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Ecological Assessment of Plant Communities and Associated Edaphic and Topographic Variables in the Peochar Valley of the Hindu Kush Mountains

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This study quantified the effect of environmental variables on plant species composition in the Peochar Valley, located in the Hindu Raj mountains of the Hindu Kush. A mixture of quadrat and transect methods were used. Quadrat sizes were 10 × 10 m, 2 × 5 m, and 1 m^2 for trees, shrubs, and herbs, respectively, determined using the minimal area method. Twenty-seven stations were established along 6 elevation transects on slopes with various aspects. Density, cover, and frequency were recorded for all species in each quadrat. Aspect, elevation, rock types, soil nature, and grazing pressure were also considered as edaphic and topographic variables. Preliminary results showed that the Peochar Valley hosts 120 species. Presence/absence data for these species were analyzed with cluster and 2-way cluster techniques to elaborate species composition in the study area; this resulted in 4 plant communities. Species abundance and environmental data matrices were developed to evaluate the ecological gradient of vegetation through canonical correspondence analysis. Of the environmental variables, elevation, aspect, grazing pressure, soil depth, and rock type showed a significant effect on species composition and diversity. We also identified the dominant and rare plant species in each plant community based on their low importance value indexes. Conservation measures are recommended for all flora of this valley and for rare species in particular.

Keywords: *Plant composition; conservation; canonical correspondence analysis; cluster analysis; Peochar Valley; Hindu Kush Mountains.*

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Introduction

There is a growing trend in ecological research to study the relationships between abiotic and biotic components of an ecosystem (Tavili and Jafari 2009; Khan et al 2016). Vegetation is the expression of environment in a specific habitat at a specific time and hence needs to be properly studied in relation to its surroundings at both species and community levels (Khan et al 2012). Vegetation composition and structure are influenced by various natural and anthropogenic disturbances on both local and broader scales (Ribichich and Protomastro 1998). It is thus imperative to understand the patterns of distribution of plant species and the influencing factors at these different scales (Bai et al 2004).

Plant species in forest ecosystems have faced various environmental changes over their long ecological and evolutionary histories. Some of these changes have been slow, but others have occurred quite rapidly in the recent past (Bryson et al 1970). The tremendous increase in research on environment-related subjects in recent decades explains the impacts of rapid changes in the environment in general and vegetation in particular. The most important factors influencing the future of plant species are the degree and rate of changes in the surrounding environment. Such changes may have serious consequences for the ability of plant species, especially those with less genetic diversity and narrow ecological amplitude, to adjust to changing conditions (Critchfield 1984; Davis and Zabinski 1992). Moreover, the rate of environmental change is so rapid that plant species with long generation times may be unable to adapt rapidly enough to keep pace (Davis and Shaw 2001).

Some species adapt to changing conditions by changing their growth forms, development, and life cycles. Changes in species life cycle ultimately bring changes in the formation of plant communities and hence ease the way for invasive species. In such scenarios, it becomes imperative for plant researchers to study environmental variations in terms of how these affect species composition and community structure (Økland and Eilertsen 1993; Guisan and Zimmermann 2000). Abiotic, biotic, historical, and human factors contribute diversity and variation in the distribution of plant species and communities (Brown 1984). The nature of these variations in temperate forests of developing countries is still insufficiently documented and analyzed (Benzing 1998).

Northern Pakistan is one such example, with mountainous temperate forests, mostly coniferous (Ilyas et al 2012), that cover an area of approximately 5% of the forest ecosystem in the country. The natural forest cover is decreasing at the rate 0.75% annually (FAO 2009). In certain regions that are difficult to study (eg Chitral, Nanga Parbat, and Naran), plant researchers have sought to elaborate the altitudinal gradient complex of the vegetation. These authors have also focused on other climatic factors, such as rainfall in relation to plant distribution, in these fragile ecosystems (Dickoré and Nüsser 2000; Nüsser and Dickoré 2002). In addition to natural hazards and other factors responsible for deterioration of natural ecosystems, anthropogenic and edaphic drivers play a vital role in vegetation dynamics. This project was initiated to better understand the role of such factors in the establishment of plant communities.

Little effort has been made to undertake quantitative analysis of the plant communities along geoclimatic environmental gradients in Hindu Kush valleys. To identify the effective determinants of local or regional vegetation and biodiversity patterns, such studies are imperative. This study seeks to help fill this knowledge gap. Moreover, there have been no previous quantitative studies of the vegetation in this valley. This study was designed to test the hypothesis that elevation, aspect, and edaphic factors are the main determinants of the vegetation of the Peochar Valley, with the following specific research objectives:

1. Use phytosociological and quantitative statistical methods to describe and analyze plant species and community diversity in the Peochar Valley, Hindu Kush.
2. Identify the edaphic and topographic factors responsible for plant community and distribution patterns along the gradients of elevation, aspect, and rock type.

