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Original Article

Composition and structure of plant communities in the Moist Temperate Forest Ecosystem of the Hindukush Mountains, Pakistan

Composição e estrutura de comunidades de plantas no Ecossistema Florestal Temperado Úmido das Montanhas Hindukush, Paquistão

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Abstract

Here, we investigated the relationship between Plant communities and the environment from the moist temperate vegetation of Lakoo mountainous forest District Swat. We sampled data from 162 sampling units (Quadrates) using 1x1m² for herbs 5x5m² and shrubs, while 10 x10m² for trees, systematically considering six elevation gradients between the altitudinal from 1970m to 3095m. We performed statistical analysis like Canonical correspondence analysis (CCA) and TWINSPAN (two-way indicator species analysis) for ecological assessment and clustering of plant communities. To check upon the correlation of species (CR) with topographic and edaphic variables we used statistical software PC-ORD version 7. We recognized 264 species plants belonging to thirty families. We recorded key sampling measurements of density, frequency, and cover for all these species which are vital for community description. The results showed Shannon-Winner,s, and Simpson diversity values as 19.18 and 3.17 respectively. The importance value indexes (IVI) were used to identify the leading and rare species of plant in each community or cluster group. In total we recognized eleven different communities as: *Berberis- Abies- Bergeni, Picea - Indigofera- Poa,Abies- Parrotiopsis- Poa, Quercus- Viburnum- Poa, Picea- Salix- Primula, Abies- Viburnum- Poa, Viburnum- Taxus- Poa, Pinus- Viburnum- Lithospermum, Abies-Berberis- carex, Pinus- Viburnum- Poa* and *Parrotiopsis-Picea- Poa* through hierarchical cluster analysis (TWINSPAN). CCA analysis revealed that of all studied edaphic and topographic variables altitude, silt, calcium carbonate, and organic matter were the strongest factors determining plant community diversity and composition in each microclimate of the eleven communities. Visually the vegetation of the forest was dominated by small-sized trees followed by shrubs, and regenerates indicating the stage of secondary regeneration. We found severe human interference in disturbing the existing biodiversity, which requires immediate conservation to ensure sustainable management and utilization of natural resources of the Lalkoo moist temperate forest.

Keywords: phytosociology, Lalkoo moist temperate forest, floristic pattern, indicator species, plant communities.

Resumo

Aqui, investigamos a relação entre as comunidades vegetais e o meio ambiente da vegetação temperada úmida da floresta montanhosa de Lalkoo, distrito de Swat. Foram amostrados dados de 162 unidades amostrais (quadrados) utilizando 1 x 1 m² para ervas, 5 x 5 m² para arbustos e 10 x 10 m² para árvores, considerando sistematicamente seis gradientes de altitude entre 1.970 m e 3.095 m. Realizamos análises estatísticas, como análise de correspondência canônica (CCA) e TWINSPAN (análise de espécies indicadoras de duas vias), para avaliação ecológica e agrupamento de comunidades de plantas. Para verificar a correlação das espécies (CR) com as variáveis topográficas e edáficas, foi utilizado o software estatístico PC-ORD, versão 7. Foram reconhecidas 264 espécies de plantas pertencentes a 30 famílias. Registramos as principais medições de amostragem de densidade, frequência e cobertura para todas essas espécies que são vitais para a descrição da comunidade. Os resultados mostraram valores de diversidade de Shannon-Wiener e Simpson de 19,18 e 3,17, respectivamente. Os índices de valor de importância (IVI) foram usados para identificar as espécies de plantas principais e raras em cada comunidade ou grupo de cluster. No total, reconhecemos 11 comunidades diferentes, como: *Berberis-Abies-Bergeni*, *Picea-Indigofera-Poa*, *Abies-Parrotiopsis-Poa*, *Quercus-Viburnum-Poa*, *Picea-Salix-Primula*, *Abies-Viburnum-Poa*, *Viburnum-Taxus-Poa*, *Pinus-Viburnum-Lithospermum*, *Abies-Berberis-Carex*, *Pinus-Viburnum-Poa* e *Parrotiopsis-Picea-Poa*, por meio de análise de agrupamento hierárquico (TWINSPAN). A análise de CCA revelou que, de todas as variáveis edáficas e topográficas estudadas, altitude, silte,

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carbonato de cálcio e matéria orgânica foram os fatores mais fortes na determinação da diversidade e composição da comunidade vegetal em cada microclima das 11 comunidades. Visualmente a vegetação da floresta foi dominada por árvores de pequeno porte, seguidas de arbustos, e se regenera, indicando o estágio de regeneração secundária. Encontramos grave interferência humana na biodiversidade existente, o que requer conservação imediata para garantir o manejo sustentável e a utilização dos recursos naturais da floresta temperada úmida de Lalkoo.

