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Species Diversity, Community Structure, and Distribution Patterns in Western Himalayan Alpine Pastures of Kashmir, Pakistan

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Western Himalayan alpine pastures are among the most diverse ecological locations on the globe. Four alpine pastures were investigated to study species distribution patterns, richness, similarity, and community structure in Bagh District,

Azad Kashmir, Pakistan. Four communities, *Poa*–*Primula*–*Sibbaldia*, *Primula*–*Caltha*–*Primula*, *Poa alpina*–*Poa pratensis*–*Scirpus*, and *Sibbaldia*–*Poa*–*Scirpus*, were identified on the basis of an importance value index. The average value of species richness was 1.42; Simpson's and Shannon–Wiener's diversity values were 3.13 and 0.91, respectively; the degree of maturity index was 44.1; and species evenness was 0.901. Local alpine flora was

dominated by a hemicryptophytic life form with microphyllous leaf spectra. The species–environment correlation was analyzed using canonical correspondence analysis. A negative correlation of both diversity and richness was revealed with altitudinal gradient. Anthropogenic disturbances showed a significant negative impact on distribution of medicinal and palatable species. Unpalatable species dominated the local flora, indicating the heavy grazing pressure in the area. Development and implementation of regional conservation strategies are recommended to protect the threatened Himalayan alpine biodiversity.

Keywords: Altitudinal gradient; canonical correspondence analysis (CCA); community evenness; grazing pressure; species richness; Pakistan.

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Introduction

The Himalayas constitute one of the richest and most unusual ecosystems on Earth (Salick et al 2009). Himalayan alpine vegetation communities retain high ecological significance, because they control the soil stability of their catchment areas, play a major role in ecosystem functioning, and are vital in cultural, ethical and aesthetic aspects (Stirling and Wilsey 2001). The alpine is characterized by low productivity, high intensity of solar radiation, and high degree of resource seasonality because of high ultraviolet (UV) radiation, high wind velocity, blizzards, low temperature, and snowstorms (Nautiyal et al 2004). The vegetation of this fragile zone is adapted to the extreme conditions occurring with sparse populations; is generally dwarfed, stunted, or spiny; and develops a mosaic patch of different forms. Alpines possess an early growth initiation with a short vegetative span ranging from several days to a few months (Tasser and Tappeiner 2002). The community usually exhibits seasonal fluctuations, and its structure and composition are strongly influenced by the extent to which periodic phenomena in the individuals are adjusted to one another (Kershaw 1973).

A linear relationship exists between vegetation attributes such as species richness, diversity, and maturity values and ecological factors such as altitude, aspect, and distance of the site from disturbance stimuli (Schuster and Diekmann 2005). Indigenous flora has a direct relationship with the regional altitude, and it has been studied since the early 19th century (Mani 1978). Species richness is currently the most widely used, simplest, and most easily interpretable indicator of biological diversity determined by a complex of environmental factors (Whittaker 1977; Shrestha and Jha 2009). Numerous studies have examined the relationships among plant species richness, climate, and spatial variables in the area (Nautiyal et al 2001; Kala and Mathur 2002; Panthi et al 2007). Results showed the inverse correlation between altitude and species richness in Himalayan alpine, indicating that for every 100-m increase in altitude, there is a loss of 35–45 species (SCBD 2003). Moisture is also one of the important determinants of species richness and composition (Vetaas 2000).

Himalayan pastures have been grazed intensely for centuries (Miller 1999). They are an important forage resource for local livestock and are grazed from March–April to September–October. Malik (1988) reported that

TABLE 1 Area, altitude, and coordinates of the studied alpine sites.

Site name	Area (ha)	Altitudinal range (masl)	Longitude	Latitude
Sankh	6.0	3100–3500	33°59'21.64"N	73°56'48.27"E
Garang Plani	4.5	2800–3200	34°00'26.46"N	73°56'16.10"E
Pirkanthi	5.0	2800–3100	34°00'55.65"N	73°54'17.87"E
Ganga	5.0	2600–2900	34°04'36.60"N	73°46'46.98"E

available grazing area in subalpine and alpine pastures of Kashmir decreased from 0.15 ha/animal in 1977 to 0.10 ha/animal in 1982 (Misri 2003) and continued to decrease thereafter (Qureshi et al 2007). It is recommended by vegetation scientists that grazing practices in these fragile alpine communities above 2000 m should be limited and controlled and that they should be carried out in late summer after the full vegetation growth (Altesor et al 2005). But in Kashmir pastures, grazing activities start soon after the snow melts, in early growing season, and continue until it again starts snowing (Gupta 1978). The degraded vegetation is further not able to repair itself because of harsh climatic conditions and a short growing period.

