Spatial patterns and diversity of alpine vegetation across Langer–Shandur Valley, Hindukush Himalayas

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While study of regional diversity and spatial distribution of species bears great relevance for conservation and management, Hindukush Himalayan (HKH) alpine zone lacks such information. The present study, through a rapid quantitative assessment of regional flora along Kukush Lake in Langar–Shandoor Valley, provides a better scientific understanding of diversity and distribution of alpine vegetation. Vegetation data were collected from eight sites using stratified random sampling. A total of 51 species (28 plant families) were recorded with an average species richness in the area of 2.14; Simpson's diversity, 0.75; evenness, 0.79 and average degree of community maturity index of 44%. Detrended correspondence analysis (DCA), regression analyses and factor analyses were used to identify vegetation associations. DCA clearly separated the associations along the first two axes. Altitude and moisture contents appeared to be key environmental factors governing the diversity and distribution of alpine vegetation. A negative correlation of altitude with diversity and richness was revealed. Vegetation exhibited significant variations in the diversity and distribution along the sampled sites. These variations may be attributed to the prevalent anthropogenic and livestock disturbances. The implications of the results have been discussed to highlight the conservation needs for protection of endemic floral elements in HKH alpine region.

Keywords: Alpine vegetation, conservation management, detrended correspondence analysis, diversity and distribution.

THE Hindukush Himalayan (HKH) region constitutes one of the unique and richest biodiversity hotspots in the world, spreading over 3000 km across South Asia[1,2]. The region represents 4 global biodiversity hotspots and 60 ecoregions with as many as 12 ecoregions, in the global top 200 ecoregions[3,4]. Nearly 80% of the western Himalayan endemic plants are found in HKH, including important endemic taxa like *Rhododendron*, *Rhodiola*, *Delphinium*, *Ranunculus*, *Aconitum*, *Fritillaria*, *Primula* and *Saussurea*[5–7].

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The Himalayas have a unique and diverse topography resulting in numerous microhabitats which support diverse floristic elements to flourish. As such, high Himalayan mountain ecosystems are governed by a mosaic of climatic and edaphic factors[8]. These along with other environmental factors such as altitude, aspect, slope, precipitation and intensity of anthropogenic disturbances directly influence vegetation attributes like diversity, richness, evenness and maturity[9,10].

The HKH alpine zone vegetation plays a vital role in ecosystem functioning, soil stabilization, livestock fodder availability and aesthetics[11]. The plant communities in the alpine region are fragile due to harsh climatic factors, including wind velocity, freezing temperatures, resource seasonality, limited growing season, blizzards and snow[12]. Vegetation in this zone appears as sparse, rosette, cushion-shaped, stunted populations in mosaic pattern showing seasonal fluctuations as an adaptation to alpine climate[13,14]. The endemism in the Himalayas follows a specific pattern of increase with altitude. However, an inverse relationship of species diversity with altitude has been reported[6], and this decrease is attributed to temperature and climatic variables[15].

The alpine flora in HKH is considered a conservation priority due to high levels of species richness, endemism, unique species composition and intense anthropogenic pressure[16]. However, conservation efforts in HKH are largely confined to forest zones[17]. Therefore, towards developing regional conservation policies for the fragile endemic flora of HKH, it is critical to understand diversity and distribution pattern of alpine flora across the region[18]. The socio-political transformations in these areas, which involve intense grazing practices, increased medicinal plant harvesting, changing land-use patterns and enhanced tourism activities, have resulted in severe degradation of the HKH alpine flora[19]. In this context, it is important to understand the diversity and composition of alpine flora in order to establish and prioritize conservation goals[20]. Realizing this need, the present study was carried out to collect information on diversity and distribution of regional alpine flora following a rapid quantitative survey. The specific objectives include: (i) determining species composition and richness; (ii) investigating relationship of phytodiversity patterns with key environmental variables, and (iii) assessing ecological stability and health of the fragile alpine ecosystem facing several natural as well as anthropogenic disturbances.