Palavras-chave: fitossociologia, floresta temperada úmida de Lalkoo, padrão florístico, espécies indicadoras, comunidades vegetais.

1. Introduction

Plant community assessments and structural studies of vegetation along ecological gradients are one of the most significant topics in community ecology (Peters et al., 2019; Iqbal et al., 2018). The study of plant associations and their classification is related to the field phytosociology while vegetation in the strict sense is the ecological quantification of plant resources (Timilehin et al., 2017; Ali et al., 2018; Veintimilla et al., 2019; Peters et al., 2019). Multilateral relationships exist between vegetation structure and prevailing ecological features like elevation (Sher et al., 2014 ; Haq et al., 2020), topographic heterogeneity (Zhang et al., 2006; Kuma and Shibru, 2015; Zeb et al., 2020; Mondal and Zhang 2018), water availability and soil Physiochemical characteristics (Forzieri et al., 2011; Li et al., 2017) and availability of light (Bonari et al., 2017; Peters et al., 2019).

A community is a cluster of plant species that present fundamental functional units both spatially and temporally, which have a direct relation to seasonal differences and sampling periods (Ali et al., 2018; Ilyas et al., 2015; Hussain et al., 2019). Species diversity plays a key role in biodiversity conservation supervision and most effectively as an indicator of community constancy in most of moist temperate and temperate forests (Shaheen et al., 2011a: Roy et al., 2015: Ali et al., 2018). Community structure, distribution pattern, and vegetative function are the greatest ecological features of forest ecosystems (Zhang et al., 2006; Timilsina et al., 2007; Ali et al., 2018). Understanding how diverse community processes interact is not only fascinating in itself but is also essential for predicting how communities will respond to various environmental conditions. Therefore distribution pattern of plant species in a community is a function of surrounding environmental variables (Weiher and Howe 2003; Götzenberger et al., 2012). Therefore, it is necessary for understanding plant community composition and distribution, along an elevation gradient in forest ecosystems (Zhang et al., 2006; Bonari et al., 2017; Li et al., 2017). Environmental gradients like topographic and edaphic factors (Zhang and Zhang, 2011; Khadanga and Jayakumar 2020) influence plant community structures in forests (Ullah et al., 2015; Ismail et al., 2019; Zeb et al., 2020). Research has shown that the patterns of vegetation are widely influenced by ecological factors, such as regional topography features (such as aspect and slope), edaphic factors, and anthropogenic pressure (Rahman et al., 2021). Relation of vegetation attributes, indicator values (predictable richness), and ecological gradients establish various community structures (Ullah et al., 2015; Iqbal et al., 2018; Ismail et al., 2019). In an ecosystem indicator species monitor outcoming changes in the component of plant associations that result from various environmental factors which are fundamental baselines in management decisions (Zhang and Zhang, 2011; Li et al., 2017; Rahman et al., 2020).

An elevation gradient is a composite environmental gradient (Zhang et al., 2006; Körner, 2007) that offers a supreme prospect for critically observing species diversity and shaping the composition of plant communities. Variations in elevation, slopes, and aspects also enhance diversity in various plant communities (Arora, 2002; Rahman et al., 2020). In tropical rain forests these gradients are measured as natural monitoring sites where drivers of community distribution patterns and ecosystem functions can be assessed over small geographical reserves (Li et al., 2017; Körner et al., 2017; Veintimilla et al., 2019).

A great concern emerged in ecological and environmental sciences about the strong relationship between biodiversity and ecological factors. Regionally Moist temperate forests with high altitudes in Hindukush-Himalaya are the most liable vegetation to environmental change (Salick et al., 2009; Shaheen et al., 2015). Among different ecological factors, elevation is the most essential ecological factor that monitors species and plant community diversity. Especially in plant community ecology, a lot of work has been carried out on the relationship between species diversity, community diversity, and elevation gradient (Donoghue, 2008; Li and Feng, 2015; Kluge et al., 2017; Lei et al., 2020). This indicates that distribution patterns and richness of plant species with elevation frequently vary along various transects and at various spatial scales in vegetation (Nogués-Bravo et al., 2008; Rowe and Lidgard, 2009).

