J. Mt. Sci. (2011) 8: 817–826
DOI: 10.1007/s11629-011-2078-7

Plant Communities and Factors Responsible for Vegetation Pattern in an Alpine Area of the Northwestern Himalaya

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Abstract: The study intended to describe the alpine vegetation of a protected area of the northwestern Himalaya and identify the important environmental variables responsible for species distribution. We placed random plots covering different habitats and altitude to record species composition and environmental variables. Vegetation was classified using hierarchical cluster analysis and vegetation-environment relationships were evaluated with Canonical Correspondence Analysis. Four communities, each in alpine shrub and meadows were delineated and well justified in the ordination plots. Indicator species for the different communities were identified. Maximum species richness and diversity were found in community IV among shrub communities and community II among the meadows. Studied environmental variables explained 61.5% variation in shrub vegetation and 59.8% variation in meadows. Soil variables explained higher variability (~35%) than spatial variables (~21%) in both shrubs and meadows. Altitude, among the spatial variables and carbon/nitrogen ratio and nitrogen among the soil variables explained maximum variation. About 40% variations left unexplained. Latitude and species diversity among the other variables had significant correlation with ordination axes. Study showed that altitude and C/N ratio played a significant role in species composition. Extensive sampling efforts and inclusion of other non-studied variables are also suggested for better understanding.

Received: 25 November 2010
Accepted: 22 August 2011

Keywords: Species diversity; Indicator species; Environmental variable; Ordination; Explained variation

Introduction

Species richness and percent endemism of plants are higher in the alpine meadows than lower elevation ecosystems (Shermann et al. 2008). Predicted increase in temperature and reduction of snow cover is likely to result in an increase in species richness and number of introduced weeds at higher altitude (Pickering et al. 2008). Climate change has already resulted in an upward shift of average 29 meters per decade in optimum elevation of species (Lenoir et al. 2008). The alpine species being located near the mountain top are highly vulnerable to these changes (Beniston 2003) since they have no place to move upward. This is also in widespread agreement with that climate change, anthropogenic activities and non-native plants may impose a threat and modify the natural functioning of the alpine ecosystem.

For conservation and management purposes, a broad level identification and classification of plant communities and understanding their relationship with the environment is obligatory. Studies were conducted on pattern and processes in community ecology (Tilman et al. 2001; Bruno et al 2003; Kikvidze et al. 2005), importance of facilitative and competitive interaction (Callaway et al 2002), positive interaction in alpine environment (Fajardo et al 2008) and effect of one or two environmental variable on species distribution (Hejcman et al 2006; Bowman et al. 2006). A perusal of the available literature also indicated that such relationships need to be explored on larger geographical scales. However, information generated is invaluable but fundamental aspects of community and abiotic drivers remain poorly understood. In the Indian Himalayan region, alpine area occupies nearly 33% of the total geographical area of the Himalaya, out of that under vegetation and snow-bound areas constitute about 25.88% and 7.22%, respectively (Anonymous 1989). 9.6% of the total area (5346.21 km^2) of Himachal Pradesh, a northwestern Himalayan state of India is under alpine meadows and 3.8% of the total area (2086.92 km^2) under alpine shrubs (Chandrashekhar et al. 2003). In the Himalayan region, the studies related to the alpine vegetation are mostly confined to floristics effect of disturbances and productivity only. Information on species environment relationship in the high altitude areas of the Himalaya is very scanty (Arya 2002; Chandrashekhar et al. 2003; Gaur et al. 2005; Chawla et al. 2008). In order to establish regional conservation goals and to develop strategies to achieve these goals, an understanding of how the plant diversity and composition of alpine communities vary among locations and with environmental factors is critical for conservation efforts.

Studies also suggest that environmental factors are responsible for vegetation patterns (Beniston 2003). However, the relative role of different factors in community composition and species distribution is not well understood. Therefore, objectives of the present study were to: (i) study distribution pattern of species (ii) classify the alpine vegetation; (iii) identify the indicator species for each community and (iv) analyze the effects of the studied environmental variables on community composition.

1 Materials and Methods

1.1 Study area

Manali Wildlife Sanctuary (MWLS) (32°13'-32°17'N Latitudes and 77°03'-77°10' E Longitudes) is located in the Kullu District of Himachal Pradesh, Northwestern Himalaya. It covers an area of 29.03 km^2, of which more than half is alpine between altitudes 3400-5100 m (Gulati et al. 2004). There is no permanent settlement inside the sanctuary. However, there are 20 temporary camping sites called *Thatches* used by Gaddies (a migratory pastoral community) in summer (May-August) during transhumance practice. More than 35% of the MWLS is inaccessible due to rocky and steep slopes in the forests as well as alpine zones. Soil is black, light to dark brown and silty to clayey loam in texture (Rana 2008). The climate of the sanctuary is typically temperate and alpine temperature ranges between -70 to 30°C in the outskirt of the sanctuary with heavy snowfall during winter (Rana 2008).

