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Influence of environmental and anthropogenic factors on the species distribution in alpine rangelands of Gurez valley, Kashmir, India

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Abstract: This study attempts to establish correlation between species assemblages and environmental factors (biotic as well as abiotic) in the alpine rangelands of Gurez valley, Kashmir Himalaya. Data were collected from 35 sites of three grasslands and processed using direct gradient analysis. Vascular flora, altitude, degree of slope, human disturbance and edaphic variables were recorded from each site. Along the first canonical axis, species distribution was mainly correlated with altitude and anthropogenic disturbances while to the second axis soil pH, soil moisture and degree of slope were important. On a smaller spatial scale, these factors strongly affected species distribution. Of these, degree of slope was over-riding as it governed nature and depth of soil, moisture availability and intensity of use by livestock.

Resumen: Este estudio intenta establecer la correlación entre los ensambles de especies y los factores ambientales (bióticos y abióticos) en las praderas alpinas del valleGurez, Himalaya de Cachemira. Los datos se obtuvieronen 35 sitios de tres praderas y se procesaron por medio de un análisis directo de gradientes. En cada sitio se registró la flora vascular, la altitud, el grado de pendiente, el disturbio humano y las variables edáficas. A lo largo del primer eje canónico, la distribución de especies estuvo correlacionada principalmente con la altitud y los disturbios antropogénicos, mientras que al segundo eje fueron importantes el pH del suelo, la humedad del suelo y el grado de la pendiente. En una escala espacial más pequeña, estos factores afectaron fuertemente la distribución de especies. De éstos, el grado de la pendiente prevaleció, ya que controla la naturaleza y la profundidad de suelo, la disponibilidad de agua y la intensidad de uso por el ganado.

Resumo: Este estudo tenta estabelecer uma correlação entre conjuntos de espécies e fatores ambientais (bióticos, bem como abióticos) nas pastagens alpinas do vale Gurez, Caxemira, Himalaia. Os dados foram coletados a partir de 35 locais de três campos e processados usando análise direta de gradiente. A flora vascular, a altitude, o declive, a perturbação humana e as variáveis edáficas foram registadas em cada local. Ao longo do primeiro eixo canónico, a distribuição das espécies foi relacionada principalmente com a altitude e as perturbações antrópicas, enquanto que para o segundo eixo o pH,a humidade do solo e o grau de declive foram importantes. Numa escala espacial menor, estes fatores afetaram fortemente a distribuição das espécies. Destes, o declivesobrepos-se, pois governaa profundidade do solo, a disponibilidade de humidade e a intensidade de uso pelo gado.

Key words: Gurez valley, high altitude grasslands, Kashmir Himalaya, species distribution.

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Introduction

Alpine rangelands in the Western Himalaya represent unique ecosystems on account of their high floristic diversity, stark seasonality and interplay of biotic and abiotic environments. These ecosystems have attracted the attention of a large number of ecologists due to their sensitivity to environmental changes, spatial pattern of species distribution and influence of micro-topographic variation in community composition (Nautiyal *et al*. 1997; Rawat & Pangtey 1987). The distribution of species and community composition in alpine rangelands is known to be greatly determined by various factors of habitat such as elevation, slope, aspect, soil moisture and soil chemistry (Kharkwal *et al*. 2005). An additional over-riding factor in the Himalayan alpine rangelands has been grazing by migratory livestock during summer-monsoon period since several centuries that is known to have a major influence on the species composition, richness and diversity of plant communities (Negi *et al*. 1993; Sundriyal & Joshi 1990). However, in the absence of long term quantitative studies, influence of livestock grazing in different rangelands of Himalaya have not been understood and often role of pastoralism on conservation of alpine biodiversity has been debated extensively (Mishra & Rawat 1998; Saberwal 1996).

High altitude grasslands and mixed herbaceous formations, collectively referred here as 'alpine rangelands' form a significant proportion of land cover in the North-Western Himalaya. According to Lal *et al*. (1991), of the total 1, 71, 464 km^2 area of alpine rangelands in the Indian Himalayan region, as much as 77 % area falls in the state of Jammu and Kashmir. These ecosystems vary considerably in their floristic composition and physiognomy owing to wide eco-climatic conditions which include moist alpine areas of Pir Panjal range, semi-arid valleys of Gurez and Zanskar and extreme cold arid regions of Ladakh. Although moist alpine rangelands of Greater Himalaya and Pir Panjal as well as cold deserts have received much attention of ecologists (Bhat *et al*. 2002; Gupta & Kachroo 1981; Rawat & Adhikari 2005), alpine rangelands of semi-arid tracts such as Gurez region in Kashmir have not been investigated adequately owing to poor accessibility and proximity to politically sensitive international border with Pakistan. Earlier studies on the rangelands of Kashmir Himalaya including those of Gurez valley confined largely to systematics and floral accounts (Ara & Naqshi 2003) and only recently have there been few studies dealing with vegetation classification and analysis of environmental factors which influence the vegetation structure and composition in moist alpine areas of Kashmir Himalaya (Dvorsky *et al*. 2011). We conducted an ecological study on the rangelands of this valley during 2008 - 2010. The major objectives of the study were to elucidate the floristic composition and distribution pattern of species across the surveyed landscape and identify role of various environmental factors in determining the structure and composition of these rangelands. Cognizant of topographical features like altitudinal gradient and degree of slope as well as prevalence of livestock grazing we tried to analyse the species distribution pattern both at landscape and local scales.