In Pakistan, moist temperate forests like Lalkoo valley are rich biodiversity hotspots of the great mountain ranges of Hindukush-Himalaya (Ahmad et al., 2016). However, some phytosociological work regarding the establishment of plant communities along an elevation gradient in moist temperate forests has been reported in some countries around the world. The pioneering work of these includes Ahmad (2009) and Siddiqui et al. (2010) used multivariate statistical analysis to inspect the vegetation-environmental complex of blue pine forests of moist temperate zones in Pakistan. Similarly, Shaheen et al. (2015) documented species distribution patterns and community structures of conifers in moist temperate forests of the Kashmir Himalayas, and Dhyani and Dhyani (2016) reported ecosystem provisioning services from moist temperate forest ecosystems in India. We aimed to investigate changes in plant community dynamics along altitudinal and edaphic gradients in Lalkoo moist temperate forest, in Pakistan.

2. Material and Methods

The investigated area Lalkoo is a mountainous moist temperate type of forest, located in the Swat district Hindukush belt of north Pakistan. The area is 60 km from the capital city Mingora/Saidu Sharif. Geographically Lalkoo area lies within the coordinates of 35°08' 27.62"N and 72°23'09.12 " E with an altitudinal range starting from about 1581m.a.s.l., and reaches the highest peak of alpine pastures of 3849 m.a.s.l. The area with a monsoon belt consists of moist temperate forests (Beg and Khan, 1974; Ullah et al., 2015). The annual temperature of the investigated area was recorded at 13.96-22.25 °C. The mean annual rainfall (RF) is 1777mm. The RF was recorded in July and August with a mean total RF of 228.9mm and 220.9mm while minimum RF occurred in November and December which is recorded at 42.4mm and 78.4mm (Data source PMD; http://www.pmd.gov.pk). Lalkoo valley lies in the Sino-Japanese (SJ) phytogeographical region (Ilyas et al., 2015). The investigated area is covered with undulating slopes and ridges covered with thick vegetation in the sub-alpine zone and scrubs and meadows in alpine pastures. Current work on Lalkoo valley is mainly concerned with the establishment of plant communities and distribution patterns in correlation with environmental variables (Zhang et al., 2006; Sanders and Rahbek, 2012; Li et al., 2017).

The phytosociological work of the study area was carried out systematically in six altitudinal transects based on, species richness and diversity, habitats, and physiognomic contrasts. Density (D), Frequency (F), and Cover (C) for each plant species was recorded to attain Importance values (IV) for the establishment of various community patterns (Figure 1). Geographical coordinates of each study site were recorded using Global Position System (GPS). The formation of various plant communities was based on the highest importance values (IV) calculated for each specie following (Badshah et al., 2016; Forzieri et al., 2011; Ilyas et al., 2015; Ali et al., 2018). Total area quantification was assessed by species-area curve by using statistical software PC-ORD version 7.0 (Figure 2).

Plant communities, organization, distribution, and diversity were evaluated along an altitudinal gradient from1970 to 3120m in 54 sites in Lalkoo valley. For detailed data, collection vegetation was systematically divided into

For detailed data, collection vegetation was systematically divided into 6 altitudinal transects, each one with 9 plots (resulting in 54 sampling units), and in each plot you established 3 quadrats – one for each strata for herbs, shrubs, and trees (Kent and Coker, 1992). Vegetation was analyzed by using quadrates 1 × 1 m^2 designed for herbs, 5 × 5 m^2 designed for shrubs and 10 × 10 m^2 for tree species, at each site. To each sampling site, relative and absolute values of density (D), frequency (F), and cover (C) along with their IVI values were recorded following the procedure of Curtis and McIntosh (1950) and Kamran et al. (2019).