1.2 Field sampling and data collection

Alpine area was stratified based on vegetation types (shrub and meadow). Sampling sites were selected on each and every accessible area between 3560-4485 m covering different habitats along an altitudinal gradient. Latitude and longitude of each sampled plot was obtained with the help of Global Positioning System (GPS, Magellan explorist, WAAS enabled with accuracy <7 m). Slope was measured with the help of Abney's level (Nexus make).

The field surveys were conducted during the summer season of 2006 and 2007 within the selected sites. In each site, a plot of 20 m × 20 m was laid. Randomly 10 quadrats (5 m × 5 m) were placed and sampled within the plot for shrubs and 20 quadrats (1 m × 1 m) for herbs. Shrubs were considered as the woody species having several branches arising from their base (Saxena and Singh 1997). All individuals of vascular plants were enumerated within each quadrat and measured by species. Species were identified *in loco* but fresh samples of unidentified species were brought to the institute and identified with the help of local and regional floras (Chowdhery and Wadhawa 1984;

Dhaliwal and Sharma 1999; Singh and Rawat 2000; Khullar 1994-2000). A total of 38 sites (19 shrub and 19 meadow) were sampled between altitude 3560-4485 m, 32°13'00" to 32°17'48" N latitudes and 77°03'01" to 77°08'07" E longitudes.

Soil samples, collected up to 20 cm depth from each plot at five locations, one from center, four from corners, were mixed together to produce a bulked quadrat sample. A composite sample weighing 200 g was brought to the laboratory in air-tight polythene bags. Fresh soil sample (10 g) was kept in oven for 5 hour at 105°C to determine moisture content immediately after reaching the laboratory. Remaining sample was dried at room temperature for 4-7 days, sieved over a 2 mm sieve and stored in an air tight polythene bag. The pH was determined in a 1:4 (w: v) suspension of soil in water using a pH meter (Elico Ltd.). Carbon and organic matter were determined by Walkely and Black method. Total nitrogen (%) was ascertained by the Kjeldhal procedure after digestion with concentrated H_2SO_4. Available potassium (K) was determined by Ammonium acetate (Hanway and Heidel 1952) method and available phosphorus (P) by Ammonium fluoride (Bray and Kurtz 1945) method at pH <7 (Singh et al. 2005).

1.3 Data analysis

Density of shrubs and herbs were calculated. The mean variance ratio method was used to analyze the distribution patterns of species using the software Biodiversity Pro (Hill 1973). Hierarchical agglomerative cluster analysis was used to classify the plant communities. Cluster analysis was performed on density of species and results were presented in a dendrogram. In this classification process, Euclidean dissimilarity was the distance measure and Ward's method was used as group linkage method. The PC-ORD for the windows 4.5 program was used for cluster analysis (McCune and Grace 2002). Multi-Response Permutational Procedure (MRPP) was used to test whether the species composition of different communities was significantly different (Biondini et al. 1988). Species diversity was determined by Shannon-Weiner's diversity index (H') (Shannon and Weaver 1963) for shrubs and herbs. Rarefaction was used to compare the species richness in identified communities, since the communities represented unequal number of sites and individuals (Hurlbert 1971). The characteristic/ indicator species of each community group were identified using species indicator analysis (Dufrene and Legendre 1997). A Monte Carlo technique is used to test the significance of the indicator values of each species within a group.

Canonical correspondence analysis (CCA) was used to describe variation and relationship among communities due to environmental variables (Ter Braak 1986) and results were presented in a CCA ordination plot. In addition, Partial Canonical Correspondence Analysis (PCCA) was used to determine the fractions of variation explained by specific sets of variables. Species data were transformed with square-root in order to reduce the effects of dominant species and down weight rare species prior to analysis. Stepwise forward selection was used to choose the environmental variables from the full set. Variables with *P* values less than 0.05 derived through Monte- Carlo permutations tests with 499 permutations were considered significant but all the environmental variables were included in the ordination plot and further analysis. Direct gradient analysis (*i.e.,* CCA) and partitioning of variation (Borcard et al. 1992; Økland 2003) with the environmental variables and species data were performed using CANOCO for Windows software (Ter Braak and Smilauer 2002).

2 Results

The habitat moist slope represented eleven sites, boulder (6 sites), dry slopes (5 sites), rocky, shrubbery and camping site (3 sites, each), moraines, water course and riverine (2 sites, each) and landslide (1 site). Maximum sites (10) were represented in east aspect, followed by north east (7 sites), west (6 sites), north west (5 sites), south (4 sites), north (3 sites), south west (2 sites) and south east (1 site) aspects.

2.1 Species distribution

In total 229 species (shrubs: 19; herbs: 210) were recorded within the sampled plots. Of these only 8 herb species had regular distribution pattern, 7 shrubs and 32 herbs had random distribution and 12 shrubs and 170 herbs had a patchy distribution pattern. Total number of species varied from 22-48 species with an average 32 species per site (20×20 m plot) in shrub sites whereas in meadows it varied from 20-36 with an average 28 species per site (20×20 m plot).

2.2 Alpine shrub communities and environmental relationship

Cluster analysis identified four communities that differed in species composition and abundance (Figure 1). MRPP analysis indicated significant difference between communities identified by the cluster analysis (A=0.50, P<0.0001).