The study was conducted in the high-altitude Kukush Lake in Langer–Shandoor Valley of Gilgit–Baltistan Province. Kukush mountains are oriented north–south along the western flanks of HKH (Figure 1). Kukush Lake (35°59′54E lat. and 72°36′54N long.), is among the largest (9.3 km long and 0.83 km wide) alpine lakes in the region. Altitude varies from 3604 m at the lake to 5073 m snowy peaks surrounding the lake. Geologically, the Langer–Shandoor Valley constitutes upper Palaeozoic

Figure 1. Location of study area and sampling sites in the Langar–Shandur Valley.

and Tertiary tectono-straitigraphic, volcano-plutonic and sedimentary sequences[2]. With short summers (mid-May to early August) having an average temperate range 0–10°C, the area experiences extended and harsh winters between September and March with an average temperature range –25°C to 0°C (ref. 18); it remains snow-covered during the whole winter. The area is visited by nomads from April to late August for livestock grazing. The prevailing vegetation types of the area are alpine meadows and screes extending from the valley basin to permanent snow line.

Inventorization of vegetation followed stratified random sampling. Eight 1 sq. km sample sites were selected randomly between 3600 and 4100 m elevation in the Langer–Shandoor Valley using 1 sq. km grid overlay map of the area. In each site, six 20 m long and 5 m wide transects were laid. Individual transects were systematically sampled with one (1 m^2) subplot at 4 m interval. Thus, a total of 30 m^2 area was sampled in each site. In all, four field expeditions (one/month) were carried out from May to August 2011 to cover maximum available vegetation across the growing period. Vegetation data were analysed to determine the density, cover, frequency, their relative values and importance value index (IVI) following Mueller-Dombois and Ellenberg[21]. Environmental information, including aspect, slope, altitude and erosion was recorded at each site. Coordinates of the study sites were recorded by GPS. Grazing intensity at the sites was determined by visual indicators, including browsed vegetation, hoof marks, droppings and trampling[22]. Plant specimens were collected, pressed, dried and transported to Herbarium of Pakistan, Quaid-I-Azam University Islamabad for identification using standard procedures[23,24].

Simpson's index[25] of diversity, which gives the probability that two individuals selected at random will belong to the same species, was calculated as follows: $D = 1 - (N(N-1)/\sum n(n-1))$, where D is the diversity index, n the number of individuals of a species and N is the number of individuals of all the species. Species evenness was calculated using the Shannon evenness index: $J' = H'/\ln(S)$, where H' is the Shannon–Wiener diversity index and S is species number[26]. The maturity index that represents a dynamic concept related to structural complexity and organization[27] was recorded using the Pichi-Sermolli method[28]

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

Separate regressions were constructed for environmental variables and attributes of identified communities, including species richness, diversity and evenness using linear generalized models. Cluster analysis was performed to obtain a dendrogram showing grouping of similar plant communities based on single linkage and Euclidian distance. The strength of variables was determined by factor analyses using Minitab 16 software. Detrended correspondence analysis (DCA) is a relatively easy method than orthodox statistical analysis, requiring much less linear data and giving precise species–environment correlation[29]. Thus DCA was used to determine and analyse the relationship between species composition and the underlying environmental factors, with the aim of grouping the vegetation communities with similar niches into the same clusters[30].

A total of 51 plant species (47 herbs, 3 shrub and 1 tree species) belonging to 28 families were recorded from the study area (Table 1). Dominant plant families included Asteraceae (12%), Lamiaceae (10%), Polygonaceae (8%), Poaceae (6%), Papilionaceae (6%), Saxifragaceae (4%), Ranunculaceae (4%), Liliaceae (4%), Rosaceae (4%), Scrophulariaceae (4%) and Primulaceae (4%). Among herb species, *Poa alpina* was the most dominant plant species (IVI 9.01) followed by *Carex diluta* (6.51), *Artemesia brevifolia* (6.08), *Bergenia ciliata* (5.92), *Thymus linnearis* (5.17), *Ephedra gerardiana* (4.92) and *Betula utilis* (5.92). *Rhodiola heterodonta*, *Astragalus rhizanthus*, *Primula denticulata* and *Aconitum heterophyllum* were other important species (Table 1). The shrubs recorded from the sites were *Rosa webbiana*, *Lonicera hypoleuca* and *Salix tetrasperma*. *Betula utilis* was the only tree species found in the study area. Eight different plant communities were recorded from the sampled sites. The attributes of these communities are summarized in Table 2.