During the study 264 plant species were documented in 162 quadrates. The slope and aspect were recorded with the help of a digital compass, elevation was measured by altimeter and the depth of soil (DS) was calculated with a 2m iron rod and ruler of 36Cm was used for analysis of depth of litter (DL). Index of Diversity (D) was measured by using methodology of Simpson (1949) and Shannon (1948) for each stand as (Equation 1):

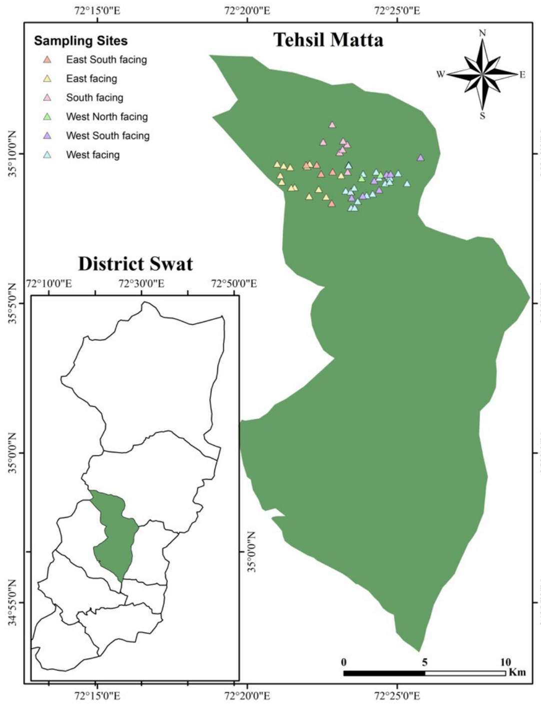

Figure 1. Samping sites in Lalkoo valley.

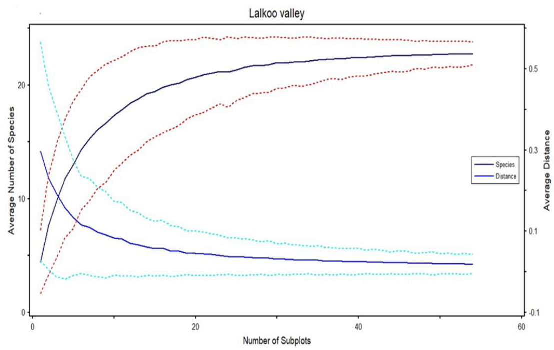

Figure 2. Species area curve obtained from 264 plant species in Lalkoo valley.

$$Diversity\ Index\ (D) = \frac{\sum n(n-1)}{N(N-1)} \tag{1}$$

were, D stands for index of diversity, n represents the sum of individuals of a particular species, and N is the sum of individuals of all species.

The Shannon Wiener index (H') is the measure of the average degree of uncertainty in expecting what species of an individual selected at arbitrary from a sampling unit will fit to (Shannon 1948).

If pi is the proportion of individuals from overall samples of species i, then Shannon Wiener indexes of diversity H' is (Equation 2).

$$H' = \sum_{i=1}^{S} pipilnpi \quad (2)$$

Multivariate analyses were carried out for clustering plant communities by using polythetic diverse classification TWINSPAN- Two-way Indicator Species Analysis (Hill, 1979). The soil texture (Sand %, Silt %, Clay %) was determined by technique as described by Koehler et al. (1984). Other factors determined were Potassium mg/Kg), Phosphorus mg/Kg) and Nitrogen % (Soltanpour, 1991; Rahman et al., 2016), EC dSm-1 (Wilson and Bayley, 2012), CaCO3% (Black, 1965), Organic matter % (Nelson and Sommers, 1982), pH (McLean, 1982), Grazing class1≤5, Anthropogenic pressure/ Deforestation class1≤5, EC dSm-1 (Rahman et al., 2021). Species-environmental correlations were assessed by applying CCA- canonical correspondence analysis using PC-ORD Version 7.0 (McCune and Mefford, 1999) to categorize main plant clusters entitled plant communities (Haq et al., 2017). The computation cluster was done on resemblance via Sorenson Distance Measurements, using Ward's linkage method and IVI (Greig- Smith 1983; Siddiqui et al., 2010; Haq, 2018). For authentic clustering of distributed plant species, the most accurate and accepted analyses TWINSPAN- Two-way Indicator Species Analysis, correlation analysis, and CCA- Canonical Correspondence Analysis were in common practice in the community ecology were followed (Ahmad, 2009 and Siddiqui et al., 2010).