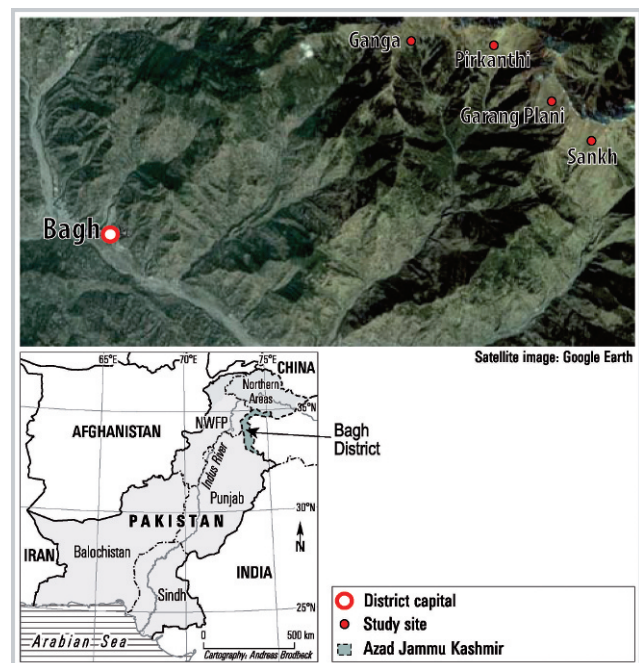
In the western Himalayan mountains, vegetation dynamics have been neglected by researchers because of their remoteness, inaccessibility, danger, and lack of local infrastructure. The community structure and distribution patterns are poorly understood, because they have not been given due attention by plant ecologists to date (Peer et al 2007). The present study made an integrated effort to analyze and discuss ecological community attributes, as well as their correlation with environmental and anthropogenic variables, using multivariate analyses. Objectives also include the evaluation of Raunkier's spectra with the quantitative vegetation data, that is, importance value index (IVI) values, being an index of all quantitative parameters used in studying vegetation dynamics.

Study area

Bagh District lies in the western Himalayas and has subtropical to moist temperate vegetation (Anonymous 2007). Four pastures, Sankh, Garang Plani, Pirkanthi, and Ganga, were selected for the study (Table 1). The study sites are located at the line of control between India and Pakistan in the Pir Panjal subrange of the Himalayas. Sankh faces southeast; Garang Plani, northeast; Pirkanthi faces north; and Ganga, northwest (Figure 1). Summers are cool, with average temperatures from 9 to 12°C, whereas winters are severe and always below freezing down to −10°C (Anonymous 2009). The area studied remains under snow cover from November to March. Locals, nomads, and shepherds use the area as their summer pastures from April to August.

Methodology

Field expeditions were made to the selected pastures from April–August 2008 and 2009. A random sampling technique was used to study and analyze the vegetation dynamics, as well as to collect the primary data for statistical analyses. Quadrates were laid in selected sites that had the best representation of floral biodiversity and geographic extent of the area. Sites were selected according to the altitude, topography, slope, and moisture to get an accurate image of whole-area vegetation. Vegetation attributes, including frequency, density, cover, and richness, were recorded, along with environmental coordinates such as latitude, longitude, altitude, and slope, using a global positioning system (Garmin model 2000). Plants from the isolated vegetation patches were also collected to record the maximum number of species and their distribution patterns. A total of 120 quadrates, 1

FIGURE 1 Location of the study area and satellite image of the studied alpine in the western Himalayas, Kashmir, Pakistan. (Location map by Andreas Brodbeck, modified by Mountain Research and Development; location of study sites by Hamayun Shaheen)

× 1 m each, (30 at each of 4 sites) were taken to record general vegetation attributes.

The index of diversity was calculated after Simpson (1948) and Shannon and Wiener (1949). Simpson's index of diversity gives the probability that two individuals selected at random will belong to the same species. It is calculated as

$$D = 1 - \frac{N(N-1)}{\sum n(n-1)},$$

where D is the diversity index, n is the number of individuals of a particular species, and N is the number of individual of all species. Shannon index is "a measure of the average degree of uncertainty in predicting what species an individual chosen at random from a sample will belong to" (Shannon 1948). If p_i is the proportion of individuals (from the sample total) of species i , then diversity (H') is

$$H' = - \sum_{i=1}^S p_i \ln p_i.$$

Species evenness was calculated using the Shannon evenness index: $J' = H' / \ln(S)$, where H' is the Shannon-Wiener diversity index and S is the number of species (Pielou 1975). The Shannon evenness index ranges from 0 (when one species is dominant) to 1 (when all species are equally abundant).