Table 1. Species composition and importance values (IV) of the alpine flora

Family	Species	Average IV
Asteraceae	*Anaphalis triplinervis*	1.42
	Inula spp	0.75
	Artemisia brevifolia	6.09
	Echinops niveus	0.58
	Saussurea simpsoniana	0.50
	Senecio chrysanthemoides	2.59
Alliaceae	*Allium fedtschenkoanum*	2.00
	Allium himalayense	1.33
Betulaceae	*Betula utilis*	4.84
Boraginaceae	*Eritrichium canum*	1.00
Brassicaceae	*Arabidopsis himalaica*	0.42
Caprifoliaceae	*Lonicera hypoleuca*	1.42
Caryophyllaceae	*Minuartia kashmirica*	0.83
Crassulaceae	*Rhodiola heterodonta*	4.00
Cyperaceae	*Carex diluta*	6.51
Ephedraceae	*Ephedra gerardiana*	4.92
Ericaceae	*Gaultheria trichophylla*	0.17
Fumariaceae	*Corydalis falconeri*	1.75
Geraniaceae	*Geranium wallichainum*	3.09
Lamiaceae	*Nepeta discolor*	0.25
	Nepeta erecta	0.42
	Mentha royleana	0.67
	Thymus linearis	5.17
	Phlomis bracteosa	0.25
Liliaceae	*Gagea elegans*	0.17
	Lloydia serotine	0.08
Onagraceae	*Epilobium latifolium*	0.25
Papilionaceae	*Astragalus himalayanus*	3.09
	Astragalus rhizanthus	3.59
	Oxytropis crassiuscula	0.67
Poaceae	*Bromus inermis*	0.33
	Piptatherum gracile	0.17
	Poa alpine	9.01
Polygonaceae	*Rumex nepalensis*	2.17
	Polygonum tortuosum	2.59
	Rheum spiciforme	1.17
	Oxyria digyna	0.25
Primulaceae	*Primula denticulate*	3.84
	Primula microphylla	3.09
Rannunculaceae	*Aconitum heterophyllum*	2.59
	Delphinium cashmerianum	0.75
Rosaceae	*Rosa webbiana*	1.17
	Potentill aeriocarpa	0.92
Rubiaceae	*Galium himalayense*	0.75
Salicaceae	*Salix tetrasperma*	2.75
Saxifragaceae	*Bergenia ciliate*	5.92
	Saxifraga asarifolia	1.08
Scrophulariaceae	*Pedicularis punctata*	1.58
	Pedicularis pyramidata,	0.17
Tachinidae	*Jurinea ceratocarpa,*	0.33
Umbelliferae	*Pleurospermum hookeri*	0.58