Maximum shrub density (1200 shrub/ha) and herb density (218.0 herbs/m^2) was found in community IV and community I, respectively (Table 1). Shannon-Wiener diversity index and rarefaction estimation showed maximum species diversity (4.05) and species richness (82.5) at the comparable number of total individuals respectively, in community IV (Table 1 and Figure 2). Indicator species analysis identified three, ten, two and five species as indicator species for the communities, I, II, III and IV, respectively at the significance level of P≤0.05 (Table 2).

Communities identified by cluster analysis were superimposed (circled) on the CCA ordination plot. CCA plot did not clearly distinguish communities along the first two axes (Figure 3). The first two axes of the CCA of the shrub communities explained 17.2 % variance in the species data (P≤0.01). Total inertia calculated for the species data was 4.889 and environmental variables (spatial and soil) explained 61.5% of the

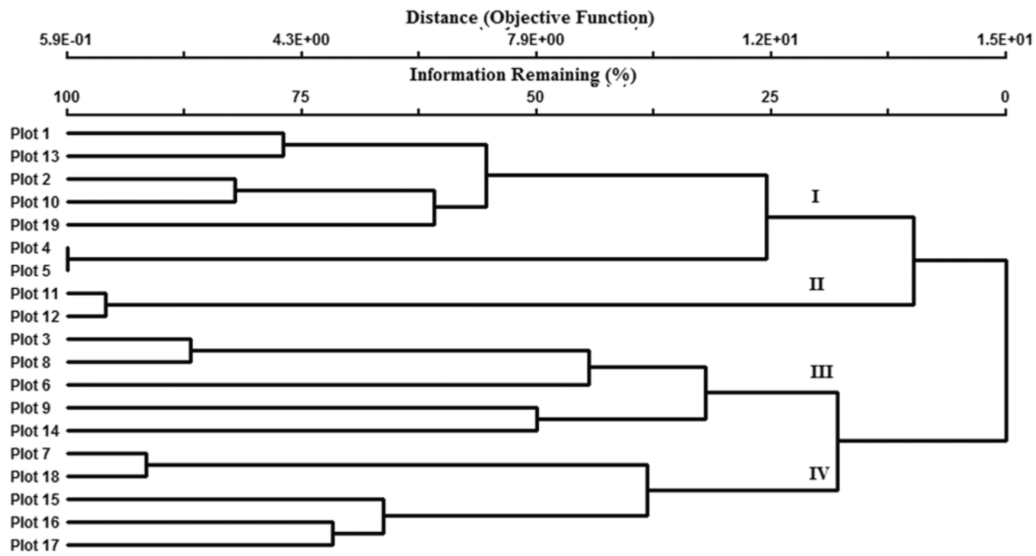

Figure 1 Dendrogram showing the different associations of shrubs identified by the hierarchical agglomerative cluster analysis

Table 1 Composition and structure of alpine shrub communities

Community	Sites	SD	HD	SR*	SD	DS (based on relative density)
I	7	680.0	218.0	71.1	3.76	*Rhododendron anthopogon, R. campanulatum, Carex setigera, Agrostis pilosula*
II	2	341.0	190.0	32.9	2.87	*Salix lindleyana, Carex nivalis, C. setigera, Sibbaldia cuneata*
III	5	1140.0	114.0	75.5	3.93	*Rhododendron campanulatum, R. anthopogon, Persicaria polystachya*
IV	5	1200.0	125.0	82.4	4.05	*Lonicera obovata, Berberis jaeskeana, Rhododendron lepidtoum, Salix denticulata, C. nivalis*

*Species richness at the comparable number of total individuals i.e., 381; Abbreviation Used: SD= Shrub Density (per ha), HD= Herb Density (per m^2), SR= Species Richness, SD= Species Diversity; DS= Dominant Species total variation. Studied soil variables accounted for 34.9% variation and spatial variable for 23.0% variation. Both variables accounted for 3.2% variation in species composition together. Altitude explained maximum (9.1%, P=0.002) variation in governing the distribution of plants in shrub communities and had the closest correlation (r=0.884) with first CCA Axis (Table 3). Other variables that had relatively high correlation with the first axis were latitude (r=0.575) and nitrogen (r=-0.464) and explained 5.27 % and 5.96 % variation respectively, at the probability level of $P \le 0.5$. Moisture content had high correlation with second axis (r=-0.722) and explain 4.58 % variation. Other variables that had relatively high correlations with the second axis were longitude (r=0.575) and species diversity (r=-0.464) and explained 7.56 %, and 7.10 % variation respectively, at the probability level of $P \le 0.05$ (Table 3). Third axis did not have many explanatory variables.