Materials and methods

Study area

The study was conducted in Gurez valley, which lies at the extreme tip of the north-western Himalaya within the Indian territory. Located close to the international border with Pakistan, this valley extends between 34° 30′ to 34° 41′ N latitudes and 74° 37′ to 74° 55′ E longitudes at an average altitude of 2370 m. With little variations driven chiefly by altitude and geographical location, the climate of the valley is temperate alpine type with four seasons viz., spring (March - May), summer (June - August), autumn (September - November) and winter (December - February). On the lower side the study area is bounded by subalpine forest and timberline ecotone characterized by dense coniferous forests mixed with broad leaved species such as *Acer caesium*, *Abies pindrow*, *Pinus wallichiana* and *Betula utilis*. Immediately above treeline a zone of alpine scrub can be seen dominated by *Syringa emodi*, *Rosa macrophylla* and *Spiraea hypericifolia*. At higher steep and bare hill slopes and exposed ridges, soil is thin and at places only bed rock is visible but lower down, soils extend to greater depths and are medium to fine textured. The valley is inhabited by a native tribal community i.e. Dards, having unique cultural and linguistic identity and have their kins in Astore, Gilgit and Chilas region of Karakoram across the Line of Control (LoC) in Pakistan.

Field methods

Three grasslands representing various topographic features and grazing pressure were selected for present study, viz., Minimarg (34° 33′ N; 74° 53′ E; altitude 3058 - 4250 m), Patalwan (34° 31′ N; 74° 51′ E; altitude 3190 - 4428 m) and Viji (34° 34′ N; 74° 45′ E; altitude 3468 - 4170 m). Intensive study was conducted during the snow free period (May - October) of the three years i.e. 2008 - 10. Stocking densities of livestock (animals ha^{-1}) at three grasslands were 0.096, 0.107 and 0.097 at Minimarg, Patalwan and Viji respectively. Total number of grazing days at any of these sites does not exceed 160. Based on landscape heterogeneity and topographical variation, a total of 35 sites were selected for intensive sampling (11 at Viji and 12 each at Minimarg and Patalwan). Vegetation parameters were recorded using random quadrats of 0.25 m^2 (50 × 50 cm) for herbs and 25 m^2 (5 × 5 m) for shrubs. Number of quadrats required at a site was calculated using running mean method (Mueller - Dombois & Ellenberg 1974) that varied between 26 and 33. For the sake of uniformity and easy comparison, 35 quadrats at each site were placed. As far as possible, on site identification of plant species was done with the help of regional floras (Dar & Naqshi 2001; Dhar & Kachroo 1983; Kaul 1997). Within each quadrat, the number and cover (%) of each vascular plant was recorded and used for the analysis.

Edaphic variables, grazing and human disturbance

At each site, soil sampling was done using a hand auger to a depth of 50 cms. Five samples per plot were taken and mixed thoroughly for determination of physical and chemical properties. Moisture content was determined gravimetrically (Gupta 1999) while soil reaction (pH) was determined using distilled water in soil : water ratio of 1:1 (Michael 1984). Electrical conductivity was determined using the 1:1 soil-water solution extraction method (Gliessman 1998) while the soil samples for determination of total N were digested using the standard Kjeldhal method with concentrated sulphuric acid (Jackson 1962) and titrating the distillate against hydrochloric acid (0.1 N). Organic carbon in soil was determined using the Walkley & Black (1934) rapid titration method. One-way analysis of variance (ANOVA) was performed to differentiate the effects of location on the chosen soil properties for each site at a 5 % probability level. Values of soil properties that differed at $P < 0.05$ were considered significant.

Environmental variables recorded at each site included altitude, aspect and degree of slope. Altitude and degree of slope were measured using GPS and a clinometer respectively. Degree of human disturbance at each site was ranked using a scale of 0 to 5 where 0 means undisturbed and 5 means highly disturbed site. Parameters used to judge the degree of disturbance were the distance of site from camping location of herdsmen; number of livestock; proportion of ruderal and noxious species at the site; presence and number of tracks and trails (human and animal) at a site and percent of exposed soil or bare earth due to trampling. The variables used in canonical correspondence analysis (CCA) were coded as MOIS= soil moisture; pH= soil acidity; COND= soil conductivity; NITR= total soil nitrogen; OCAR= soil organic carbon; SLOP = degree of slope; ALTI= altitude (m) and DIST= anthropogenic disturbance.