Material and methods

Study area

The Peochar Valley is located in Tehsil Matta of the famous Swat District (Figure 1), in the Hindu Raj Mountains of the greater Hindu Kush range. It is located at 35°07′ to 35°22′N and 72°29′ to 72°39′E and has a total area of 4877 ha. About half (2450 ha) of the total area is cultivated, and the rest (2427 ha) is forest range land. The valley is bounded by the valley of Nihak Dara on the west, the Beha Valley on the north, the valley of Tehsil Kabal on the south, and the Shawar Valley on the east (Figure 1) (Islam et al 2006; Khan et al 2007). Most residents are Gujjars, descendants of the ancient Kushan dynasty (Lyon 2002), Yousafzai Afghans, and a few Sayed families. Pushto and Gujri are the main languages (Ahmad and Ahmad 2003; Islam et al 2006).

The area comprises moist temperate forests (Beg and Khan 1974); the valley is in the monsoon belt. The upper part of the valley has moist temperate and alpine ecosystems with coniferous forests. Because of its varied climate, the valley is home to a variety of plant species, a number of which are edible, aromatic, or medicinal (Sher et al 2007; Ahmad et al 2015).

Methodology

Quantitative ecological techniques were applied to evaluate species composition, distribution pattern, and abundance under the influence of edaphic and topographic variability in the targeted region. This study was conducted in summer 2013. Elevation transects were established at sites with various mountain aspects—north, south, west, and east faces. Stations were established at 200-m elevation along each transect, resulting in 27 stations. Quadrats were placed systematically along each transect at 200-m intervals using global positioning system (GPS) technology (Khan et al 2013). Quadrat sizes, determined using the minimal area method, were 10×10 m for trees, 2×5 m for shrubs, and 1 m^2 for herbs (Salzer and Willoughby 2004). Three quadrats were placed at the same elevation (Khan et al 2011, 2013). Edaphic and topographic factors such as aspect, elevation, and soil physical and chemical features were recorded, while recent anthropogenic impacts like grazing pressure were estimated, based on observations, on a scale of 1–5 (low to high). Plant specimens were collected from each quadrat and labeled. Specimens were identified using *Flora of Pakistan* and other literature (Ali and Qaiser 1993–2007). The collected specimens were mounted on standard sheets and kept in the herbarium of the University of Haripur.

Analyses

Floristic composition (presence or absence), density, and cover for all higher plant species were recorded in each quadrat. Diameter at breast height (Dbh) was measured for tree species. Stem basal area of each tree species was calculated as πr^2 or $(\text{Dbh}/2)^2 \times 3.143$. Relative values of density, cover, and frequency of species in each transect were also calculated and summed to get the importance value index (IVI). Based on IVI, rare species were identified for the region and for each plant community.

Soil samples up to 30 cm in depth were collected in soil sampling tubes from each quadrat. The collected

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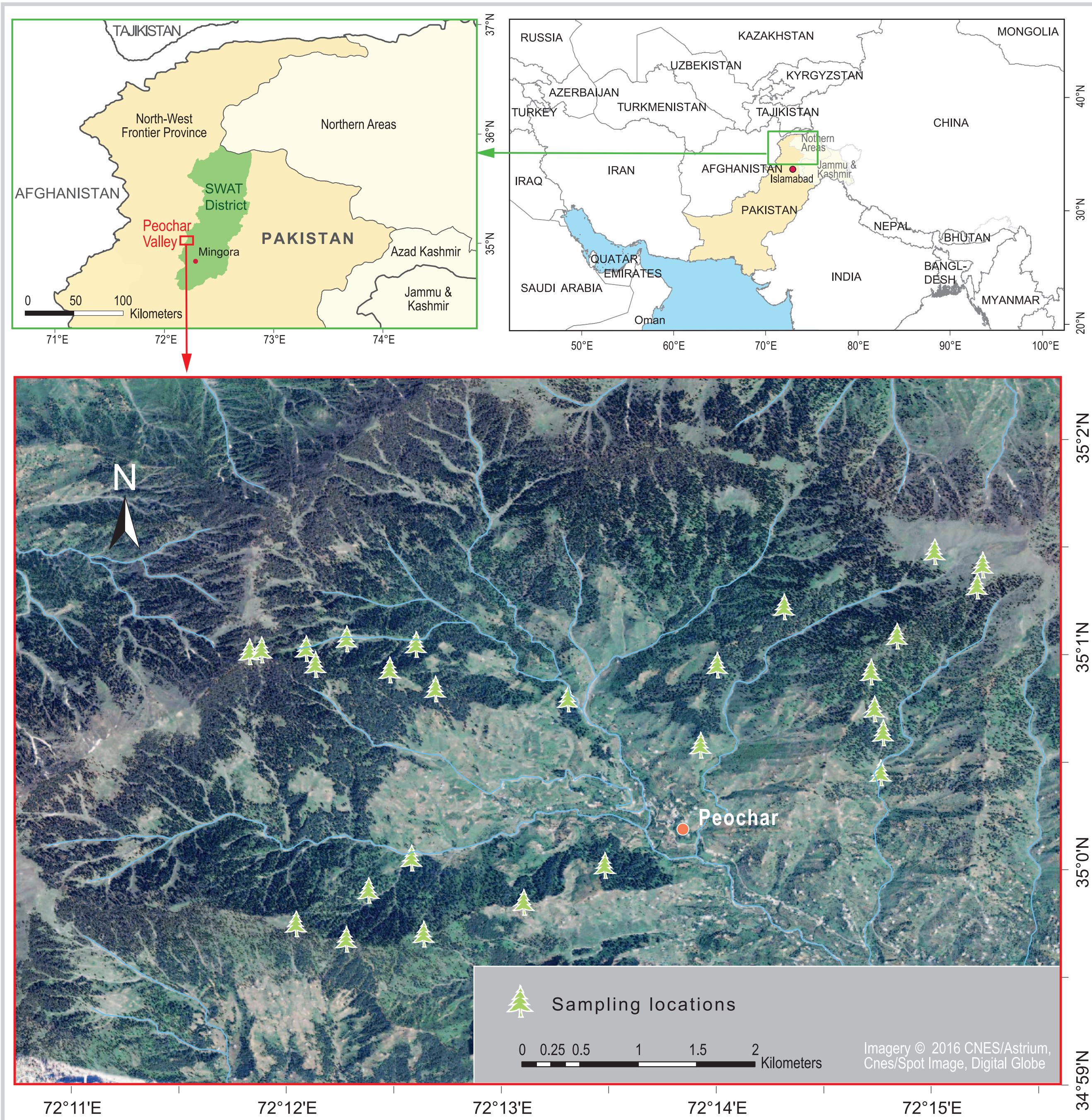
FIGURE 1 Map of the Peochar Valley. (Map by Aziz Ur Rahman and Shujaul Mulk Khan)