Table 2 Indicator species of communities in alpine shrubbery

Taxa	Family	*P*-Value	Taxa	Family	*P*-Value
Community I					
Agrostis pilosula	Poaceae	0.050	*Polygonum tubulosum*	Polygonaceae	0.056
Pleurospermum brunonis	Apiaceae	0.053			
Community II					
Cremanthodium arnecoides	Asteraceae	0.025	*Picrorhiza kurooa*	Scrophulariaceae	
Epilobium angustifolium	Onagraceae	0.047	*Saxifraga asarifolia*	Saxifragaceae	0.044
Salix lindleyana	Salicaceae	0.057	*Saxifraga brunonis*	Saxifragaceae	0.008
Potentilla argyrophylla	Rosaceae	0.008	*Saxifraga mucronulata*	Saxifragaceae	0.049
Rhodiola wallichiana	Crassulaceae	0.008	*Sibbaldia cuneata*	Rosaceae	0.023
Community III					
Gaultheria trichophylla	Ericaceae	0.045	*Potentilla atrosanguinea*	Rosaceae	0.046
Community IV					
Arnebia benthamii	Boraginaceae	0.008	*Lonicera obvata*	Caprifoliaceae	0.046
Artemisia stricta	Asteraceae	0.043	*Ploemonium caeruleum*	Polemoniaceae	0.019
Juniperus indica	Cupressaceae	0.037			

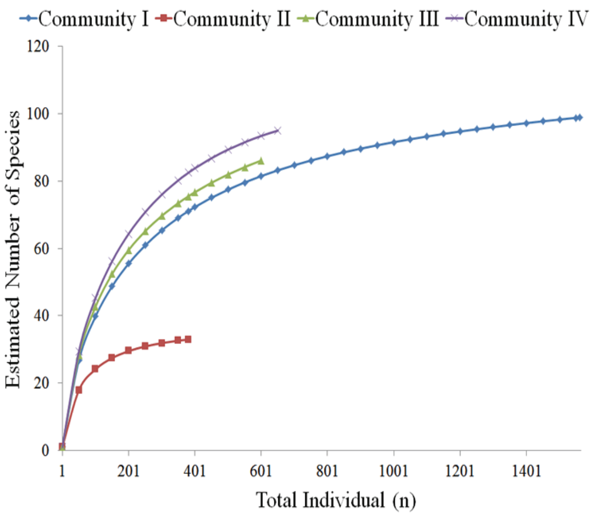

Figure 2 Individual based rarefaction curves for four identified shrub communities

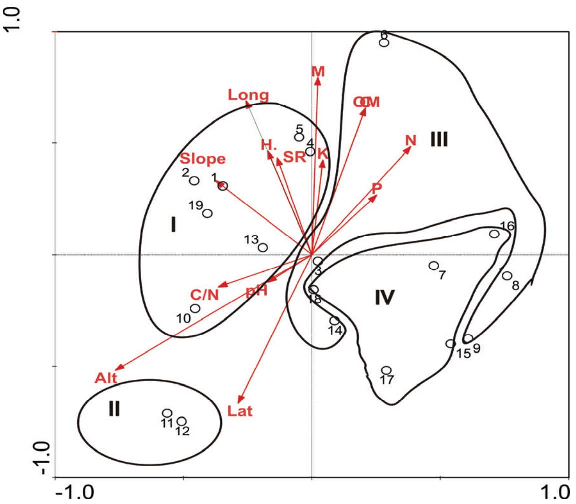

Figure 3 CCA ordination plot of samples and environmental variables in alpine shrub vegetation. Communities identified by cluster analysis are circled.

Table 3 Environmental variables (n=14) with explained variation and correlation with CCA axes for all sampled plot of shrub communities

Variables	VR	VE	EV	*P*-value	Correlation with CCA Axes		
					Axis 1	Axis 2	Axis 3
Altitude (m)	3540-4330	9.05	0.39	0.002	0.884	0.389	0.166
Longitude	77.052-77.135	7.56	0.33	0.004	0.091	-0.652	-0.221
Species Diversity	2.77-3.61	7.10	0.31	0.030	-0.066	-0.431	0.564
Slope (°)	10.00-75.00	5.96	0.26	0.144	0.130	-0.267	0.188
Nitrogen (%)	0.06-1.05	5.96	0.26	0.200	-0.464	-0.264	-0.140
Latitude	32.22-32.29	5.27	0.23	0.478	0.575	0.632	0.019
pH	4.31-6.68	4.81	0.21	0.462	0.071	-0.052	0.298
Carbon/Nitrogen	4.24-26.09	5.04	0.22	0.502	0.328	0.039	0.063
Organic Matter (%)	1.02-12.29	5.04	0.22	0.456	-0.345	-0.455	-0.181
Moisture Content (%)	12.68-50.16	4.58	0.20	0.566	-0.232	-0.722	-0.246
AP (mg/l)	0.5-3.0	4.58	0.20	0.554	-0.290	-0.308	0.197
Species Richness	19.00-44.00	5.04	0.22	0.468	-0.096	-0.468	0.540
Available phosphorous	0.05-0.68	4.81	0.21	0.518	-0.354	-0.134	-0.002
Carbon (%)	0.59-7.13	0.00	0.00	1.000	-0.345	-0.455	-0.181

Abbreviation Used: VR= Variable range, VE= Variation explained (%), EV= Eigen Values, AP= Available Potassium