Data analysis

Importance values calculated from relative cover, relative frequency and relative density of species at each site were summed and changed into percentages for each grassland and then for whole landscape to study the species distribution pattern. The species occurrence and frequency distribution was calculated by dividing the number of sites in which a species occurred by total sampling sites (n = 35) and then multiplying by 100. The frequencies were then grouped into 10 classes (from 1 - 10), each with 10 % range (e.g. 1 = 0 - 10 %, 2 = 11 - 20 %...... 10 = 91 - 100 %).

The relationship between species composition and distribution in relation to various environmental and anthropogenic variables was determined employing Canonical Correspondence Analysis using CANOCO for Windows 4.5 (ter Braak & Smilauer 2002). We used the importance value index (IVI) of each species for this analysis and down weighted rare species. Correlation was drawn with the help of ordination diagrams by using Canonical Correspondance Analysis (CCA). Only the species with best fit were plotted in ordination diagrams, as their positions have a more meaningful ecological interpretation. The species plotted in the ordination graphs were abbreviated into seven characters viz. first four letters of the genus name and first three letters of the species name. Statistical significance of results was tested using global Monte Carlo Permutation test ($P < 0.05$ at 999 permutations).

Results

Floristic composition

A total of 232 species of vascular plants were recorded within the study sites. These species belong to 147 genera and 44 families. Dicotyledons accounted for 34 families, 130 genera and 205 species while the monocotyledons were represented by 7 families, 15 genera and 24 species. Pteridophytes accounted for only two species while the gymnosperms were represented by a single species of *Juniperus indica*. Eight large families accounted for 53.4 % of all the species with Asteraceae (20 genera/29 species), Lamiaceae and Ranunculaceae (10/16 each), Brassicaceae (9/15), Rosaceae (8/13), Caryophyllaceae (8/11) Scrophulariaceae (6/14) and Poaceae (6/10). As reflected by rank abundance, the frequency distribution of the species varied considerably and across ten classes (1 - 10), the frequencies recorded were 70.9, 13.1, 6.8, 4.0, 2.4, 2.0, 0.4, 0.3, 0 and 0 (Fig. 1). Thus the species composition over the total area was very heterogeneous and over 70 % of the recorded species had frequencies between 0 - 10 % and none of the species had frequencies more than 80 %. The species with a highest importance value index were *Sibbaldia cuneata* (16.02), *Lagotis cashmeriana* (5.36), *Poa annua* (5.11) and *Geum urbanum* (3.76). Among other species, the important grass species were *Poa angustifolia*, *Dactylis glomerata* and *Chrysopogon gryllus*. *Rhododendron anthopogan* and *Cassiope fastigiata* were the prominent shrubs.

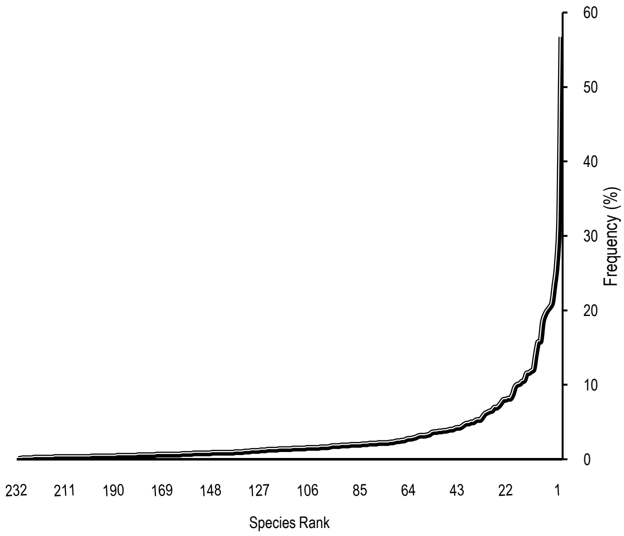

Fig. 1. Species abundance distribution across the surveyed landscape at Gurez valley, Kashmir.

Soil characteristics

Soil properties of the study area have been given in Table 1. It was found that soils across all the sites were acidic with a high electrical conductivity. Soil moisture ranged between 11 - 66 %. The total soil nitrogen content ranged between 0.28 and 1.36 %. Soil carbon content of the sampled sites ranged between 1.09 and 3.12 %. All the sites differed in terms of soil properties significantly ($P < 0.05$).

Table 1. Edaphic environmental data measured during the study period, illustrating the general characteristics of the surveyed landscape.

