls, AP = Abies *pindrow* Royle, CD = *Cedrus deodara (*Roxb.) G. Donf., RB = *Rosa brunoni* Lindl, BL = *Berberis lyceum.* Royle I.C.,

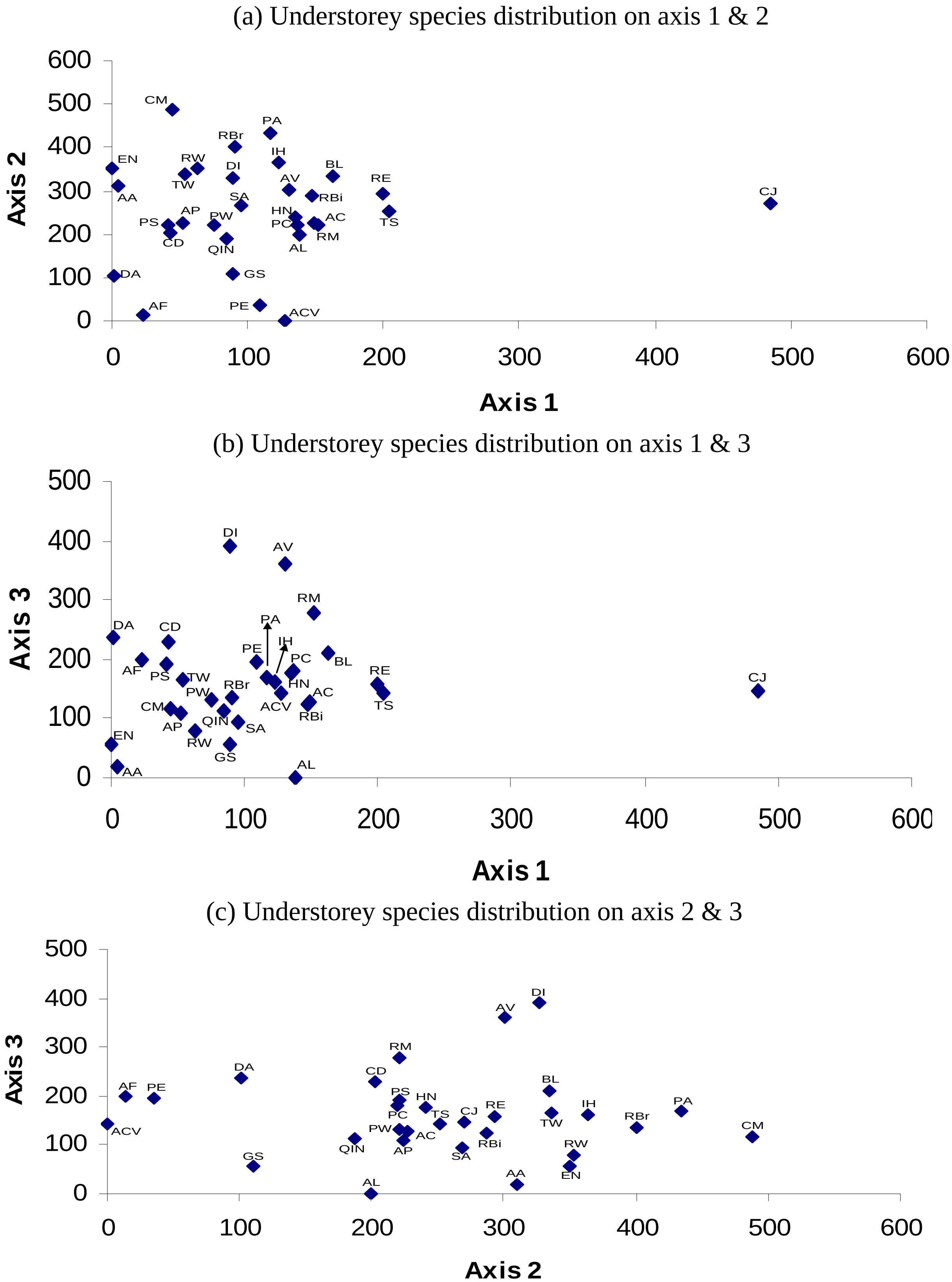


Fig. 11. Two-dimensional DCA ordination of 31 understorey species of 41 stands of moist temperate areas of Pakistan. (a) Ordination of axis 1 & 2, (b) Ordination of axis 1 & 3, while (c) Ordination of axis 2 & 3.

HN = *Hedera nepalensis* K. Koch, RB = *Rubus biflorus* Ham ex Sm., TS = *Thymus serpyllum.* L, RW = *Rosa wabbiana* Wall ex Royle, RE = *Rubus ellipticus* Smith, AV =

Adiantum venustam D.Don, EN = *Echinophs niveus* Wall ex D.C., ACV = *Adiantum capillus veneris* L, AA = *Aristida adscensionis* L, CJ = *Cymbopogon jawarancusa* (Jones) Schult, DI = *Duchesnea indica* (Andr), DA = *Dicanthium annulatum* (Forssk), IH = *Indigofera hebepatela* Ali, PS = *Picea smithiana* (Wall.) Boiss, PE = *Podophylum emodi* Wall, QIN = *Quercus incana* Roxb, AL = *Andropogon lancifolius* . (Toin) Hochst, AF = *Asplenium filix foemina.* (L), CM = *Cotoneaster microphylla* Wall ex Lindl, GS = *Gloriosa superba* L, PA = *Plantago asciatica* L, RM = *Ranunculus muricatus* L, SA = *Sinapis arvensis* L, TW = *Taxus wallichiana* Zucc.