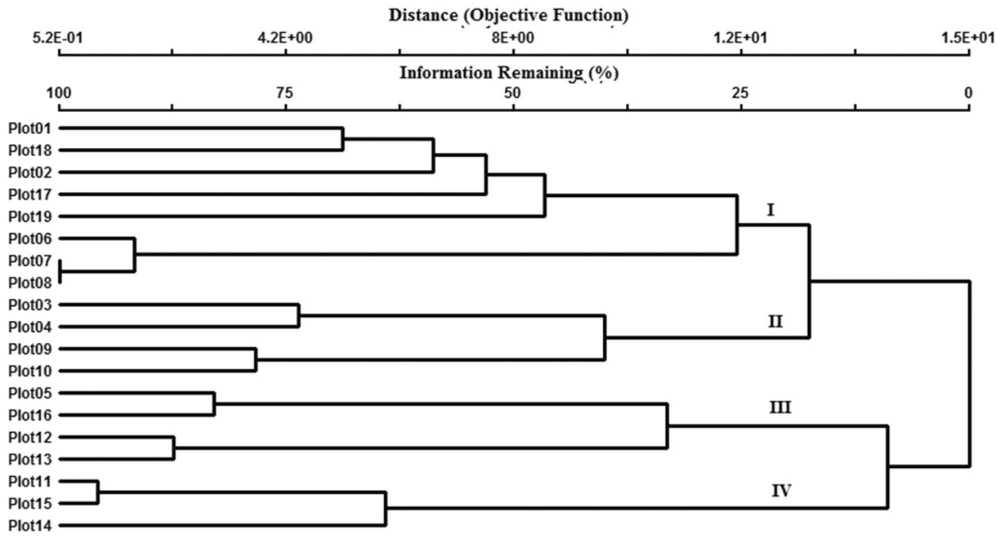

Figure 4 Dendrogram showing the different associations of meadows identified by the hierarchical agglomerative cluster analysis

2.3 Alpine meadow communities and environmental relationship

Cluster analysis identified four communities in meadows (Figure 4). MRPP analysis showed a significant difference between communities (A=0.421, P<0.0001). Maximum herb density (258.0 herbs.m^{-2}) was found in Community II (Table 4). Shannon-Wiener diversity index and rarefaction estimation showed maximum species diversity (3.64) and species richness (68.5) respectively, in Community II (Table 4 and Figure 5). Indicator species analysis identified one, four, two and nine species as indicator species for communities I, II, III and IV, respectively at significance level of P≤0.05 (Table 5). Communities identified by cluster analysis were

Table 4 Composition and structure of alpine meadow communities

Community	Sites	HD	SR*	SD	DS (based on relative density)
I	8	234.0	67.5	3.35	*Carex nivalis, Agrostis munroana, Danthonia cachemyriana, Phleum alpinum*
II	4	258.0	68.5	3.64	*Carex nubigena, Agrostis pilosula, Carex setigera, C. nivalis, Bistorta affinis*
III	4	179.0	50.1	2.98	*Poa alpina, Carex setigera, C. nubigena, Trachydium roylei,*
IV	3	180.0	58.0	3.48	*C. nubigena, Phleum alpinum, Iris hookeriana, Sibbaldia cuneata*

*Species richness at the comparable number of total individuals i.e., 541; Abbreviation Used: HD= Herb Density (per m²), SR= Species Richness, SD= Species Diversity, DS= Dominant Species

Table 5 Indicator species of communities in alpine meadows

Taxa	Family	PV	Taxa	Family	P V
Community I					
Picrorhiza kurooa	Scrophulariaceae	0.053			
Community II					
Corydalis cashmeriana	Fumariaceae	0.029	*Ligularia amplexicaulis*	Asteraceae	0.009
Dryopteris barbigera	Dryopteridaceae	0.002	*Swertia angustifolia*	Gentianaceae	0.006
Community III					
Poa alpina	Poaceae	0.001	*Polygonum tubulosum*	Polygonaceae	0.067
Community IV					
Aconitum heterophyllum	Ranunculaceae	0.014	*Nepata leavigata*	Lamiaceae	0.040
Artemisia nilagirica	Asteraceae	0.002	*Polemonium caeruleum*	Polemoniaceae	0.026
Aster himalaicus	Asteraceae	0.001	*Potentilla atrosanguinea*	Rosaceae	0.002
Delphinium vestitum	Ranunculaceae	0.026	*Selinum tenuifolium*	Apiaceae	0.004
Iris hookeriana	Iridaceae	0.001			

Abbreviation Used: PV= P Value

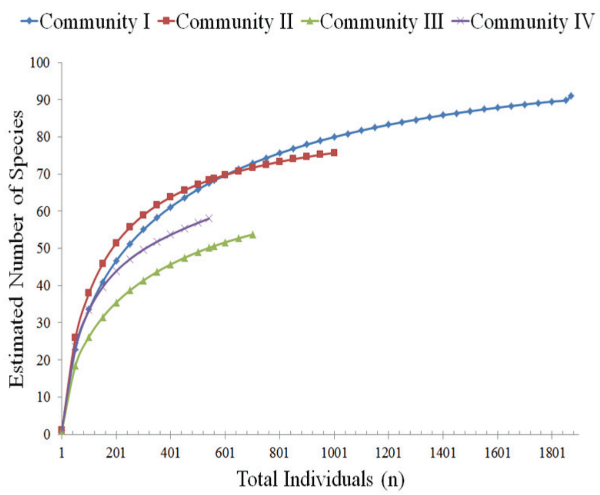

Figure 5 Individual based rarefaction curves for four identified communities in alpine meadows