Variable	Abbreviation	Range	Average ± SD	
pH	pH	3.56 - 6.61	4.66 ± 0.51	**
Conductivity (mS)	COND	0.21 - 2.55	0.81 ± 0.74	*
Total Nitrogen (%)	NITR	0.28 - 1.36	0.51 ± 0.21	**
Organic Carbon (%)	OCAR	1.09 - 3.12	2.26 ± 0.51	*
Moisture (%)	MOIS	11.1 - 65.7	29.27 ± 18.5	**

Note : $n = 35$; * $P < 0.05$; ** $P < 0.01$

Influence of environmental factors on vegetation

Results of CCA with edaphic and environment data have been given in Table 2. The first two ordination axes explained 13.8 % of the variability in the species data with a cumulative percentage variation of 53 % in species - environment correlation. Low difference between the sum of unconstrained eigenvalues (a measure of the strength of an axis) and a high species environment correlation of 0.93 and 0.79 along the first two axes showed that the selected environmental and edaphic variables supported the explained variation fully and were the determinants of species variation in the data set. The effects of the variables investigated were statistically validated ($P < 0.05$ at 999 permutations).

The arrangement of data in the CCA ordination illustrated an important pattern of topographic and edaphic gradients determining species composition. As shown by strength, magnitude and direction of the different variables in CCA output (Fig. 2), the variables that had the closest correlation with first axis were altitude and disturbance while to second axis variables best fitted were slope, soil acidity and soil moisture. Other variables were

Table 2. Eigen values and percentage of variance explained by CCA along with results of intraset correlation for environmental factors.

		Axis 1	Axis 2	Axis 3	Axis 4
CCA					
Eigenvalues		0.477	0.14	0.125	0.126
Species-environment correlations		0.932	0.791	0.874	0.848
Cumulative percentage variance of species data		10.6	13.8	16.6	19.4
Species-environment relation		41	53	63.8	74.5
Sum of all eigenvalues		4.487			
Sum of all canonical eigenvalues		1.165			
Inter-Set Correlations for Environmental Factors					
Variable	Code	Axis 1	Axis 2	Axis 3	Axis 4
Moisture	MOIS	0.2001	-0.4012	-0.247	**-0.7066**
pH	pH	-0.2705	0.5123	0.2496	-0.2863
Conductivity	COND	-0.3268	-0.2297	-0.3271	-0.0425
Slope	SLOP	-0.0494	**-0.6026**	0.4823	0.356
Altitude	ALTI	**0.8585**	-0.256	-0.2112	0.1875
Nitrogen	NITR	-0.1676	-0.1428	-0.2961	0.0412
Organic Carbon	OCAR	-0.1091	-0.2625	-0.2994	0.0022
Disturbance	DIST	**-0.8083**	0.102	-0.4824	0.1118

Note : Values in bold are significant at 5 % probability level.

at lower magnitude and thus had a relatively little correlation with the plant distribution. The CCA ordination plot showed that though the species did not cluster perfectly into well defined groups but it loosely differentiated the species that could be easily identified with the heavily grazed and trampled sites. These sites typically represent moderate slopes at lower altitudes (< 3500 m) and support ruderal communities which are tolerant of trampling and other biotic interference. The characteristic species are *Rumex nepalensis*, *Sambucus wightiana* and *Cirsium wallichii*. Other opportunistic species at such sites include *Malva neglecta*, *Polygonum aviculare* and *Fragaria nubicola*. High altitude (> 4000 m) lightly grazed sites (Fig. 2) ordinate diagonally opposite to heavily grazed sites. Of the various species found at such sites many are medicinally important e.g. *Aconitum heterophyllum*, *Primula rosea*, *Picrorhiza kurrooa* and *Lagotis cashmeriana*. The soils at these sites have relatively lower nutrient levels.

The first two ordination axes explained 33.4 %, 28.6 % and 33.7 % of the variability in the species data at Patalwan, Minimarg and Viji respectively (Table 3). A high species-environment correlation at each of these grasslands along with a high eigenvalue of 0.705 and 0.459; 0.669 and 0.495 and 0.523 and 0.460 for the first and second axis respectively for Minimarg, Patalwan and Viji connotes that the ordinated axis explains well their species variation.

Comparing the ordination biplots of individual grasslands it is well evident that on both species ordination and influence of different variables, a slightly different scenario evolves (Fig. 3, Table 4). Although both the altitude and disturbance showed a high magnitude of influence at each of the individual grasslands but other variables particularly soil acidity at Patalwan, surface slope at Viji and soil moisture at Minimarg were also considerably important and ordinated several species across the grasslands. However, a significant similarity between grasslands, as shown by their CCA ordination diagrams (Fig. 3), relating to their floristic changes is that with increasing disturbance and grazing intensity, species like *Dactylorhiza hatagirea*, *Rheum webbianum* and *Fritillaria roylei* tend to disappear whereas *Rumex nepalensis*, *Impatiens brachycentra* and *Euphorbia wallichii* grow abundantly independent of altitude and separate well from other species assemblages.