samples were brought to the laboratory and dried at room temperature, ground, thoroughly mixed, and sieved through 2-mm mesh to form 1 composite sample. Physiochemical analysis of these soil samples was done in the soil science laboratory of the Agricultural Research Institute, Tarnab Farm, Peshawar.

Soil samples were analyzed using standard methods for various physical and chemical properties. Soil texture was determined using a hydrometer (Page 1982), lime content was determined using acid neutralization (Cottenie 1980), organic matter was determined using the Walky-Black procedure (Nelson and Sommers 1982), soil nitrogen was determined using the Kjeldhal method (Bremner and Mulvaney 1982), soil pH was determined by testing a 1:5 soil:water suspension with a pH meter, electrical conductivity was determined by testing a 1:5 soil:water

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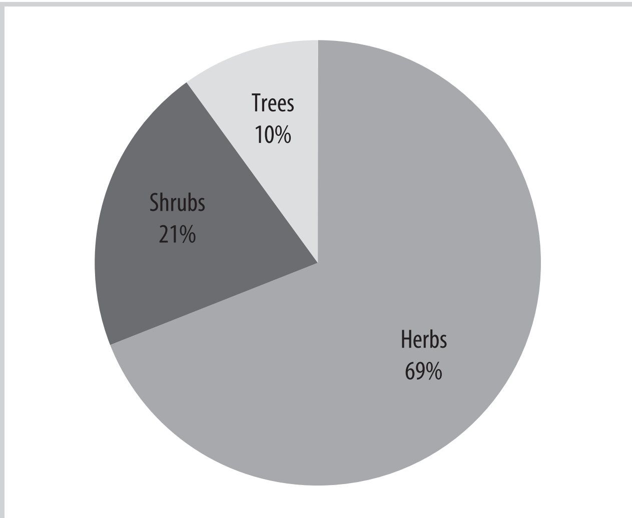
FIGURE 2 Proportion of trees, shrubs, and herbs in Peochar Valley vegetation, summer 2013.



suspension with a conductivity meter (Rhoades 1990), and extractable phosphorus and potassium were determined using the method described by Soltanpour (1985).