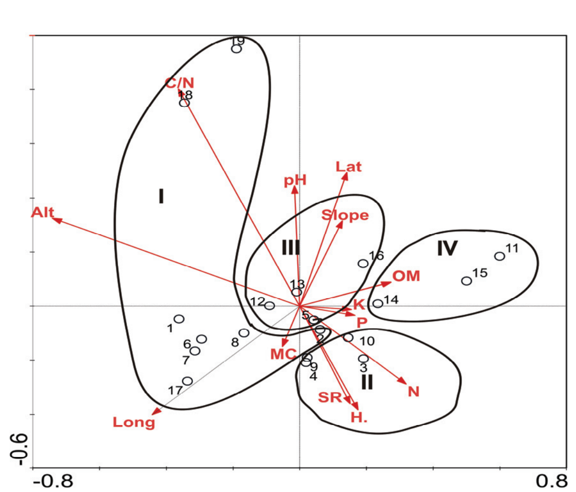

Figure 6 CCA ordination plot of sample and environmental variables for alpine meadow vegetation. Communities identified by cluster analysis are circled.

superimposed (circled) on the CCA ordination plot. The communities were clearly separated in CCA plot in comparison to shrub communities (Figure 6).The first two axes of the CCA explained 23.2 % variance in the species composition. Total inertia calculated for the species data was 4.586 and environmental variables (spatial and soil) explained 59.8% of the total variation. Studied soil variables accounted for 35.3% variation and spatial variable for 20.9% variation. Both variables lead to 3.6% variation in species composition together. Further, C/N ratio explained the maximum variation (8.1%, *P*=0.01) in governing the distribution of vascular plants and had a close correlation (*r*=0.663) with second CCA Axis (Table 6). Other variables that had a relatively high correlation with the second axis were latitude (*r*=0.592) and species diversity (*r*=-0.513) that explained 6.60 % (*P*=0.018) and 4.74 % (*P*=0.2) variation, respectively. Altitude showed a strong correlation with first axis of CCA (*r*=-0.813) and explained 6.60% variation. Other variables that had a relatively high correlation with the first axis were C/N ratio (*r*=-0.479) and nitrogen (*r*=-0.435) and explained 8.04% (*P*=0.01) and 4.95 % (*P*=0.43) variation, respectively (Table 6). Third axis did not have many explanatory variables.

3 Discussion

The present study conducted in a small spatial scale elucidated high alpha and beta diversity. However, communities identified by Cluster analysis could not be justified perfectly in CCA ordination for shrub communities, but it is well justified for herb communities. Hence, explaining the stronger influence of the environmental factors on the species composition of communities in the meadow. The timing of snowmelt may be an important ecological factor for creating diverse plant communities in the alpine ecosystem (Billings and Bliss 1959; Kudo and Ito 1992) and Giant mountain, Czech Republic (Hejcmen et al. 2006) because snow distribution and melting time in alpine region is heterogeneous. Indicator species identified for community types besides, some of these species may truly provide the valuable information on unique habitats and environmental conditions.

Occurrence of a large number of species in one or two plots and distribution of more than half of the total species in patches indicated that the species were locally rare and non-random. Patchy distribution of the species may be due to availability of nutrients and positive plant-plant

Table 6 Environmental variables (n=14) with explained variation and correlation with CCA axes for all sampled plot in alpine meadows

Variables	VR	VE (%)	EV	*P*-values	Correlation with CCA Axes		
					Axis 1	Axis 2	Axis 3
Carbon/Nitrogen	4.19-23.31	8.04	0.39	0.010	-0.479	0.663	0.371
Altitude (m)	3565-4485	6.60	0.32	0.010	-0.813	0.206	0.299
Latitudes	32.22-32.30	6.60	0.32	0.018	-0.315	0.592	-0.008
Available Phosphorous (mg/l)	0.07-3.20	6.19	0.30	0.160	0.231	0.175	-0.213
Longitudes	77.05-77.13	5.57	0.27	0.180	-0.126	-0.411	-0.111
Available Potassium (mg/l)	0.65-7.25	5.77	0.28	0.226	0.212	-0.003	-0.373
Nitrogen (%)	0.12-1.54	4.95	0.24	0.390	0.435	-0.245	-0.321
pH	4.46-6.55	4.33	0.21	0.522	-0.212	0.392	0.369
Species Diversity	2.58-3.30	4.74	0.23	0.486	0.183	-0.513	-0.420
Slope (°)	10.00-65.00	4.95	0.24	0.364	0.059	0.137	-0.001
Species Richness	17.00-34.00	4.74	0.23	0.490	0.171	-0.432	0.237
Moisture Content (%)	17.92-44.17	4.12	0.20	0.518	0.118	-0.181	-0.535
Organic Matter (%)	2.38-11.31	3.51	0.17	0.702	0.338	0.035	-0.201
Carbon (%)	1.38-6.56	0.82	0.04	0.988	0.338	0.035	-0.201

Abbreviation Used: VR= Variables range, VE=Variation Explained, EV= Eigen Value interactions. Positive interactions are non-trophic relations between species that increase the fitness of at least one of the species involved in the interaction (Callaway 1995; Bruno et al. 2003). It may be in response to severe climatic conditions at high altitudes that were found in many studies in the stressful environment (Callaway et al. 2002; Kikvidze et al. 2005).