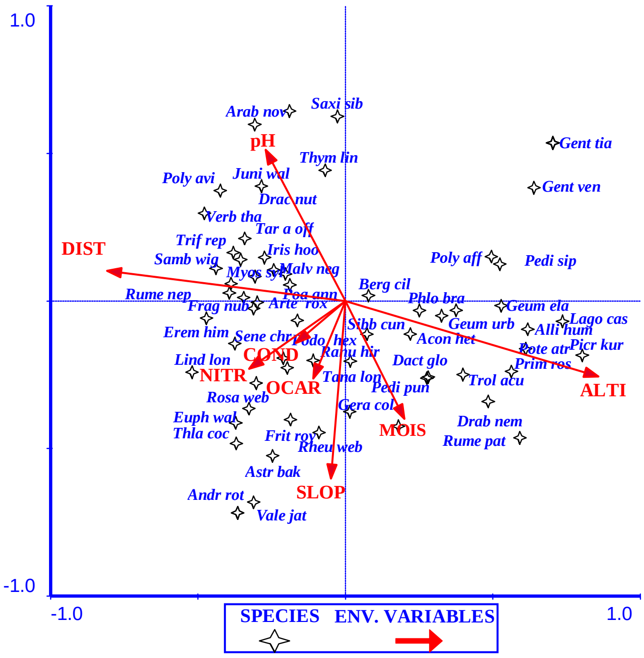

Fig. 2. Canonical correspondence analysis (CCA) displaying relation of species to environmental factors. The first two axes explained 53 % of the total variation in the data set. Species are indicated by abbreviations in appendix table 1.

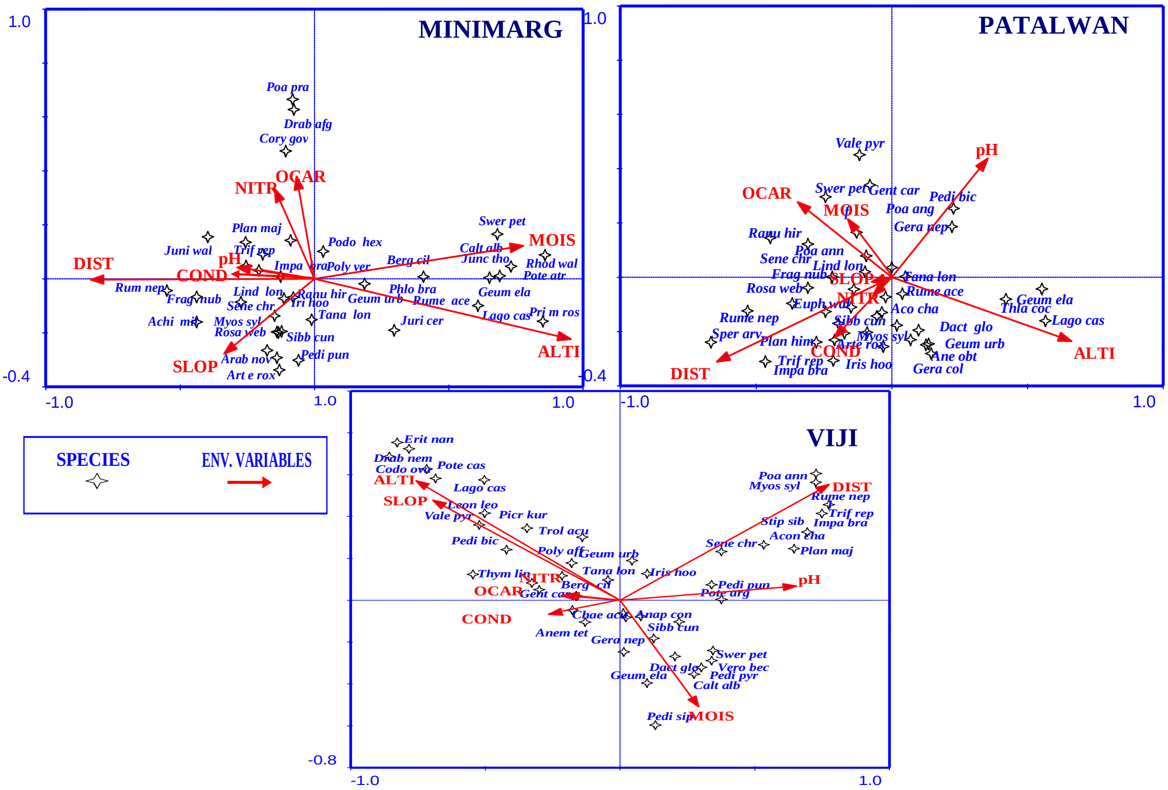

Fig. 3. Canonical correspondence analysis (CCA) displaying relation of species to environmental factors, with axes 1 and 2 explaining 41.1 %, 43.9 %, and 37.9 % of the total variation at Viji, Minimarg and Patalwan respectively. For abbreviations see appendix table 1.