Results

Species composition in the Peochar Valley

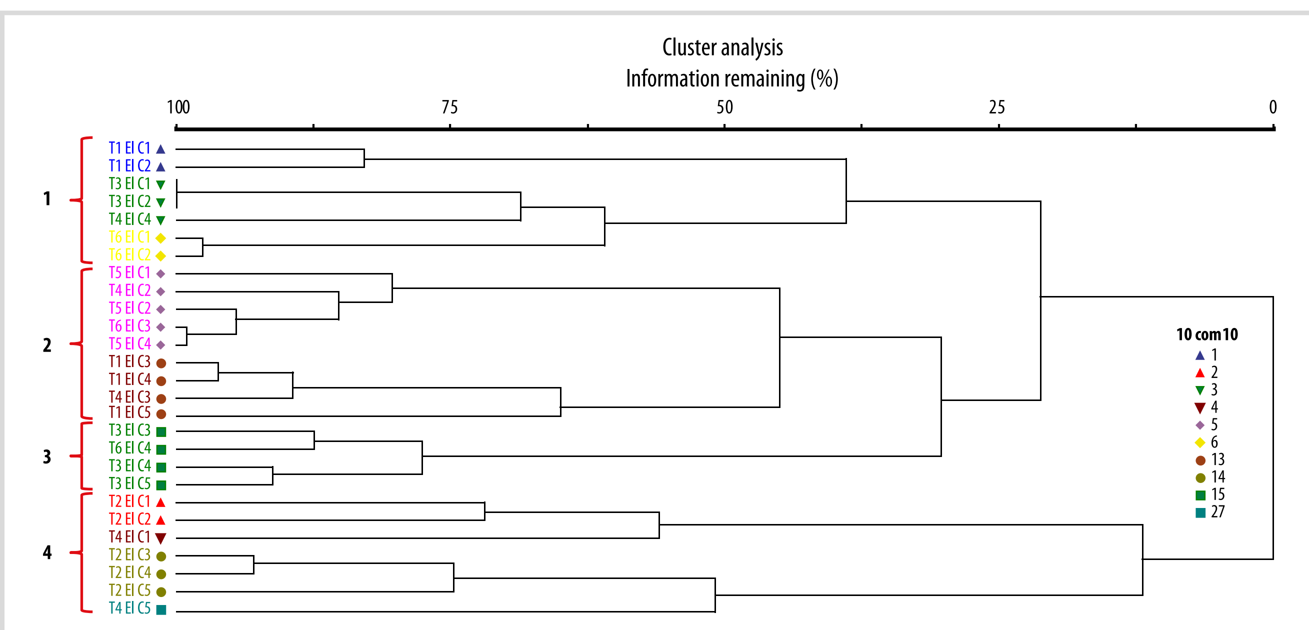
A total of 120 species belonging to 57 families were collected along 5 elevation transects from the Peochar Valley, including 12 (10%) tree, 25 (21%) shrub, and 83 (69%) herb (Figure 2). The most dominant family was Poaceae, with 14 species (12% of all species), followed by Rosaceae, with 13 species (11%). Other dominant families were Lamiaceae, with 10 species, and Asteraceae, with 5 species.

Plant communities and habitat types

Presence/absence (1/0) data were analyzed using cluster and 2-way cluster analyses via PCORD version 5 (Leps and Smilauer 2003). Cluster analysis placed the 27 stations (representing different elevations) in 4 groups (plant communities) (Figure 3). These 4 groups are described later. Rare herb species in the region, from all plant communities, are shown in *Supplemental material,* Table S1 (http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00100.S1).

Pinus–Sarcococca–Dryopteris *community:* This community was established at lower elevations (1975–2297 m above sea level [masl]). *Pinus wallichiana, Sarcococca saligna,* and *Dryopteris stewartii,* on which the community name is based, were the characteristic species of the tree, shrub, and herb layers, respectively. Other dominant tree species were *Quercus dilatata* and *Taxus baccata*. The rare tree species in this community were *Picea smithiana, Ilex dipyrena,* and *Quercus incana*. The shrub layer was dominated by *Berberis lyceum* and *Wikstroemia canescens*; rare species were *Sorbaria tomentosa, Rosa moschata,* and *Rubus ulmifolius*. Dominant species of the herb layer were *Eleusine indica, Themeda anathera, Brachiaria ramosa,* and *Fragaria vesca*. Rare herbs

FIGURE 3 Results of cluster analysis showing 4 plant communities. T, transect; El C, elevation class; El C1 = 1950–2200 masl; El C2 = 2200–2400 masl; El C3 = 2400–2600 masl; El C4 = 2600–2800 masl; El C5 = 2800–3000 masl.



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were *Epipactis veratrifolia, Geranium wallichianum, Cerastium fontanum, Podophyllum emodi,* and *Myosotis caespitosa*. Data-attribute plots of indicator species of this community show that grazing pressure has had less effect on these species than on other communities. This community was mainly observed on rocky steep slopes with shallow soil.

Picea–Parrotiopsis–Fragaria *community:* This community was found at midelevations (2296–2658 masl). *P. smithiana* characterized the tree layer. Other dominant species in the tree layer included *Abies pindrow* and *P. wallichiana;* rare tree species were *Acer cappadocicum, Celtis australis,* and *T. baccata*. In the shrub layer, *Parrotiopsis jacquemontiana* was the indicator or dominant species; codominant species were *Viburnum grandiflorum* and *W. canescens*. Parrotiopsis is monotypic genus endemic to the Hindu Kush–Himalayas. Rare species of the shrub layer were *Rubus sanctus, R. ulmifolius,* and *R. moschata*. The characteristic species of the herb layer was *F. vesca;* other dominant species included *Trifolium repens, Dryopteris filix-mas, Viola canescens,* and *Artemisia vulgaris*. Rare species were *Solanum nigrum, Bergenia ciliata, Phytolacca acinosa, Bistorta amplexicaulis,* and *Polygonatum verticillatum*. Of the characteristic species for each layer, the IVI was 1.15 for *P. smithiana,* 0.727 for *P. jacquemontiana,* and 11.47 for *F. vesca*. This community was present mostly on northern slopes.