Spatial and soil factors are expected to play a greater role in composition and distribution of species. In this study, we found the interactions between soil and spatial variables to be largely responsible for determination of community composition and species distribution. Soil variables explained variability higher than spatial variables in both shrubbery and meadows. Variation partitioning explained that small amount (~3%) of variation is shared by both the variables. Among the spatial variables, altitude had its stronger effect on both alpine shrub and meadow species with the maximum explained variation, whereas among the soil variables carbon/nitrogen ratio and nitrogen were responsible for the species distribution and community composition. Change in C: N ratio, associated with increasing N deposition due to anthropogenic activities, may cause change in the community composition (Bowman et al. 2006). Increasing tracking, camping sites for trackers and herdsman, and grazing of leftover domestic animals in the alpine during summer season may be responsible anthropogenic activities. In contrast to studies carried out in other areas (Hokkanen 2006) pH didn't explain significant variation, which may be due to its smaller range in the study area. Soil moisture and acidity have been considered the most important ecological environmental factor explaining a pattern of species (Kaakinen 1992) but contrastingly in this study neither of them was responsible for variation in both shrubs and meadows, although moisture had a significant correlation with CCA axes. Some variables explained less and non-significant variation, but a strong correlation with CCA axes might have biological significance. Because these variables may have shared effect with significant variable, which could not be partialed out in the study.

On the other hand, high percentage (~40%) of variation remained unexplained in species data which may be caused by unmeasured spatial, soil and biotic variables. Other reasons for the unexplained variation in the species composition data may be missing small-scale environmental variables (Rosenzweig 1997). Therefore, the total explained variation can be enhanced by taking climatic and biotic variables into account which have been found to be important determinants of species composition (Grace 2001; Grime 2001; Boyce et al. 2005).

It can be concluded from the study that C/N ratio of soil and altitude (spatial) had a significant role in species composition in the study area. However, more extensive sampling efforts and inclusion of other environmental variables in the study on larger spatial scales are necessary. So that vegetation pattern and relationship with the environment can be better understood in view of the unique topography and climate of the Himalayan region.

Acknowledgements

The authors are thankful to Dr. L.M.S. Palni, Director, G.B. Pant Institute of Himalayan Environment and Development, Kosi-Katarmal, Almora for the facilities and financial support. Dr. Manohar Lal, Dr Sakshi Bhandari, Dr. Aman Sharma and Mr. Karam Dass Thakur are acknowledged for their help during the field work and manuscript preparation.

References

Anonymous (1989) The State of Forest Report 1989. Forest Survey of India, Government of India, Dehradun.

Arya SC (2002) Assessment of habitat diversity, distribution of vegetation and Human dependence in alpine meadows of Nanda Devi Biosphere Reserve of West Himalaya. Ph.D. Thesis, Kumaon University, Nainital, India.

Beniston M (2003) Climatic change in mountain regions: a review of possible impacts. Climate Change 59: 5-31.

Billings WD, Bliss LC (1959) An alpine showbank environment and its effect on vegetation, plant development and productivity. Ecology 40: 389-397.

Biondini, M.E., Mielke, P.W. and Berry, K.J. 1988. Data dependent permutation for the analysis of ecological data. Vegetatio 75: 161-168.

Borcard D, Legendre P, Drapeau P (1992) Partialling out the spatial component of ecological variation. Ecology 73: 1045-