Species richness was calculated after Menhinick (1964) as

$$d = \frac{S}{\sqrt{N}},$$

where d is species richness, S is the total number of species in a community, and N is the total number of individuals of all species in a community. The maturity index was recorded after Pichi-Sermolli's method (1948). Maturity is a dynamic concept and is related to structural complexity and organization (Margalef 1968).

$$\text{Degree of maturity} = \frac{\text{Frequency of all species in a stand}}{\text{Total no. of all species}}$$

The index of similarity was calculated after Sorensen (1948) by using importance values. Sorensen's test is used to measure the ecological similarities and differences among the compared vegetation communities based on their presence or absence and associations. The lowest values in two communities were considered for comparison.

$$IS_s = \frac{2C}{A+B} \times 100$$

where C is the total importance value for all species common in two communities, A is the total importance value in community A, B is the total importance value in community B, and IS_s is the Sorensen index, with the index of dissimilarity = $100 - IS_s$. Leaf spectra and life form

classification was carried out according to Raunkier (1956) to determine the biological spectrum of local alpine flora.

Data about medicinally important plant species were acquired by direct interviews with 97 locals. Respondents consisted of 15% of the total population and were selected randomly from all 4 study sites. Village elders, especially women, were preferred because of their strong and continuous relation with medicinal plants.

CCA was used to determine and analyze the relationship between species composition and underlying environmental and anthropogenic factors, including altitude, slope, grazing intensity, and distance from settlements. Mostly, it was observed that a single or a few environmental gradients acted as limiting factors and constructed the whole structure of species distribution pattern (Zahran et al 1990; Ter Braak 1987). CCA is simpler and more efficient than orthodox statistical analyses, requiring much less linear data and giving precise species-environment correlation (Jongman et al 1987). The identified vegetation communities characterized by the phytosociological attributes (Table 2) were compared to get a precise picture of overall vegetation dynamics of the area.

Results

A total of 69 plant species belonging to 28 families were recorded from the area. Predominant plant families in the area included Asteraceae with 10 species, followed by Polygonaceae, Ranunculaceae, Labiateae, Rosaceae, and Poaceae with 5 species each. The biological spectrum of the local alpine flora revealed the dominance of a hemicryptophytic life form (40%) with microphyllous leaf spectra (Figure 2).

Poa-Primula-Sibbaldia community (Pirkanthi site)

The *Poa-Primula-Sibbaldia* community persisted on northern slopes with altitudes of 2700–3100 m. *Poa alpina* was the most dominant species, with an IVI value of 33.04, followed by *Primula denticulata* (24.85) and *Sibbaldia cunneata* (23.02). The other codominant species were *Scirpus* spp (19.75), *Primula macrophylla* (15.79), and *Artemisia vulgare* (14.41). The total number of species recorded was 41. Diversity values according to the Simpson and Shannon-Wiener indices were 0.91 and 3.25, respectively. The species richness value was 1.82, and the species maturity index was measured at 42.37. Species evenness was 0.876 (Tables 2 and S1, *Supplemental data*; <http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00091.S1>).

Primula-Caltha-P. macrophylla community (Sankh site)

The *Primula-Caltha-P. macrophylla* community was established on southeastern slopes with an altitude of 3500 m. *P. denticulata* was the leading species, with an IVI value of 34.04, followed by *Caltha alba* (29.44) and *P. macrophylla* (24.93). The other codominant species were

TABLE 2 Ecological attributes of alpine communities at the studied sites.

Site name	Community name	Distance from nearest settlement (km)	Species diversity		Species richness (S)	Maturity index values	Species evenness (E)
			Simpson	Shannon–Wiener			
Ganga	Sc–Pa–S	2.0	0.88	3.04	1.03	41.38	0.869
Garang Plani	Pa–Ps–S	10.0	0.92	3.33	1.28	47.65	0.961
Sankh	Pd–Ca–Pm	9.0	0.93	2.89	1.53	45.00	0.898
Pirkanthi	Pa–Pd–Sc	9.0	0.91	3.25	1.82	42.37	0.876
Average		7.5	0.91	3.13	1.42	44.10	0.901

Sc, *Sibbaldia cunneata*; Pa, *Poa alpina*; S, *Scirpus* spp; Ps, *Poa stewartii*; Pd, *Primula denticulata*; Ca, *Caltha alba*; Pm, *Primula macrophylla*.