Abies–Viburnum–Carex *community:* This community was found at higher elevations (2536–2708 masl). Characteristic species of tree and shrub layers were *A. pindrow* and *V. grandiflorum* (IV = 1.53). The other dominant species of the tree layer were *P. wallichiana* and *P. smithiana* and of the shrub layer were *R. moschata* and *Indigofera heterantha*. Rare tree species were *A. cappadocicum, I. dipyrena,* and *Aesculus indica;* rare shrub species were *Cotoneaster nummularius, Plectranthus rugosus,* and *S. tomentosa*. The characteristic species of the herb layer was *Carex schlagintweitiana* (IV = 22.71). The dominant species of this community were *Sibbaldia cuneata, Thymus linearis, Poa annua,* and *B. amplexicaulis;* rare species were *Skimmia laureola, Trillium govanianum, Ajuga parviflora, G. wallichianum,* and *Agrimonia eupatoria*. This community was mainly established on southern slopes.

Indigofera–Plectranthus–Viola *community:* This community was located at 2485–2937 masl. There is no dominant tree species, though a few rare trees were present, including *P. wallichiana, P. smithiana, I. dipyrena,* and *Prunus cornuta*. The characteristic shrub species were *I. heterantha* and *P. rugosus*. The dominant shrub species was *V. grandiflorum,* and rare shrubs were *B. lyceum* and *R. moschata*. The characteristic species of the herb layer was *Viola bicolor,* with codominant species such as *C. schlagintweitiana, T. govanianum, T. linearis,* and *Galium aparine*. Rare herbs in this community were *Hypericum perforatum, Leonurus cardiaca, Origanum vulgare, Oxalis corniculata,* and *Desmodium laxiflorum*. The characteristic tree, shrub, and herb species in this community were *I. heterantha, P. rugosus,* and *V. bicolor,* with IVIs of 1.37, 1.06, and 11.15, respectively. This community had a wider range of occurrence in varying habitats.

Environmental gradient

Species and environmental data matrices were analyzed together in CANOCO software version 4.5. Results showed that environmental (edaphic, topographic, and anthropogenic) variables had significant effects on species composition and diversity. Significant environmental variables were elevation, aspect, grazing pressure, pH, soil depth, and presence of organic matter, phosphorus, potassium, silt, and rocky soil. It was hypothesized that aspect and elevation could be the main driving forces of vegetation variation in the valley, and the low P value (≤ 0.012) showed that the results were highly significant in terms of test statistics. Canonical correspondence analysis (CCA) of environmental data identifies the main driving environmental variable for the constitution of a specific community type. CCA results showed that both the composition and the abundance of plant species were a reflection of differences in these environmental variables.

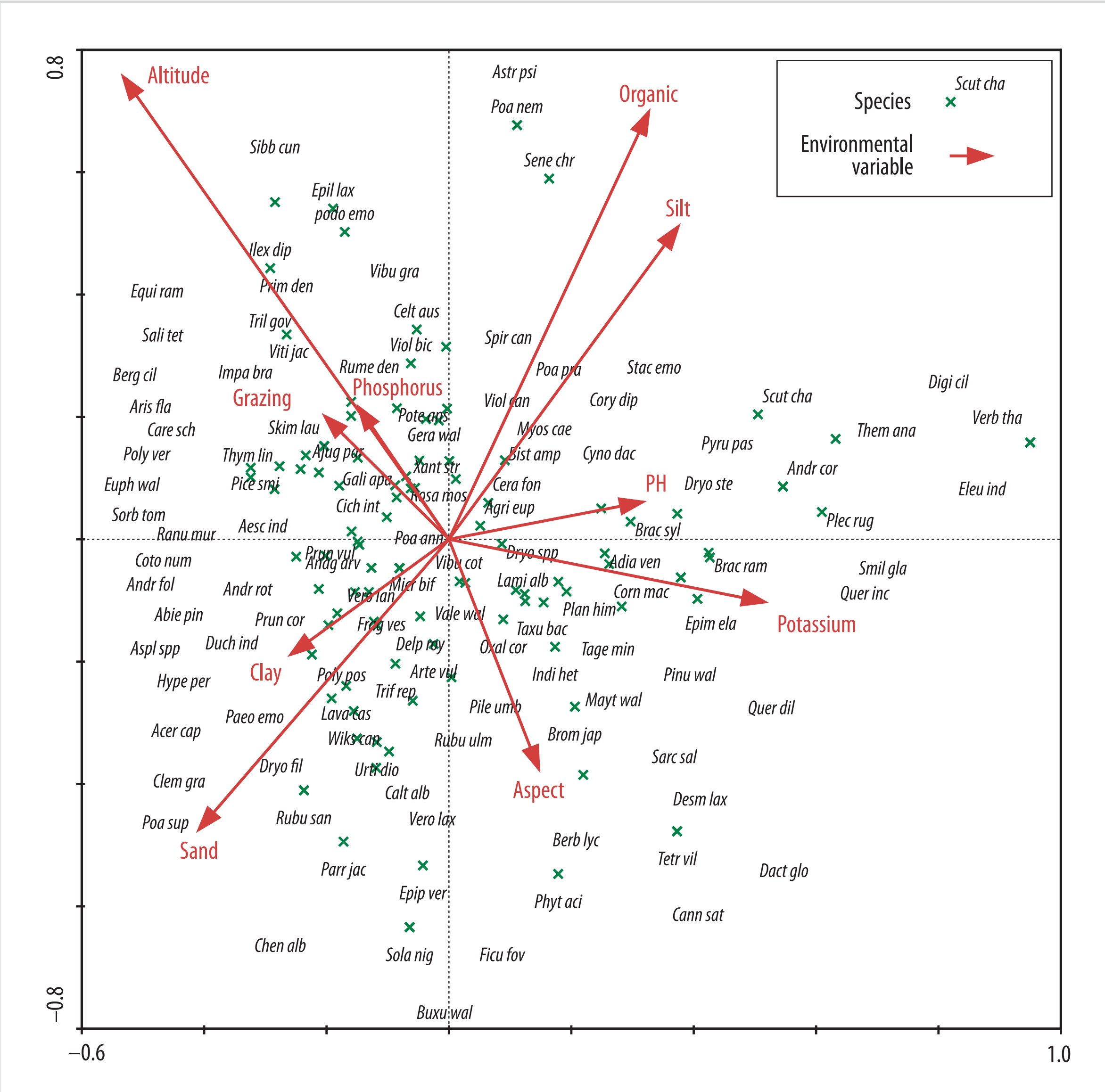
The CCA ordination procedures for samples and species indicated that the first axis was primarily correlated with elevation and aspect, the second axis was correlated with soil depth and grazing, and the third axis was correlated partially with grazing pressure, soil depth, and rock types. The fundamental ecological gradient of the first axis can be clearly recognized from the biplots, relating key environmental variables to plant species distribution (Figure 4) and elevation-based stations (Figure 5), which confirm each other. Pearson's correlation with ordination axes for the CCA plot pointed out a significant correlation of axis with the geoclimatic variables (elevation and soil depth). Data attribute plots strengthened the position of the indicator or characteristic species of each community (the species from which the communities' names were derived).