1. *Allium–Carex–Delphinum* community: This community recorded at an altitude of 3574 m comprised of 31 species. The dominant species constituting the bulk of the community were *Allium fedtchenkoanum*, *Carex diluta* and *Delphinium cashmerianum*. Co-dominant species included *Epilobium latifolium*, *Potentilla eriocarpa* and *Polygonum tortosum*.
2. *Salix–Carex–Poa* community: Located at 3621 m elevation, this community comprised of 23 species. Dominant ones included *Salix tetrasperma*, *Carex diluta* and *Poa alpina* followed by *Piptatherum gracile*, *Pedicularis pyramidata* and *Rumex nepalenses*.
3. *Ephedra–Astragallus–Thymus* community: This community was recorded from an altitude of 3831 m and consisted of 25 species. Dominants included *Ephedra gerardiana*, *Astragallus himalayanus* and *Thymus linearis*. The co-dominant species included *Artemsia bravifolia*, *Rhodiola heterodonta*, *Senecioc hrysanthemoides* and *Corydalis falconeri*.
4. *Poa–Allium–Aconitum* community: Recorded from an altitude of 3682 m, this community consisted of 29 species, with *Poa alpina*, *Allium himalaica* and *Geranium wallichianum* as dominant species. Co-dominants included *Rosa webbiana*, *Rumex nepalenses* and *Polygonum tortuosum*.
5. *Artemesia–Ephedra–Thymus* community: This community at an altitude of 3897 m comprised of nine species. *Artemesia bravifolia*, *Ehedra gerardiana* and *Thymus linnearis* were the dominant species. The co-dominants were *Echinopus nivus*, *Nepeta discolour* and *Rhodiola heterodonta*.
6. *Senecio–Bergenia–Aconitum* community: This community was recorded from an altitude of 3763 m and comprised of 21 species. The dominant species included *Senecio chrysanthemoides*, *Bergenia ciliata* and *Aconitum heterophyllum*. The co-dominants were *Nepeta erecta*, *Poa alpina*, *Saxifraga asarifolia* and *Primula macrophylla*.
7. *Primula–Astragallus–Pedicularis* community: At an altitude of 3712 m this community consisted of 19 species with *Primula denticulata*, *Astragallus rhizanthus* and *Pedicularis punctata* as dominant and *Polygonum tortuosum*, *Mentha royeleana*, *Rumex nepalenses* and *Artemesia bravifolia* as co-dominants.
8. *Thymus–Ephedra–Artemesia* community: This community, recorded at an altitude of 3902 m, comprised

Table 2. Plant community attributes

Community	Altitude (m)	Species richness	Simpson's diversity	Evenness	Maturity index
Allium–Carex–Delphinum	3574	31	0.92	0.81	37.4
Salix–Carex–Poa	3621	23	0.76	0.87	41.7
Ephedra–Astragallus–Thymus	3821	25	0.74	0.83	46.8
Poa–Allium–Aconitum	3682	29	0.89	0.62	39.1
Artemesia–Ephedra–Thymus	3897	09	0.43	0.90	48.7
Senecio–Bergenia–Aconitum	3763	21	0.91	0.77	51
Primula–Astragallus–Pedicularis	3712	19	0.82	0.58	36.4
Thymus–Ephedra–Artemesia	3902	14	0.59	0.94	56.3

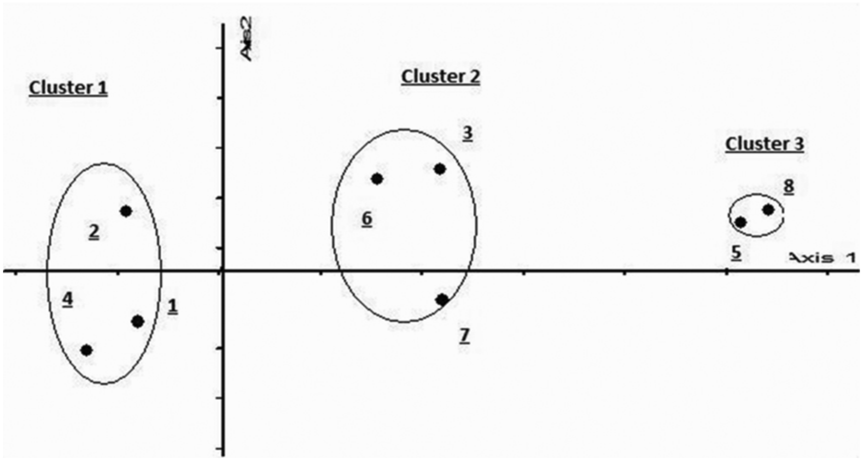

Figure 2. DCA plot showing distribution of vegetation sites with respect to environmental gradient.

of 14 species. Dominants were *Thymus linnearis*, *Ephedra gerardiana* and *Artemesia bravifolia* followed by *Eritrichum canum*, *Innula* spp. and *Piptatherum gracile*.