Geranium wallichianum (16.46), *Geum elatum* (12.89), and *A. vulgare* (11.59). The total number of species recorded was 25. Diversity values according to the Simpson and Shannon–Wiener indices were 0.93 and 2.89, respectively (Tables 2 and S1, *Supplemental data*; <http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00091.S1>). The species richness value was 1.53, and the species maturity index was measured at 45. Species evenness was 0.898.

***P. alpina*–*Poa stewartii*–*Scirpus* community (Garang Plani site)**

The *P. alpina*–*P. stewartii*–*Scirpus* community occurred on northeastern slopes with altitudes of 3290 m. *P. alpina* was the most dominant species, with an IVI value of 27.28, *P. stewartii* (24.04) being the second and *Scirpus* spp (19.89) the third. Other codominant species at this site included *S. cunneata* (18.27), *P. denticulata* (13.94), and *Fritillaria roylei* (13.27). The total number of species recorded was 32. Diversity values according to the Simpson and Shannon–Wiener indices were 0.92 and 3.33, respectively. The species richness value was 1.28, and the species maturity index was measured at 47.65. Species evenness was 0.961 (Tables 2 and S1, *Supplemental data*; <http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00091.S1>).

***Sibbaldia*–*Poa*–*Scirpus* community (Ganga site)**

The *Sibbaldia*–*Poa*–*Scirpus* community was found on northwestern slopes with altitudes of 2900 m. *S. cunneata* was the most dominant species, with an IVI of 41.03, followed by *P. alpina* (34.32) and *Scirpus* spp (28.13). The codominant species included *P. stewartii* (22.57), *Gnaphalium affine* (20.51) and *Prunella vulgaris* (13.57). The total number of species recorded was 33. Diversity values according to the Simpson and Shannon–Wiener indices were 0.88 and 3.04, respectively. The species richness value was 1.03, and the species maturity index was measured at 41.38. Species evenness was 0.869 (Tables 2 and S1, *Supplemental data*; <http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00091.S1>).

The IVI is the most precise measure of species attributes that we could achieve in this study. On

comparing average IVIs for all species from the 4 study sites, we found that *S. cunneata* was the most dominant species, with an average IVI of 28.98 represented at all 4 sites. It was followed by *P. alpina* (23.66) at 3 sites and *P. denticulata* (17.8) at 4 sites.

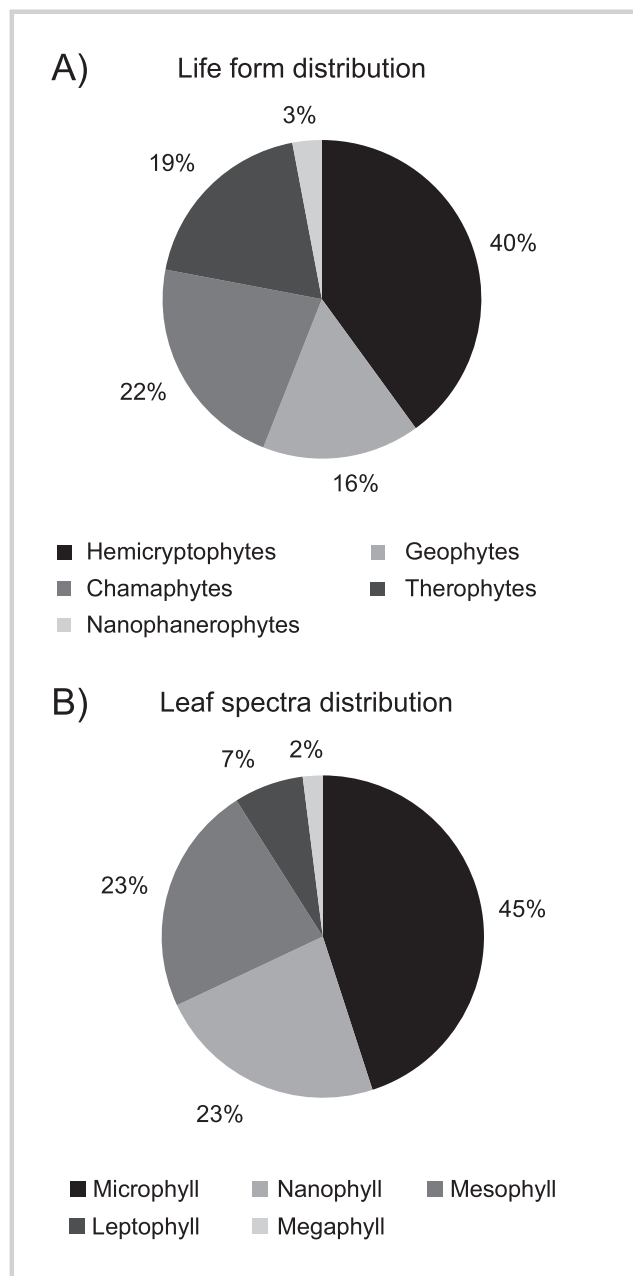
Medicinally important herbs distributed in studied alpine