Discussion

During the last several decades, studies of environmental changes have emerged more rapidly than other studies in the life sciences. The effects of these environmental changes have been intensified by recent anthropogenic activities (Davis and Zabinski 1992; Ali et al 2002). In mountain ecosystems, the initial trophic level is made up of vegetation; therefore, proper quantification and documentation of vegetation in relation to the abiotic environment is required (Khan et al 2012).

In terms of floristic groups, our findings can be compared with those of other studies from mountain valleys in the Himalayas, where plant families like Poaceae, Asteraceae, Lamiaceae, and Rosaceae were the

FIGURE 4 Results of CCA showing the biplot distribution of 120 plant species and 10 environmental variables.



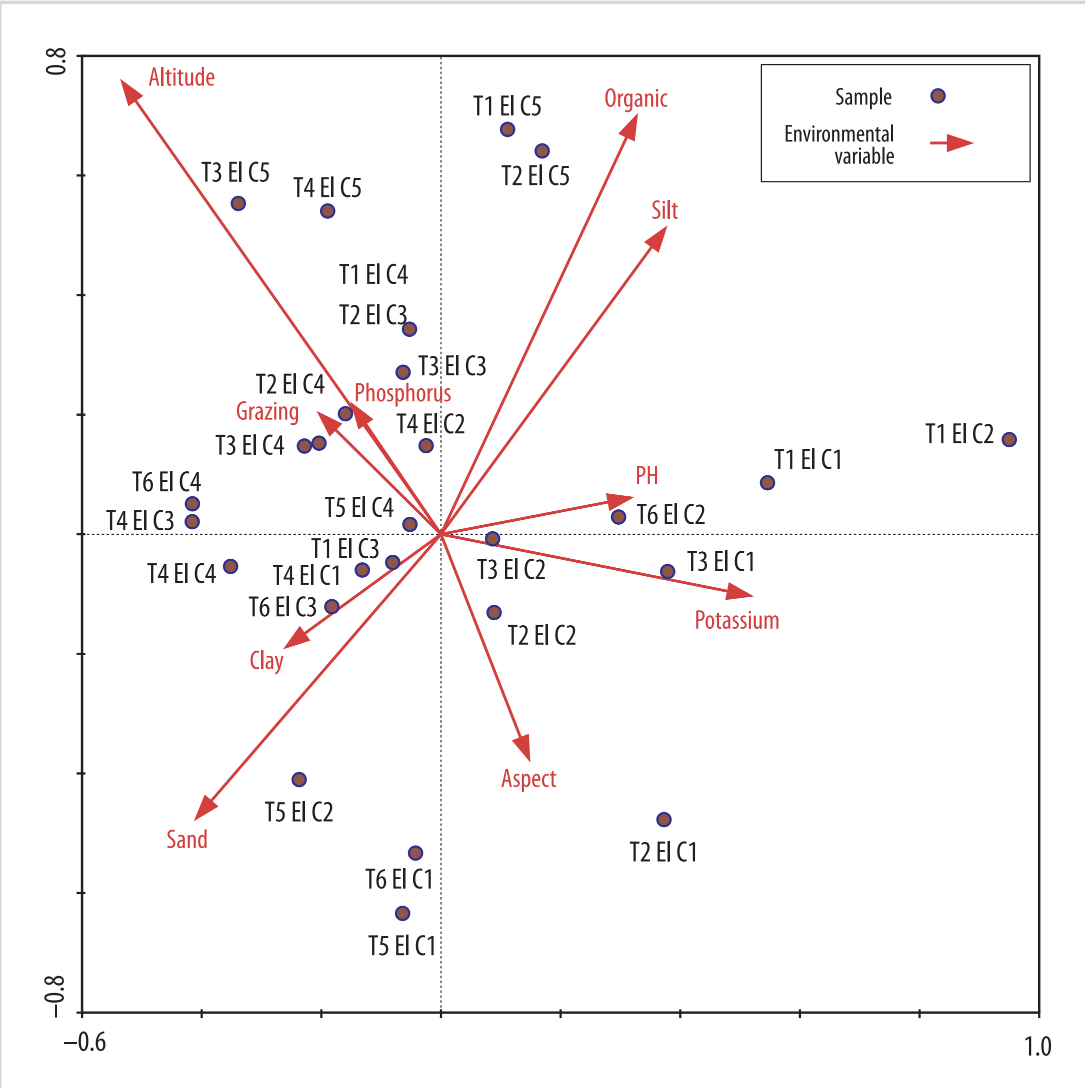
most representative of the vegetation (Khan et al 2011, 2015; Shaheen et al 2011). Our study confirms Poaceae with 14 plant species (12% of all species), Rosaceae with 13 species (11%), Lamiaceae with 10 species (9%), and Asteraceae with 5 species (4%).