Following the visual indicators, five out of the eight study sites were under heavy grazing pressure. Four sites exhibited moderate erosion effects, whereas four sites located at steeper slopes showed severe erosion effects with deeper gully networks.

DCA clearly distinguished three community groups which were distinctly separated along the first DCA axis (Figure 2). Along this axis, elevation appears to be the major limiting factor governing the distribution of alpine communities (Figure 2). The communities at highest altitudes (communities 5 and 8) are grouped together at the extreme right, clearly separated from the central and extreme left clusters comprised of low-altitude communities. The first DCA axis explained 63% of the total variance in species data. The second DCA axis appears to be under the influence of moisture gradient of the sites. The high moisture sites (communities 1, 2 and 4) at lower altitudes are grouped together at the extreme left of the second DCA axis, separating them from high-altitude dry sites. DCA clustering is also verified by the results of the single linkage Euclidean distance dendrogram (Figure 3). It indicates that the HKH alpines harbour distinct species assemblages correlated with the corresponding geographic features of different sites.

The HKH alpine flora exhibited highly heterogeneous patterns across the landscape with species and communities distributed across a broad geographic range in distinct patterns. Results revealed high level of beta diversity among the separated community clusters with very little overlap in species composition. This corresponds with the report that alpine species have localized distribution as the amount of overlap in communities decreased with increasing distance and altitude[31]. Factor analyses and DCA revealed that altitude and moisture are the main factors controlling diversity and distribution of alpine flora. These results are in accordance with the earlier reports from different parts of Himalayas demonstrating the importance of environmental variables in governing vegetation formation and distribution[32,33].

The linear regression models (Figure 4) exhibited a negative correlation of richness and diversity with increasing altitude, which has been a well-established fact in the region[34]. The decline in species richness along the altitudinal gradient is also attributed to the eco-physiological constraints, including low temperatures, limited growing season and low productivity. Further, the Himalayan mountain slopes are isolated and narrow having

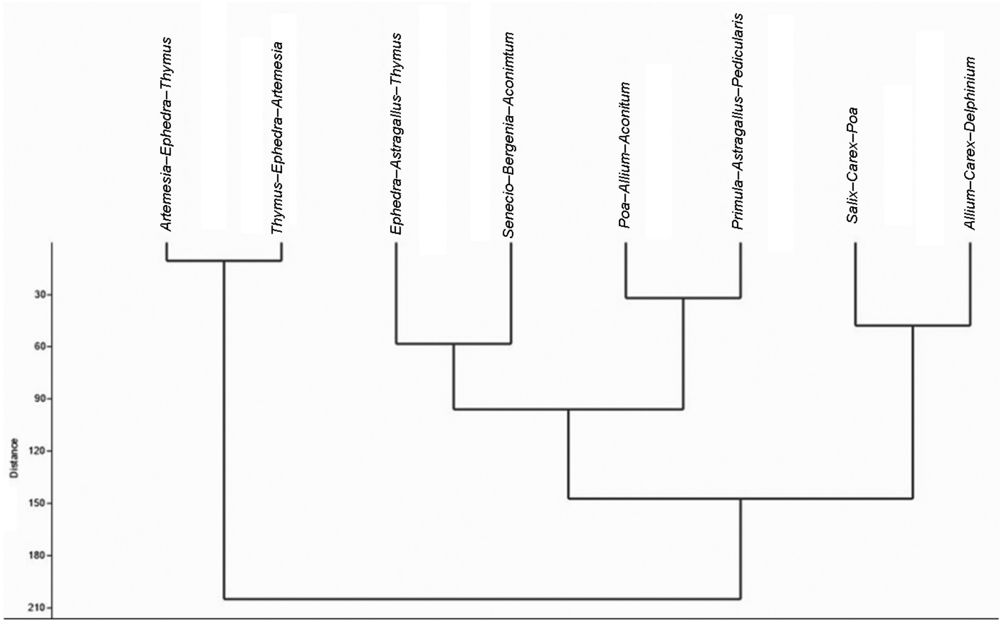

Figure 3. Dendrogram showing single linkage based upon Euclidean distance between communities.