Respondents mentioned that 46 herb species were medicinally important and were regularly collected and used by the local communities. A large proportion (69%) of the respondents were involved in the use of medicinal plants for health problems. Some highly valued medicinal herbs included *Arisaema jacquemontii* Blume, *Achillea millefolium* L, *Artemisia vulgaris* L, *Bergenia ciliata* (Haw) Sternb, *Bistorta affinis* D Don, *C. alba* Jacq ex Com, *Corydalis gowaniana* Wall, *F. roylei* Hook f, *G. wallichianum* D Don ex Sweet, *Gerbera gossypina* Royle, *Nepeta erecta* (Bth) Bth, *Onopordum acanthium* L, *Pimpinella diversifolia* DC, *Plantago major* L, *P. macrophylla* D Don, *Rumex hastatus* D Don, *Rumex nepalensis* Spreng, *Taraxacum officinale* Weber, *Thymus linearis* Benth, *Valeriana pyrolifera* Medik, *Valeriana jatamansii* Jones, and *Viola canescens* Wall ex Roxb. These important medicinal herbs were distributed throughout the study area. Various ailments treated by ethnomedicinal remedies were fevers, cough, cold, asthma, rheumatism, stomach disorders, parasitic worms, kidney stones, and body weaknesses.

Canonical correspondence analysis

Canonical correspondence analysis (CCA) results showed a total inertia of 0.938. The first axis alone explained 54.3% of total unexplained variance. Taken together, the first and second axes of the data set explained 80% of total inertia, indicating a high species–environment correlation. The altitude, slope, erosion, and distance from settlements all showed strong positive correlation with the first CCA axis, whereas grazing intensity showed strong correlation along the second CCA axis. Although all environmental variables showed great strength, the most influential limiting factor was altitude. The three relatively lower sites, Ganga, Garang, and Pirkanthi, and their respective vegetation are clustered

FIGURE 2 Percentage of weight of life form (A) and leaf spectra (B) classes of alpine vegetation in the study area.



to the left of the CCA plot, clearly separated from the highest and unique Sankh site (Figure 3). The lower site's vegetation cluster is dominated by alpine grasses, including *P. alpina*, *Scirpus* spp, *P. vulgaris*, and *S. cuneata*. These dominant unpalatable species showed a strong affiliation with grazing intensity, because the lower sites experienced more grazing pressure. The higher elevation cluster comprises rare and threatened herbs, including *P. denticulata*, *P. macrophylla*, *Tussilago farfara*, *Cichorium intybus*, *B. affinis*, and *B. ciliata*, restricted to most remote, isolated and protected habitat. The results of Sorensen's test showing

the striking dissimilarity of the Sankh site to others also support the segregation of its community from the rest.