Table 3. Results of canonical correspondence analysis (CCA) with edaphic and environment data at the three grasslands.

CCA	Minimarg		Patalwan		Viji	
	Axis 1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
Eigenvalues	0.705	0.459	0.669	0.495	0.523	0.460
Species-environment correlations	0.996	0.979	0.994	0.997	0.999	0.991
Cumulative percentage variance of species data	20.3	33.4	16.4	28.6	17.9	33.7
Species-environment relation	26.6	43.9	21.7	37.9	21.9	41.1
Sum of all eigenvalues	3.483		4.068		2.922	
Sum of all canonical eigenvalues	2.654		3.075		2.392	

Table 4. Canonical co-efficient and intra-set correlation of environmental variables for the first two axes of CCA of the three surveyed grasslands.

EV	Canonical Co-efficient						Inter-set Correlation					
	Viji		Patalwan		Minimarg		Viji		Patalwan		Minimarg	
	Axis1	Axis 2	Axis 1	Axis 2	Axis1	Axis 2	Axis1	Axis 2	Axis 1	Axis 2	Axis 1	Axis 2
MOIS	-0.159	-0.906	-0.159	0.197	0.247	1.128	0.291	-0.508	-0.161	0.213	0.774	0.119
pH	-0.044	-0.126	0.376	0.378	0.023	-0.146	**0.654**	0.067	0.351	0.436	-0.286	0.041
COND	-0.201	-0.521	-0.195	-0.437	0.037	-0.645	-0.263	-0.067	-0.210	-0.227	-0.192	0.032
SLOP	-0.325	-0.353	**-0.534**	-0.173	-0.208	-0.271	**-0.692**	0.478	-0.474	-0.017	-0.334	-0.272
ALTI	-0.486	**0.524**	**-0.536**	-0.058	**0.588**	**-0.585**	**-0.754**	**0.571**	**0.658**	-0.235	**0.950**	-0.218
NITR	-0.363	0.313	0.402	-0.037	-0.099	0.406	-0.200	0.026	-0.069	-0.068	-0.147	0.326
OCAR	-0.231	0.118	0.415	**0.626**	0.193	-1.502	-0.217	0.023	-0.345	0.275	-0.066	0.371
DIST	0.607	0.657	-0.427	-0.501	-0.325	-0.907	**0.775**	**0.552**	**-0.643**	-0.310	**-0.830**	-0.002

EV= Environmental Variable. Values in bold are significant at 5 % probability level.

Table 5. Correlation coefficients of the measured environmental variables.

MOIS	1							
pH	-0.1515	1						
COND	0.2332	-0.019	1					
ALTI	0.007	-0.0147	0.2323	1				
SLOP	-0.2256	-0.2827	-0.1239	0.2064	1			
NITR	0.3281	-0.0482	0.0891	0.2949	-0.0202	1		
OCAR	0.2168	-0.0623	0.456	0.1400	-0.0849	0.6119	1	
DIST	-0.1984	0.1723	0.2027	-0.4419	-0.5452	0.0391	0.0033	1
	MOIS	pH	COND	ALTI	SLOP	NITR	OCAR	DIST

Discussion

Despite a relatively small geographical area and high livestock grazing pressure, species richness of the study area is fairly high. This high richness could possibly be due to the habitat heterogeneity as well as the geographical proximity of the study area to various phytogeographic zones viz., Central Asian and Irano-Turanian. The present study also resulted in the first report of *Arabis nova*, *Gentiana venusta*, *Primula involucrata* and *Thlaspi cocleariöides* from Gurez valley which reveals that systematic surveys are likely to add many more species that could even be new to the flora of Kashmir.

As with other mountain rangelands, our findings also suggest that various environmental and edaphic factors shape and structure the species distribution of rangelands in Gurez valley, Kashmir. Although a single exclusively dominant gradient could not be differentiated for the study area, the influence of grazing and other anthropogenic disturbances on the overall floristic composition was well supported by a strong correlation along the first two axes of ordination plot, between vegetation distribution and various variables. Of these various variables, altitude explained the major variation in species composition (Table 2). These observations about the relationship between topographical variables such as altitude and slope and floristic composition are in agreement with the results of earlier studies in other mountainous areas (Kikuchi & Miura 1993; Rudmann-Maurer *et al.* 2008). Given the gradient length of altitude in our study area that stretches from 3058 - 4428 meters, its ability to affect several other co-varying environmental variables could also be high. It is because of this ability that altitude has been found to be very important in structuring the species distribution in other regions also (Austin *et al.* 1996).