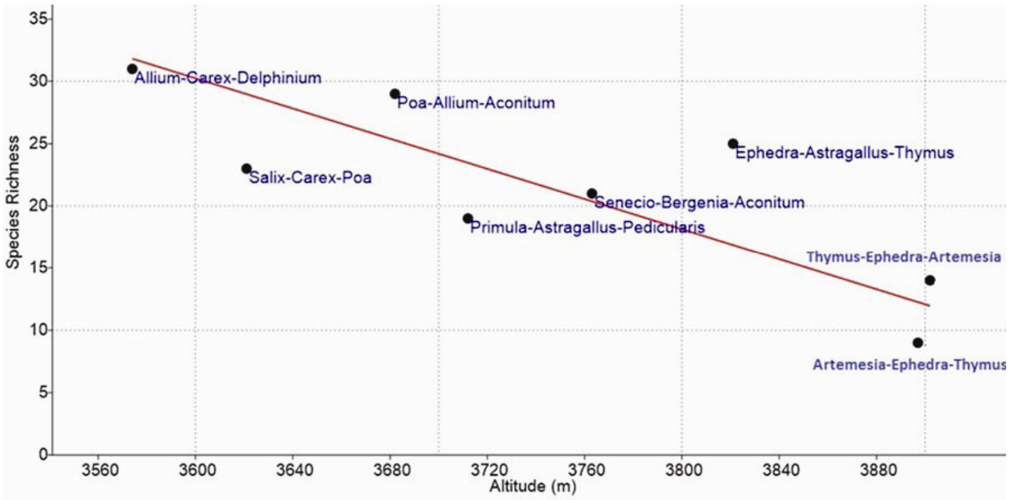

Figure 4. Bivariate linear fit model of altitude with species richness (r^2: 0.64).

reduced connectivity with the species migration channels, resulting in reduced species richness[35,36]. Also, the fact that reduced area provides few micro sites for the development of adaptive traits in plants and community maturity[7], is evident from present results of low maturity index value for all the communities.

The dominance of few unpalatable species like *Potentilla*, *Astragallus* and *Rhodiola* suggests higher incidence of grazing pressure in the study area. This was also evident from uprooted herbaceous vegetation, trampling and exposed soil surface as an overgrazing consequence[37]. Overgrazing is one of the serious threats to many of the threatened endemic palatable plant species such as *Arabidopsis himalaica*, *Phlomis bracteosa*, *Piptatherum gracile*, *Galium himalayense* and *Pedicularis pyramidata* in the area (Table 1). The HKH pastures have been the main source of local livestock since ages. The vegetation, if overgrazed, is not allowed to re-establish itself due to extremely harsh climatic conditions in HKH. Intense grazing intensity was recorded at all the sites, synchronized with resulting erosion[38]. Some studies suggest that grazing practices above 2500 m should be controlled and limited due to fragile nature of vegetation[39]. However, in practice, the HKH pastures continue to be grazed unchecked. This results in over-grazing, which is a serious threat to the highly sensitive alpine flora[40].

This quantitative analysis of vegetation from alpines in Langar–Shandoor Valley reveals that the regional flora is heterogeneous across the complex landscape; and majority of the species have patchy distribution. The local sites exhibit differences in species composition, with each site harbouring unique sets of endemic species. Vegetation attributes in this region strongly respond to the climatic factors and anthropogenic disturbances. While climatic factors determine diversity of floral components, overgrazing poses a great threat to the endemic alpine flora. Need for an immediate and extensive sampling effort across the HKH alpines for better scientific understanding of vegetation diversity patterns is imminent. Further, rehabilitation of the degraded HKH alpines emerges as an important consideration for vegetation specialists to ensure conservation of threatened endemic flora in the HKH region.

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