3. Results

3.1. Plant community classification

Clustering describes the unsupervised learning task of partitioning observations into homogenous subsets, or clusters, to uncover subpopulation structure in a dataset. Hierarchical cluster analysis (TWINSPAN) classified 264 plant species into eleven community types by using PC-ORD 7. Figure 3. A comprehensive explanation of these community types concerning associated species of plants and ecological edaphic and topographic variables (Supplementary material 1).

3.2. Berberis -Abies -Bergenia community (BAB)

BAB community was established in 06 sampling sites comprising 47 species of plant and is located from 2125-2240m, latitude (35°08'45.95" - 35°09'36.58"N) and longitude (72°23'17.47" -72°23'19.08 "E). The leading indicator species of this association were *Berberis lyceum (*35.02 IVI), *Abies pindrow* (107.1 IVI), *Bergenia ciliate* (14.2 IVI) as indicated in Table 1 Other most co-dominant shrubs were *Rubus sanctus* (23.3 IVI), *Indigofera heterantha* (41.7 IVI). Herbs of this community with the highest importance values were *Agrostis tenella* (12.5 IVI), *Carex remota* (10.4), *Pseudomartensia parvifolia* (9.7), *Polygonum alpinum* (8.2 IVI), *Microstegium nudum* (8.2 IVI), *Plantago lanceolata* (7.5 IVI), *Rumex hastatus* (7.4 IVI), *Thlaspi arvense* (7.4 IVI), *Veronica anagalis-aquatica* (7.2 IVI), *Androsace rotundifolia* (14.2 IVI) . The trees were *Celtis australis* (22.2 IVI) and *Juglans regia* (22.2 IVI). Due to large number of the co-dominant/ associated species, so they are resented in supplementary material 3. The soil of this community was sandy loam with slightly acidic (pH 4.9-4.3) and contained 6.8±2.3% organic matter, potassium 132.67-87.37 mg/Kg, 9.3-7.9% calcium carbonate, phosphorous 3.09-1.72 mg/Kg, nitrogen 0.35-0.13%, EC 0.27-0.27dSm^{-1}. The content of silt, sand, and clay was 51.7-31.2%, 37.7-15.1%, and 6.3-2.7% respectively. This community was under high grazing (GP=4), and deforestation pressure (DP=5) as presented in Supplementary material 1.

3.3. Picea- Indigofera- Poa community (PIP)

Picea- Indigofera- Poa association was evaluated in 21 sampling sites between the elevation range of 2125-

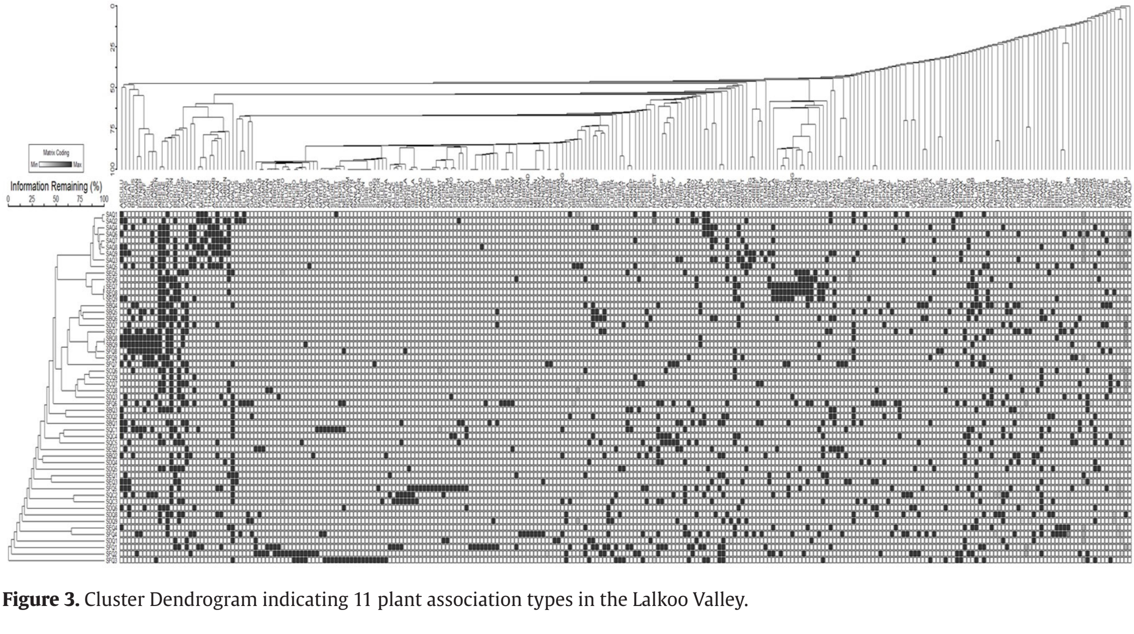

Figure 3. Cluster Dendrogram indicating 11 plant association types in the Lalkoo Valley.