Anthropogenic disturbance has been reported to be an important factor in determining the vegetation pattern across different ecosystems (Angassa & Oba 2010; Dargie & Demerdash 1991; Gunaga *et al.* 2013) and often more dominating as compared to other climatic effects (Körner 1995). The human induced changes have also been reported as the major reason for changes in vegetation composition of alpine region of Garhwal Himalaya (Nautiyal *et al.* 2004). Our findings also illustrated that anthropogenic disturbance has affected the structural variability of these grasslands, at least at the local scale. This is well evident as disturbance variables had a pronounced effect on species distribution and along the first ordination axis but diagonally opposite to the altitudinal variable ordinated many species (Table 2 & Fig. 2). Consequently, the lower altitude sites subjected to high anthropogenic disturbance differ significantly from other high altitude sites. This could be mainly because disturbances modify the nutritional status of soils and the identity of plants developing in them (Canals & Sebastia 2000). Of the different variables that were used in measuring disturbance, grazing is considered as the most important factor altering the natural processes, affecting species persistence, influencing the structure and composition of plant communities (Olff & Ritchie 1998) besides having an impact on the abiotic components of the ecosystem (Facelli & Springbett 2009). As it has been experimentally shown that overgrazing results in changes in N:P ratio with critical consequences for species interactions in herbaceous communities (Güsswell & Bollens 2003), other possible explanation for high abundance of ruderal species at low elevation and highly disturbed sites could be trampling, phosphorus enrichment and nitrogen availability.

The study also revealed that along an altitudinal gradient, there was a decrease in intensity of livestock grazing which influenced distribution of certain species. Specifically, the lower elevation sites subjected to high grazing were characterised by many ruderal species (*Rumex nepalensis*, *Euphorbia wallichii*), which were extremely rare or absent in low to moderately grazed sites at the same altitude. Species like *Leontopodium leontopodinum*, *Lagotis cashmeriana* and *Picrorhiza kurrooa* that are unlikely to be adapted to these overgrazed and disturbed sites were restricted to higher alpines. These high altitude sites also harbor many other important species such as *Nepeta govaniana* and *Gentiana tianschanica*. The success and survival of plant species is jointly affected by grazing and other disturbance factors. In our study area, a possible explanation of the greater vulnerability of lower altitude sites to these disturbance factors is the higher frequency of human trails and tracks, animal and human resting places and steeper slopes which affect and constrain the overall development of vegetation in these areas. With no prior information on these grasslands we hypothesise that except livestock grazing, many of the disturbance factors are only new to these grasslands. Furthermore, a strong negative correlation (Table 5) between the disturbance and altitude proposes that a major part of this change has occurred in the lower altitudes where the additive or synergistic effects from multiple sources of disturbance may have operated over a period of time.

Vital to the plant growth and vegetation development and spatial distribution of plant resources, the importance of soil nutrients in a region depends on their amount and distribution (Saarsalmi *et al.* 2001). Among the studied soil variables, soil acidity and moisture too had a pronounced effect on species distribution and together exerted a stronger effect on second ordination axis. These findings are consistent with earlier studies that indicate that soil moisture and soil acidity are most important ecological factors explaining species pattern (Hokkanen 2006). In the present study, a high correlation of these factors with CCA axes and explaining a pattern of species may be due to their uneven distribution and greater range in the surveyed grasslands (Table 1). The positive affect of soil acidity was more on distribution of shrubs like *Juniperus indica* and *Thymus linearis* whereas *Caltha alba*, *Poa pratensis*, *Swertia petiolata* and *Pedicularis* *siphonantha* were affected mostly by soil moisture. As evident from their occupying the space opposite to soil moisture, these shrub species mostly grow on drier surfaces and prefer relatively acidic soils. Soil acidity is considered a good indicator of nutritional standing of the soils and has been correlated to strong differences in vegetation (Tilman & Olff 1991). Besides the degradation of organic materials, a possible explanation for the greater effect of the soil acidity on shrub distribution could be the higher urine and dung depositions of grazers at those areas. This is primarily because the combined effect of dung and urine depositions with cattle grazing are known to increase both soil acidity (Johnston *et al.* 1971) and salinity (Chaneton & Lavado 1996). Our results indicated that among the topographic variables along the second ordination axis, slope was also significant. This is consistent with studies conducted on the mountain vegetation in other regions, wherein authors have also found slope to be an important factor in affecting the species distribution (Zhang 2002). It may be that because slope not only affects the accretion and degradation of various nutrients, soil particles and organic matter but it also is vital in influencing evapo-transpiration and soil water conditions.