1055.
Bowman WD, Gartner JR, Holland K, Wiedermann (2006) Nitrogen critical loads for alpine vegetation and terrestrial ecosystem response: are we there yet? Ecological Application 16: 1183-1193.
Boyce RL, Clark R, Dawson C, (2005) Factors Determining Alpine Species Distribution on Goliath Peak, Front Range, Colorado, U.S.A. Arctic Antarctic and Alpine Research 37: 88-96.
Bray RH, Kurtz LT (1945) Determination of total, organic and available form of Phosphorous in soils. Soil Science 59: 39-45.
Bruno JF, Stachowicz JJ, Bertness MD (2003) Inclusion of facilitation into ecological theory. Trends in Ecology and Evolution 18: 119-125.
Callaway RM (1995) Positive interactions among plants. Botanical Review 61: 306-349.
Callaway RM, Brooker RW, Choler P, Kikvidze Z, Lortie CJ, Michalet R, Paolini L, Pugnaire FI, Newingham B, Aschehoug ET, Armas C, Kikodze D, Cook BJ (2002) Positive interactions among plants increase with stress. Nature 417: 2130-2141.
Chandrashekhar MB, Singh S, Roy PS (2003) Geospatial modelling techniques for rapid assessment of phytodiversity at landscape level in western Himalaya, Himachal Pradesh. Current Science 84: 663-670.
Chawla A, Rajkumar S, Singh KN, Lal B, Singh RD (2005) Plant species diversity along an altitudinal gradient of Bhabha Valley in Western Himalaya. Journal of Mountains Science 5: 157-177.
Chowdhery HJ, Wadhwa BM (1984) Flora of Himachal Pradesh, Vols. 1-3. Botanical Survey of India, Calcutta, India
Dhaliwal DS, Sharma M (1999) Flora of Kullu District (Himachal Pradesh). Bishen Singh Mahendra Pal Singh, Dehra Dun, India.
Dufrene M, Legendre P (1997) Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monograph 67: 345-366.
Fajardo A, Quiroz CA, Cavieres LA (2008) Spatial patterns in cushion dominated plant communities of the high Andes of central Chile: How frequent are positive interactions? Journal of Vegetation Science, 19: 87-96.
Gaur UN, Raturi GP, Bhatt AB (2005) Current vegetation pattern along glacial landscape in Central (Garhwal) Himalaya, India. Journal of Mountain Science 2: 255-264.
Grace JB (2001) The roles of community biomass and species pools in the regulation of plant diversity. Oikos 92: 191-207.
Grime JP (2001) Plant strategies, vegetation processes, and ecosystems properties, 2nd ed. John Wiley & Sons, Chichester.
Gulati, AK, Pandey S, Gupta S (2004) A guide to National Parks and Wildlife Sanctuaries of Himachal Pradesh. Wildlife Wing, Forest Department, Himachal Pradesh, India.
Hejcman M, Dvorak IJ, Kocianova M, Pavlu V, Nezerkova P, Vitek O, Rauch O, Jenik J, (2006) Snow Depth and Vegetation Pattern in a Late-melting Snowbed Analyzed by GPS and GIS in the Giant Mountains, Czech Republic. Arctic Antarctic and Alpine Research 38: 90-98.
Hill MO (1973) The intensity of spatial pattern in plant communities. Journal of Ecology 61: 225-235.
Hokkanen PJ (2006) Environmental patterns and gradients in the vascular plants and bryophytes of eastern Fennoscandian herb-rich forests. Forest Ecology and Management 229: 73-87.
Hanway JJ, Heidel H (1952) Soil analysis methods as used in Iowa state college soil testing laboratory. Iowa Agriculture 57: 1-31.
Hurlbert SH (1971) The non-concept of species diversity: a critique and alternative parameters. Ecology 52: 577-586.
Kaakinen E (1992) Finnish herb-rich forests. Memoranda Societatis pro Fauna et Flora Fennica 68: 67-71.
Khullar SP (1994-2000). An illustrated fern flora of the West Himalaya Vol I & II. International Book Distributors, Dehradun.
Kikvidze Z, Pugnaire FI, Brooker RW, Choler P, Lortie CJ, Michalet R, Callaway RM (2005) Linking patterns and processes in alpine plant communities: a global study. Ecology 86: 1395-1400.
Kudo G, Ito K (1992) Plant distribution in relation to the length of the growing season in the Taisetsu Mountains, northern Japan. Vegetatio 98: 165-174.
Lenoir J, Gegout JC, Marquet TPA, De Ruffray P, Brisse H (2008) A Significant Upward Shift in Plant Species Optimum Elevation During the 20th Century. Science 320: 1768-1771.
McCune B, Grace JB (2002) Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, OR, USA.
Økland RH (2003) Partitioning the variation in a plot by species data matrix that is related to n sets of explanatory variables. Journal of Vegetation Science 14: 693-700.
Pickering C, Hill W, Green K (2008) Vascular plant diversity and climate change in the alpine zone of the Snowy Mountains, Australia. Biodiversity and Conservation 17: 1627-1644.
Rana MS (2008) Assessment of floristic diversity and prioritization of communities for conservation in Manali Wildlife Sanctuary of Himachal Pradesh in Northwestern Himalaya. Ph.D. Thesis, Kumaon Univeristy, Nainital, India.
Rosenzweig ML (1997) Species diversity in space and time. Cambridge University Press.
Saxena AK, Singh JS (1982) A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. Vegetatio 50: 3-22.
Shannon CE, Weaver W (1963) The Mathematical Theory of Communication. University of Illinois Press, Urbana.
Sherman R, Mullen R, Haomin L, Zhendong F, Yi W (2008) Spatial pattern of plant diversity and communities in alpine ecosystems of the Hengduan mountains, Northwest Yunnan, China. Journal of Plant Ecology 1: 117-136.
Singh D, Chhonkar PK, Dwivedi BS (2005) Manual on soil, plant and water analysis. Westville Publishing House, New Delhi.
Singh SK, Rawat GS, (2000) Flora of Great Himalayan National Park, Himachal Pradesh. Bishen Singh Mahendra Pal Singh, Dehradun, India.
Ter Braak CJF (1986) Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology 67: 1167-1179.
Ter Braak CJF, Smilauer P (2002) Canoco Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5), Microcomputer Power, Ithaca, NY.
Tilman D, Reich PB, Knops J, Wedin D, Mielke T, Lehman C (2001) Diversity and productivity in a long term grassland experiment. Science 294: 843-845.