Table 1. Overall indicator species from eleven plant communities with the highest importance value index (IVI) in Lalkoo valley.

Botanical Name	ROD/C	RD	RF	IVI	IVI%
Berberis lyceum Royle	16.82	0.02	18.18	35.02	11.67
Bergenia ciliate (Haw.) Sternb.	11.53	0.24	2.43	14.2	4.73
Indigofera heterantha Brandis	6.52	20.63	14.632	41.7	13.90
Poa alpina L.	1.20	30.31	7.46	38.9	12.96
Quercus dilatata A.Kern.	44.25	5.08	24.99	74.3	24.76
Viburnum cotinifolium D. Don	9.37	28.3	16.66	54.3	18.10
Picea smithiana (Wall.) Boiss.	33.45	24.44	18.75	76.6	25.53
Salix acmophylla Boiss.	6.48	9.37	13.04	28.9	9.63
Primula rosea Royle	5.72	0.02	1.44	7.3	2.43
Abies pindrow (Royle ex D.Don) Royle	43.85	42.25	21.05	107.1	35.70
Taxus wallichina Zucc.	15	5.24	3.70	23.5	7.83
Poa supina Schrad.	0.26	7.58	2.2	10	3.33
Viburnum grandiflorum Wall. ex DC.	10.70	2.11	7.14	19.9	6.63
Lithospermum arvense L.	1.54	3.29	1.92	6.7	2.23
Berberis pseudoumbellata R.Parker	8.35	12.13	16.66	37.1	12.36
Carex cardiolepis Nees	1.98	9.48	5.26	16.7	5.56
Pinus wallichiana A.B.Jacks.	67.79	45.43	19.05	123.2	41.06
Poa nemoralis L.	0.71	17.09	4.76	22.6	7.53.
Parrotiopsis jacquemontiana (Decne.) Rehder	10.35	38.98	21.05	70.3	23.43
Poa annua L.	1.051	42.79	10.63	54.4	18.13

Abbreviations: RDO/C = Relative dominance or cover; RF = Relative frequency; IVI = Importance values index; RD = Relative density.

3045m. A total of 67 plant species were recorded in PIP community; *Picea smithiana* was the leading specie with the highest IVI value (76.6) followed by *Indigofera heterantha* (41.7) and *Poa alpine* (38.9). Tree species of this association were *Abies pindrow* (107.1), *Alnus nitida* (32.8 IVI), *Taxus wallichina* (23.5 IVI), and *Quercus baloot* (22.5 IVI) were stands as Co-dominant. While *Viburnum grandiflorum* (19.9 IVI), *Andrachne cordifoli* (33.1 IVI), and *Thalictrum cultratum* (31.1 IVI) were co-dominant shrubby vegetation in the study area. Topmost common co-dominant herbs (supplementary material 3) recorded were *Plantago major* (19.9 IVI), *Plantago lanceolata* (17.6 IVI), *Poa bulbosa* (14.6 IVI), *Achillea ambugas* (10.7 IVI), *Bergenia ciliata* (14.2 IVI) and *Polygonum aviculare* (9.1 IVI) as presented (supplementary material 3). Overall, some herbs were found with the lowest importance values (rare species) including *Ajuga parviflora* (2.7 IVI), *Bistorta amplexcaulis* (2.2 IVI), *Bromus pectinatus* (2.7 IVI), *Poa nemoralis* (22.6 IVI), *Poa supina* (10 IVI), *Viola biflora* (2.2 IVI) and *Stellaria media* (2.9 IVI).

Soil content of *Picea- Indigofera- Poa* association was loamy with a slightly acidic nature having a pH of 5.3-4.6. Soil texture content includes silt (41.7-32.2%), clay (8.2-4.7%) and sand (31.3-13.3%). Electrical conductivity 0.33-0.11 dSm^{-1} was recorded. The soil contained 3.63-1.83 mg/Kg phosphorus, 0.31-0.18% nitrogen, 135.45±86.787 mg/Kg potassium, 8.9-3.7% calcium carbonate and 3.1-2.3% organic matter. PIP association was recorded under the low effect of grazing pressure(GP=2) and deforestation pressure (DP=1).