Discussion

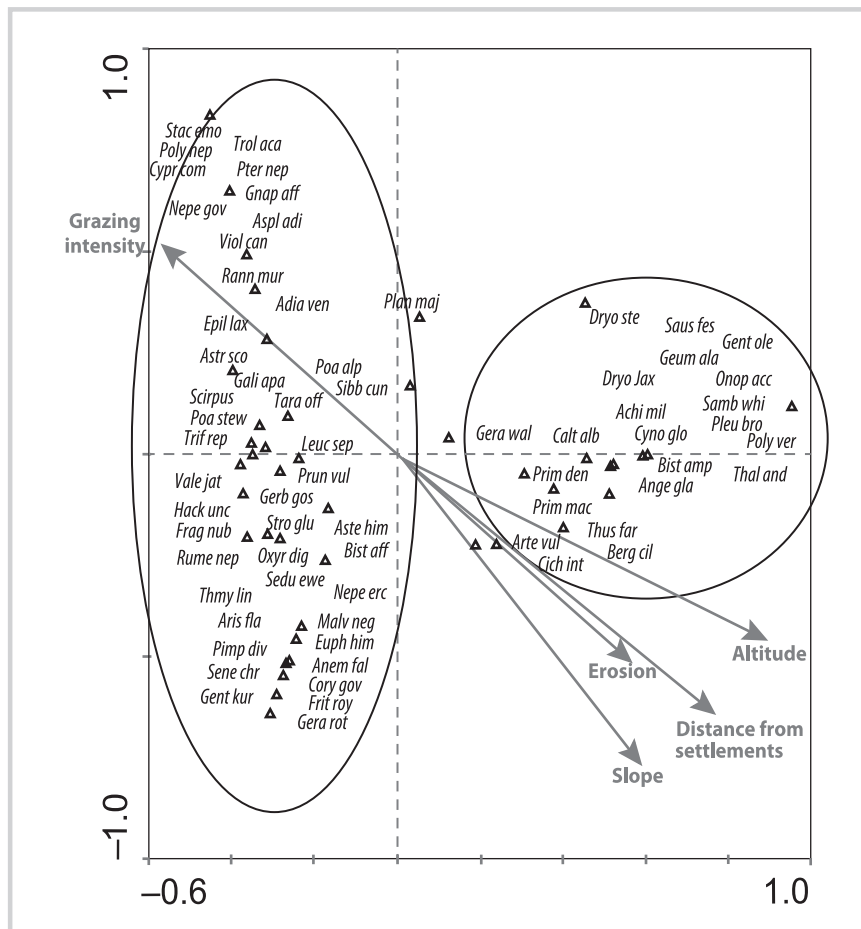
The average species diversity of 3.13 recorded in the present study is comparable to the results of similar investigations in different Himalayan regions: 1.53–2.88 in the western Himalayas (Samant et al 1998; Guar and Joshi 2006), 2.39–4.63 in the Gharwal Himalayas (Nautiyal and Guar 1999), and 2.5–3.10 in the trans-Himalayan alpine of Nepal (Panthi et al 2007). The overall dominance of a few alpine grasses and herbs, including *P. alpina*, *S. cuneata*, *P. stewartii*, *P. denticulata*, and *P. vulgaris*, indicates their broad ecological amplitude (Ge et al 2005). Although the 3 lower pastures showed an overall similarity because of their similar geoclimatic conditions and human interactions, little variation in diversity and richness was observed that can be attributed to the seasonal live stock movements (Bhattarai et al 2004). The similarity in species composition and community structure differed with increasing distance among sites, indicating high beta diversity in the area (Table 3).

A negative correlation between altitude and vegetation attributes, including species diversity, richness, and community maturity, was observed in the area. The highest Sankh site exhibited patchy and isolated vegetation distribution with little species overlap, also evidenced by the clear separation along the CCA first axis.

Grazing activity was prevalent throughout the study area, with clear impacts on vegetation structure evidenced by the dominance of rosette herbaceous flora. The dominance of unpalatable species such as *Primula*, *Poa*, and *Sibbaldia* indicates the high grazing pressure in the alpine pastures. Medicinally important rare herbs were observed to be confined to remote and isolated places in the pastures. According to the local elders, the medicinally important plants previously enjoyed abundant distribution in the alpine, but because of overgrazing and overharvesting, their distribution and abundance has been reduced. Unsustainable anthropogenic activities are posing a serious threat to these precious plant resources (Mayer et al 2009).

The studied vegetation communities were characterized by a high degree of species evenness (ie 0.901), indicating that individual species exhibit uniform distribution. Fewer numbers of species in each community decreases interspecific competition, which results in a high degree of species evenness. All communities exhibited low maturity index values (Table 2), which indicated disturbed and heterogeneous community structure (Tiessen and Wu 2002). The high intensity of anthropogenic disturbances and harsh climatic conditions regularly disturb the natural balance of fragile alpine vegetation communities during the short growing season, thus preventing them from reaching a climax stage of community maturity (Saxena and Singh 1982).

FIGURE 3 CCA biplot showing species distribution along environmental and biotic gradients, including grazing intensity, slope, altitude, and distance from settlements. Full names of plants are available in Supplemental data, Table S1 (<http://dx.doi.org/10.1659/MRD-JOURNAL-D-10-00091.S1>).



Conclusion

The community attributes, including species richness, evenness, diversity, and maturity, responded significantly to environmental, as well as anthropogenic, stimuli. Anthropogenic and biotic disturbances such as uncontrolled heavy seasonal grazing, trampling, and harvesting of medicinal plants were identified as the potential threats causing degradation and retrogression of

pastures and affecting the natural diversity and community structure of this fragile alpine biome. There is a need to control the degradation and disturbance processes deteriorating the community structure and plant biodiversity of the western Himalayan alpine. However, this requires a detailed socioeconomic study in the area, which is beyond the scope of the present study. Development and implementation of regional conservation strategies are necessary to protect Himalayan alpine biodiversity.