We suggest that the differences among various variables both with respect to their impact on species distribution as well as the percentage of variability which they explained in the species data at each of the studied grasslands (Fig. 3, Tables 3 & 4), could be due to the widespread micro-scale heterogeneity that shadows differences between variables operating at broader scale. This is particularly important considering that at a broader scale almost similar geo-climatic, use pattern and human interactions prevail across grasslands. Though essentially our findings further support the argument that relative role of different structuring agents depends on the scale considered (Rahel 1990), but despite this scale dependence, the pattern of species variation across the landscape was consistent and species were grouped into categories influenced chiefly by altitude and degree of human disturbance. To summarize, our results highlighted the role of various biotic and abiotic factors in affecting the species assemblages of these grasslands. However, a more elaborated study covering a larger geographic area would be required to provide more detailed insights into the vegetation- environment interrelationships at these high altitudes.

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Appendix Table 1. Species name abbreviations.

Species Name	Abbreviation
Achillea millefolium	*Achi mil*
Aconitum chasmanthum	*Acon cha*
Aconitum heterophyllum	*Acon het*
Allium humile	*Alli hum*
Anaphalis contorta	*Anap con*
Androsace rotundifolia	*Andr rot*
Anemone tetresepala	*Anem tet*
Arabis nova	*Arab nov*
Artemisia roxburghiana	*Arte rox*
Astragalus bakeri	*Astr bak*
Bergenia ciliata	*Berg cil*
Caltha alba	*Calt alb*
Cerastium ceratoides	*Cera cer*
Chaerophyllum acuminatum	*Chae acu*
Codonopsis ovata	*Codo ova*
Corydalis govaniana	*Cory gov*
Dactylis glomerata	*Dact glo*
Draba affghanica	*Drab aff*
Draba nemarosa	*Drab nem*
Dracocephalum nutans	*Drac nut*
Eremurus himalaicus	*Erem him*
Eritrichum nanum	*Erit nan*
Euphorbia wallichii	*Euph wal*
Fragaria nubicola	*Frag nub*
Fritillaria roylei	*Frit roy*
Gentiana carinata	*Gent car*
Gentiana tianschanica	*Gent tia*
Gentiana venusta	*Gent ven*
Geranium collinum	*Gera col*
Geranium nepalensis	*Gera nep*
Geum elatum	*Geum ela*
Geum urbanum	*Geum urb*
Impatiens brachycentra	*Impa bra*
Iris hookeriana	*Iris hoo*
Juncus thomsonii	*Junc tho*
Juniperus indica	*Juni ind*
Juniperus wallichiana	*Juni wal*
Jurinea ceratocarpa	*Juri cer*
Lagotis cashmeriana	*Lago cas*
Leontopodium leontopodinum	*Leon leo*
Lindelofia longiflora	*Lind lon*
Malva neglecta	*Malv neg*
Myosotis sylvatica	*Myos syl*
Pedicularis bicornuta	*Pedi bic*
Pedicularis punctata	*Pedi pun*
Pedicularis siphonantha	*Pedi sip*
Phlomis bracteosa	*Phlo bra*
Picrorhiza kurrooa	*Picr kur*
Plantago himaliaca	*Plan him*
Plantago major	*Plan maj*
Poa annua	*Poa ann*
Poa pratensis	*Poa pra*
Podophyllum hexandrum	*Podo hex*
Polygonatum verticillatum	*Poly ver*
Polygonum affine	*Poly aff*
Polygonum aviculare	*Poly avi*
Potentilla argyrophylla	*Pote arg*
Potentilla atrosanguinea	*Pote atr*
Potentilla cashmeriana	*Pote cas*
Primula rosea	*Prim ros*
Ranunculus hirtellus	*Ranu hir*
Rheum webbianum	*Rheu web*
Rhodiola wallichiana	*Rhod wal*
Rosa webbiana	*Rosa web*
Rumex acetosa	*Rume ace*
Rumex nepalensis	*Rume nep*
Rumex patientia	*Rume pat*
Sambucus wightiana	*Samb wig*
Saxifraga sibirica	*Saxi sib*
Senecio chrysanthemoides	*Sene chr*
Sibbaldia cuneata	*Sibb cun*
Spergula arvensis	*Sper arv*
Stipa sibirica	*Stip sib*
Swertia petiolata	*Swer pet*
Tanaceteum longifolium	*Tana lon*
Taraxicum officinale	*Tara off*
Thlaspi coclearioides	*Thla coc*
Thymus linearis	*Thym lin*
Trifolium repens	*Trif rep*
Trollius acaulis	*Trol aca*
Valeriana jatamansi	*Vale jat*
Valeriana pyrolifolia	*Vale pyr*
Verbascum thapsus	*Verb tha*
Veronica beccabunga	*Vero bac*