Plant species are successively replaced as a function of variation in the environment; hence, composition and distribution of plant species in communities vary along ecological gradients. The 4 plant communities were determined through way cluster analysis and the IVI (Figure 6). Influencing edaphic factors and their strength are shown in Table 1.

Other studies (Desalegn 2002; Shaheen et al 2011; Khan et al 2012) have also found a relationship between plant communities and environmental gradients. The dominant tree species in most of the study area (communities 1–3) are *P. wallichiana, P. smithiana,* and *A. pindrow;* a similar pattern was reported for the Naran Valley of the western Himalayas (Khan et al 2011).

CCA was used to evaluate the distribution pattern of 120 plant species in 27 elevational stations under the influence of various environmental variables. Of the environmental variables, elevation, aspect, grazing pressure, pH, depth of soil, and presence of organic matter, phosphorus, potassium, silt, and rocky soil significantly ($P \geq 0.0120$) affect species composition and community classification (Table 2). Similar impacts on

FIGURE 5 Results of CCA showing the biplot distribution of 27 elevation classes in relation to 10 environmental variables. T, transect; El C, elevation class. El C1 = 1950–2200 masl; El C2 = 2200–2400 masl; El C3 = 2400–2600 masl; El C4 = 2600–2800 masl; El C5 = 2800–3000 masl.



species composition were reported for adjacent temperate regions of Pakistan (Khan et al 2012).

The environment has been changing on local and global scales because of anthropogenic activities coupled with climate change (Schwartz et al 2000; Sax and Gaines 2003). Grazing pressure can create a severe threat to plant biodiversity (Mayer et al 2009) and species composition. Major palatable species in the Peochar Valley are *R. moschata, R. ulmifolius, C. fontanum,* and *G. wallichianum*. *T. govanianum* was scarcely present in the area at high elevations. Because of its high medicinal value, this species has been greatly affected by anthropogenic pressure. In the tree layer, *Q. dilatata* and *Q. incana* were rare and found in lower altitudes, which makes it easy for inhabitants of the area to use them for animal fodder and fuel.

Soil in the Peochar Valley is mostly sandy loam. Similar soil was reported in vegetation studies of the adjacent Girbanr Hills, Swat District, Pakistan (Hussain et al 1995). The amount of calcium carbonate increases with elevation from 8.55 to 9.18%. Phosphorus also increases in area from 11.73 to 29.42 mg kg^{-1}. Potassium ranged from 113.4 to 171 mg kg^{-1}. Organic matter showed less difference, ranging from 1.3 to 1.7%. The area has mostly rocky soil, with 60.5 to 66.73% sand. Soil was weakly acidic, with pH ranging from 6.5 to 6.8.

In mountainous regions, elevation shows the greatest effect in limiting plant species and community types (Chawla et al 2008). Numerous studies have concentrated on variations of species richness and diversity along elevation gradients in hilly areas to find the patterns of

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FIGURE 6 The 20 rare herb species with the lowest IVIs in the study area.