Relationship (correlation coefficient) of 3 ordination axes with environmental variables.

Three axes were generated by DCA ordination. Ordination axis 1 was found positively correlated with elevation ($P<0.01$) and pH ($P<0.05$). Ordination axis 2 did not showed a significant correlation with any environmental variables. Axis 3 was highly correlated with elevation ($P<0.001$) and showed a moderate correlation with conductivity ($P<0.05$) and K ($P<0.05$). The other environmental variables did not show significant correlation with DCA ordination axes. It could be due to long history of anthropogenic disturbance.

Discussion

Multivariate analysis showed group structure and trends in the vegetation of the study area. The resulting clusters obtained by TWINSPAN based on tree vegetation data were matched with the clusters (groups) derived from Ward's method of agglomerative clustering, some similarities were evident. Group II+III of TWINSPAN that contained 19 individuals were similar to group I of Ward's method with nine stands common out of a total of 12. Likewise, group VI+VII of TWINSPAN is similar to group II of Ward's method with 13 out of 17 members (stands) being common.

The resulting clusters of TWINSPAN based on understorey species data were matched with the clusters derived from Ward's method of agglomerative clustering based on understorey vegetation, some similarities emerged. Group IV of TWINSPAN that contained 24 individuals (stands) was similar to group II of Ward's method with 18 individuals (stands) common out of a total of 18. Likewise, group III of TWINSPAN is similar to group II of Ward's method with 8 out of 9 members (stands) being common. Another similarity found between groups V of TWINSPAN comprises of five stands similar with the group I of Ward's clustering method out of twenty stands.

Clear similarity was observed between Ward's cluster analysis of tree vegetation data and understorey vegetation data. Group I of tree vegetation data comprises of twelve individuals (stands) was similar with group I of understorey cluster analysis with eleven individuals. Similarly, group II of tree vegetation data consisting of 17 individuals was also similar with group II of understorey cluster with 12 individuals. Group III of understorey data that consists of only 2 individuals (stands) which were present in group III of tree vegetation data.

With respect to environmental variables the three groups derived from Ward's cluster analysis in both tree and understorey species data showed some similar results like water holding capacity and salinity of all three groups showed similar values while elevation, slope, aspect, soil compaction, conductivity, organic matter of soil, Mg and Na were quite similar in group I & II of both the data sets. Potassium of group III showed similarity. Nitrogen and pH for the groups did not show any similarity among each other.

The vegetational and ecological groups extracted from clustering strategies separated out quite distinctly in the DCA ordination planes, particularly on axes 1 and 2. There seems to be a good correspondence between the results of clusters analysis and those of ordination. Greig-Smith (1983) has advocated the use of both approaches concomitantly on the grounds that they yield complementary results and as such useful for better interpretation of ecological results. For the complex vegetation under study it is expected that a number of ecological gradients may be involved in determining the distribution pattern of vegetation. Correlation of individual environmental variables with the DCA ordination axes disclosed that elevation is highly significantly associated with DCA axis 1 (in tree vegetation data) while on axis 3 (in understorey vegetation data) suggesting the prevalence of an elevation gradient. On the other hand, elevation to a great extent controls the climatic conditions. In addition, slope was significantly correlated with axis 1 (in tree vegetation data) of the ordination, suggesting the existence of a moisture gradient since the degree of slope is an important factor determining the moisture regime of a stand. Conductivity also showed correlation with axis 1 in tree vegetation data and with axis 3 of understorey vegetation data. Water holding capacity is good parameter to evaluate the growth of plants, exhibits correlation with DCA axis 2 in tree vegetation data, similarly salinity and sodium showed correlation with axis 1 and axis 3 respectively in DCA of tree vegetation data. DCA axes 1 and 3 of understorey species data showed correlation with soil pH and K. Univariate comparison (single factor ANOVA) and multivariate comparison (Hotelling's T^2) were performed on both the vegetation data (tree and understorey) between the groups derived from Ward's cluster analysis with environmental variables (topographic, edaphic and soil nutrients) showed some significant differences were observed in both the analysis. Elevation showed differences in groups for both tree species ($P < 0.01$) and understorey species data ($P < 0.001$) while aspect ($P < 0.05$) and pH ($P < 0.01$) were also found significant in univariate ANOVA. Kutnar & Martincic (2003) also used analysis of variance (ANOVA) to test differences of soil parameters between vegetation types and found significant differences. Hotelling's T^2 test is an effective tool for multivariate comparison. Among environmental variables group I, II and group II, III of topographic variables were highly significant in both data (tree vegetation and understorey) while group I, II of edaphic variables (understorey species data) were also significant. Other environmental variables did not show any effect on phytosociological attributes, however considerable agreement were achieved despite long history of anthropogenic disturbance, especially in last 50 to 60 years. Summing together it seems that the first axis of DCA ordination represents an amalgam of environmental gradients including moisture and climatic gradients.

On the basis of above investigation it may be concluded that detailed understanding of vegetation and its relation to environmental variables may be achieved using these advanced multivariate techniques in conjunction with each other. In addition, it may also be anticipated that detailed understanding of vegetation-environmental complex may be achieved using advanced multivariate techniques in conjunction with each other.

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