TABLE 3 Sorensen's similarity and dissimilarity values for the alpine sites.

Sites	Dissimilarity values			
	Pirkanthi	Ganga	Garang Plani	Sankh
Pirkanthi	—	45.15	40.12	67.60
Ganga	54.84	—	45.35	87.88
Garang Plani	59.84	54.64	—	72.90
Sankh	32.39	12.21	27.30	—
Similarity values				

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REFERENCES

- Altesor A, Oesterheld M, Leoni E, Lezama F, Rodriguez C.** 2005. Effect of grazing on community structure and productivity of a Uruguayan grassland. *Plant Ecology* 179:83–91.
- [Anonymous].** 2007. *AJK at a Glance*. Muzaffarabad, Pakistan: Planning & Development Department, Government of Azad Jammu and Kashmir.
- [Anonymous].** 2009. *The Normals of Climatic Data of Azad Jammu & Kashmir*. Islamabad, Pakistan: Pakistan Meteorological Department.
- Bhattarai KR, Vetaas OR, Grytnes JA.** 2004. Relationship between plant species richness and biomass in arid sub-alpine grassland of the central Himalayas, Nepal. *Folia Geobotanica* 39:57–71.
- Guar RS, Joshi BD.** 2006. Some medicinal flora in the riparian zone of river Ganga at Saptrishi, Haridwar, Uttarakhand. *Himalayan Journal of Environment and Zoology* 20(2):237–241.
- Ge XJ, Zhang LB, Yuan YM, Hao G, Chiang TY.** 2005. Strong genetic differentiation of the East-Himalayan *Megacodon stylophorus* (Gentianaceae) detected by inter-simple sequence repeats (ISSR). *Biodiversity and Conservation* 14:849–861.
- Gupta RK.** 1978. Impact of human influences on the vegetation of the western Himalaya. *Vegetatio* 37(2):111–118.
- Jongman RHG, Ter Braak CJF, Van Tongeren OFR, editors.** 1987. *Data Analysis in Community and Landscape Ecology*. Wageningen, The Netherlands: Centre for Agricultural Publishing and Documentation.
- Kala CP, Mathur V.** 2002. Patterns of plant species distribution in the trans-Himalayan region of Ladakh, India. *Journal of Vegetation Science* 13:751–754.
- Kershaw RA.** 1973. *Quantitative and Dynamic Plant Ecology*. London, United Kingdom: Edward Arnold.
- Malik AY.** 1988. Feed availability, requirements for animals and current pattern of utilization in Pakistan. In: Devendra C, editor. *Non-conventional Feed Resources and Fibrous Agricultural Residues, Strategies for Expanded Utilization*. Jodhpur, India: International Development Research Centre, Indian Council of Agricultural Research.
- Mani MS.** 1978. *Ecology and Phytogeography of the High Altitude Plants of the Northwest Himalaya*. New Delhi, India: Oxford & IBH.
- Margalef R.** 1968. *Perspectives in Ecological Theory*. Chicago, IL: University of Chicago Press.
- Mayer R, Kaufmann R, Vorhauser K, Erschbamer B.** 2009. Effects of grazing exclusion on species composition in high-altitude grasslands of the Central Alps. *Basic and Applied Ecology* 10(5):447–455.
- Menhinick EF.** 1964. A Comparison of some species diversity indices applied to samples of field insects. *Ecology* 45:859–861.
- Miller DJ.** 1999. Herders of forty centuries: Nomads of Tibetan rangelands in western China. In: Eldridge D, Freudenberger D, editors. *People and Rangelands: Building the Future*. International Rangeland Congress Proceedings 6. Townsville, Australia: [no publisher], pp 402–403. <http://www.rangelandcongress.com/VI%20Proceedings/AAH-WELCOME.pdf>; accessed on 11 April 2011.
- Misri B.** 2003. *Improvement of Sub-alpine and Alpine Himalayan Pastures*. Palampur, India: Research Centre, Indian Grassland and Fodder Research Institute, HPKV Campus.
- Nautiyal DC, Gaur RD.** 1999. Structural attributes and productivity potential of an alpine pasture of Garhwal Himalaya. *Journal of the Indian Botanical Society* 78(3–4):321–329.
- Nautiyal MC, Nautiyal BP, Prakash V.** 2001. Phenology and growth form distribution in an alpine pasture at Tungnath, Garhwal, Himalaya. *Mountain Research and Development* 21(2):168–174.
- Nautiyal MC, Nautiyal BP, Prakash V.** 2004. Effect of grazing and climatic changes on alpine vegetation of Tungnath, Garhwal Himalaya, India. *Environmentalist* 24:125–134.