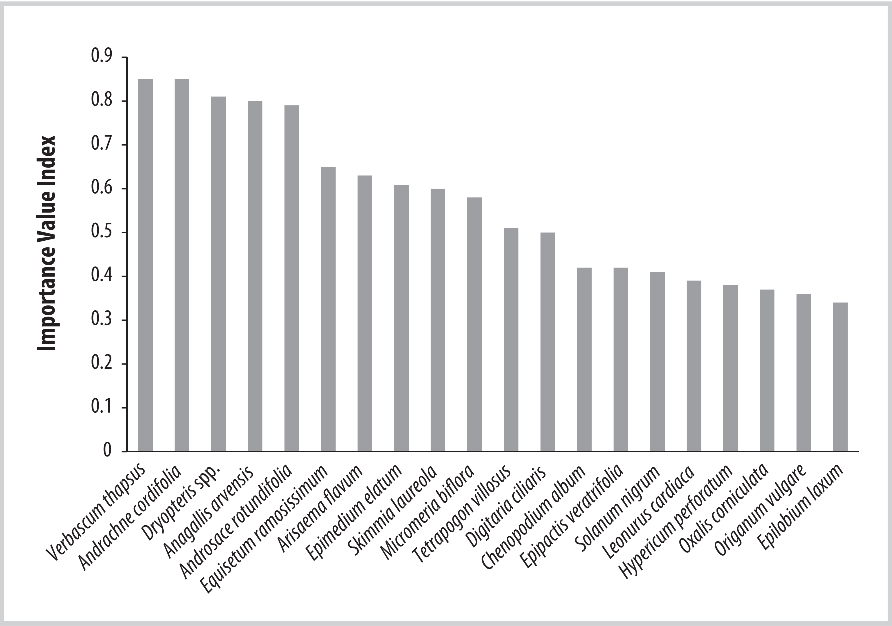

TABLE 1 Key environmental variables in the 4 plant communities.

Variable	1	2	3	4
Elevation	1975–2297 masl	2296–2658 masl	2536–2708 masl	2485–2937 masl
Aspect	Eastern and southern	Western	Southern	Southern
Mean grazing pressure (on a scale of 1–5)	2.5	3	3	2
Mean proportion of clay-size particles	9.37%	11.26%	11.10%	11.00%
Mean proportion of sand	54.91%			
Mean proportion of rocky soil		63.21%	65.40%	65.40%

TABLE 2 Results of CCA.

Canonical axis	1	2	3	4	Total inertia
Eigenvalue	0.545	0.455	0.427	0.276	8.194
Species–environment correlation	0.928	0.880	0.937	0.868	
Cumulative percentage variance of species data	6.7	12.2	17.4	20.8	
Species–environment relation	28.7	52.6	75.0	89.5	
Summary of Monte Carlo test (499 permutations under reduced model)					
Test of significance	First axis	All axes			
Eigenvalue	0.545	Trace			1.903
F ratio	1.498	*F* ratio			1.271
P value	0.0600	*P* value			0.0120

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distribution (Lomolino 2001). We found a range of occurrences of various indicator species as well. For example, *P. wallichiana* was found at elevations of 1990 to 2870 masl but most abundantly at 1990 to 2297 masl. *A. pindrow* was distributed dominantly at high elevations, from 2296 to 2708 masl. *P. smithiana* ranged from 2085 to 2937 masl and was dominant at 2296 to 2658 masl. *Q. dilatata* was found at lower elevations, from 1975 to 2205 masl, with *Q. incana* at 2085 masl. Other studies in the Hindu Kush–Himalayas have documented similar elevation ranges for these characteristic species of temperate ecosystems (Dickoré 1995; Shaheen et al 2012).

Most of the species are related to a particular habitat and found to be richer around their particular environmental optimum. *P. jacquemontiana* and *Buxus wallichiana* were also recorded in the region at lower elevations of 1990 to 2296 masl. These species are endemic to the western Himalaya, especially Kashmir, Murree, Hazara, and Swat, at elevations from 1200 to 2800 masl (Takhtajan et al 1986). Three species of the Buxaceae family have been reported from Pakistan; 2 of them were recorded during this study in the Peochar Valley: *B. wallichiana* and *S. saligna*. *Parrotiopsis* is the only species in the genus (mono-specific). Therefore, proper measures for conservation of these rarely occurring endemic species must be given high priority.

These findings can be used for conservation of rare species—that is, species that have restricted distribution and special or fragmented habitats, are endemic, and decrease more quickly in population. These results also open new ways to study and manage ecosystem services and environmental sustainability. Our findings, based on ecological approaches, can be used as one of the criteria for prioritization of protected areas, special habitats, and species of conservation importance.

Although the Hindu Kush region is famous for its indicator and endemic flora and unique ecosystems, there has been limited research on the region's endangered plant species. One of the reasons for this is the political conflict of the last few decades, which has prevented detailed work for environment sustainability. Few comparators exist to evaluate endangered and critical species at the national level, but new efforts have emerged in recent years (Ali and Qaiser 1986; Ali 2008; Alam et al 2011; Shinwari and Qaiser 2011), though these described few species.

The quantitative description of plant abundance in our findings is distinctive, like the one described by Nüsser and Dickoré (2002) for Chitral Valley, and can be used for comparison, confirmation, and assessment of anthropogenic pressures while planning conservation strategies, as suggested by a number of people. Nevertheless, our study can be compared to other regions of the Himalaya in terms of potential for endemism and ecosystem services.

Documentation that critically evaluates plant biodiversity and the factors driving it at regional and national levels is mandated by law in the developed world. This approach can be adopted in the developing world as well for long-term management and sustainability of the natural environment.

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Supplemental material

TABLE S1 Detailed list of species of the Peochar Valley. [b)] D, total density; C, cover; F, frequency; RD, relative density; RC, relative cover; RF, relative frequency.

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