- Panthi MP, Chaudhary RP, Vetaas OR.** 2007. Plant species richness and composition in a trans-Himalayan inner valley of Manang district, central Nepal. *Himalayan Journal of Sciences* 4(6):57–64.
- Peer T, Gruber JP, Millingard A, Hussain F.** 2007. Phytosociology, structure and diversity of the steppes vegetation in the mountains of Northern Pakistan. *Phytocoenologia* 37:1–65.
- Pichi-Sermolli RE.** 1948. An index for establishing the degree of maturity in plant communities. *Journal of Ecology* 36(1):85–90.
- Pielou EC.** 1975. *Ecological Diversity*. New York, NY: Wiley.
- Qureshi RA, Ghufuran MA, Gilani SA, Sultana K, Ashraf M.** 2007. Ethnobotanical studies of selected medicinal plants of Sudhan Gali and Ganga Chotti hills, district Bagh, Azad Kashmir. *Pakistan Journal of Botany* 39(7):2275–2283.
- Raunkier C.** 1956. *The Life Form of Plants and Statistical Plant Geography*. Oxford, United Kingdom: Clarendon Press.
- Salick J, Zhendong F, Byg A.** 2009. Eastern Himalayan alpine plant ecology, Tibetan ethnobotany, and climate change. *Global Environmental Change* 19:147–155.
- Samant SS, Dhar U, Rawal RS.** 1998. Biodiversity status of a protected area in West Himalaya: Askot Wildlife Sanctuary. *International Journal of Sustainable Development and World Ecology* 5:194–203.
- Saxena AK, Singh JS.** 1982. A phytosociological analysis of woody species in forest communities of a part of Kumaun Himalaya. *Vegetatio* 50:3–22.
- SCBD [Secretariat of the Convention on Biological Diversity].** 2003. *Status and Trends of, and Threats to, Mountain Biodiversity, Marine, Coastal and Inland Water Ecosystems*. Subsidiary Body on Scientific, Technical and Technological Advice of the Convention on Biological Diversity. Meeting 8. Abstracts of poster presentations. CBD Technical Series 8. Montreal, Canada: SCBD. <http://www.cbd.int/doc/publications/cbd-ts-08.pdf>; accessed on 11 April 2011.
- Schuster B, Diekmann M.** 2005. Species richness and environmental correlates in deciduous forests of northwest Germany. *Forest Ecology and Management* 206:197–205.
- Shannon CE.** 1948. A mathematical theory of communication. *Bell System Technical Journal* 27:379–423, 623–656.
- Shannon CE, Wiener W.** 1949. *The Mathematical Theory of Communication*. Urbana, IL: University of Illinois Press.
- Shrestha BB, Jha PK.** 2009. Habitat range of two alpine medicinal plants in a trans-Himalayan dry valley, central Nepal. *Journal of Mountain Science* 6:66–77.
- Simpson EH.** 1948. Measurement of diversity. *Nature* 163:688–689. <http://dx.doi.org/10.1038/163688a0>.
- Sorensen TA.** 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. *Kongelige Danske Videnskabskabernes Selskabs Biologiske Skrifter* 5(4):1–34.
- Stirling G, Wilsey B.** 2001. Empirical relationships between species richness, evenness, and proportional diversity. *American Naturalist* 158(3):286–299.
- Tasser E, Tappeiner U.** 2002. Impact of land use changes on mountain vegetation. *Applied Vegetation Science* 5(2):173–184.
- Ter Braak CJF.** 1987. The analysis of vegetation–environment relationship by canonical correspondence analysis. *Vegetatio* 69:69–77.
- Tiessen H, Wu R.** 2002. Effect of land use on soil degradation in alpine grassland soil, China. *Soil Science Society of America Journal* 66:1648–1655.
- Vetaas OR.** 2000. Comparing species temperature response curves: Population density versus second-hand data. *Journal of Vegetation Science* 11:659–666.
- Whittaker RH.** 1977. Evolution of species diversity in land plant communities. *Evolutionary Biology* 10:1–67.
- Zahran MA, El-Demerdash MA, Mashaly IA.** 1990. Vegetation types of the Deltaic Mediterranean coast of Egypt and their environment. *Journal of Vegetation Science* 1:305–310.

Supplemental data

TABLE S1 Importance value index (IVI) values, leaf spectra, and life form data of alpine species at the 4 studied sites.

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