3.4. Abies - Parrotiopsis - Poa community (APP)

This community was distributed from 2092-3095m, latitude (35°08'15.23"- 35°09'39.83"N) and longitude (72°23'39.01" -72°20'59.96 "E).The leading species of APP community were *A-pindrow*, *P-jacquemontiana* and *P-alpina* having importance values 107.1, 70.3 and 38.9 respectively. The second most diagnostic tree species were *Quercus dilatata* (74.3 IVI) and *Pinus wallichiana* (123.2 IVI). The second most leading shrubby plant species were *Viburnum grandiflorum* (19.9 IVI), *Juniperus communis* (25.9 IVI) and *Rhamnus purpurea* (23.2 IVI), while herbs were *Poa nemoralis* (13.7 IVI), *Valariana jatamansi* (10.2 IVI), *Agrostis tenella* (10.2 IVI), *Filipendula ulmaria* (9.3 IVI), *Aconitum violaceum* (8.4 IVI), *Anaphalis nepelnsis* (2.4 IVI), *Ipomoea hederacea* (8.3 IVI) and *Poa annua* (8.2 IVI) . Very rare species of APP were *Gagea elegans* (3.4 IVI), *Gallium asplenioides* (3.4 IVI), *Justicia adhatoda* (3.3 IVI), *Arisaema flavum* (3.1 IVI) and *Swertia ciliate* (3.0 IVI). The soil was mostly silt loam that contained 3.9-2.5% organic matter, 9.3-2.4% calcium carbonate, 167.23-71.34 mg/Kg potassium, 0.6-0.17% nitrogen, 2.3-1.84 mg/Kg phosphorus and 4.9-6.1 pH. Soil content with silt, clay and sand were 53.5-37.9%, 6.3-2.9%, 21.5-15.6% respectively. Grazing was low while deforestation pressure was slightly moderate (Supplementary material 1).

3.5. Quercus - Viburnum - Poa community (QVP)

QVP community existed in high elevation flora between 2368-2920m with latitude (35°09'12.32" - 35°09'15.16"N) and longitude (72°24'45.50" - 72°20'39.43"E). The prominant (Table 1) dominant species includes *Quercus dilatata* (74.3 IVI), *Viburnum cotinifolium* (54.3 IVI) and *Poa alpina* (38.9 IVI). The co-dominant herbs included *Rumex nepalensis* (17.5 IVI), *Persicaria capitate* (15.4 IVI), *Potentilla atrosanguinea* (15.2 IVI), *Digitaria ciliaris* (15.1 IVI), *Viola canescens* (12.2 IVI), *Potentilla nepalensis* (11.6 IVI) and *Nepeta laevigata* (11.4 IVI). Common representative co-dominant trees were *Quercus semecarpifolia* (50.25 IVI) and shrubs with importance values were *Salix acmophylla* (28.9 IVI), *Parthenocissus semicordata* (37.5 IVI) and *Buxus wallichiana* (34.6 IVI). Soil of QVP community the was slightly acidic with percentage of 39.4-16.7 sand, 5.3-2.7 clay, 93.1-31.9 silt. Recorded phosphorus values of soil were 3.09-1.91 mg/Kg, potassium 135.45-61.56 mg/Kg, EC were 0.17-0.007 dSm^{-1}, nitrogen 0.38-0.18%, organic matter 2.8-2.3% and CaCO3% were 7.5-3.6% (Supplementary material 1).

3.6. Picea - Salix -Primula community (PSP)

Picea - Salix -Primula possesses an average number of 81 plant species concerning other community types in the study area. This association was found in 12 sampling sites accompanied by 81 plant species located between 2087-2865m. The representative indicator species of this vegetation type were *Picea smithiana*, *Salix acmophylla* and *Primula rosea* with the highest importance values (76.6 IVI), (28.9 IVI) and (7.3 IVI) respectively. The second topmost dominant species of trees were *Abies pindrow* (107.1 IVI) and *Pinus wallichiana* (123.2 IVI) while shrubby vegetation included *Viburnum cotinifolium* (54.3 IVI), *Parrotiopsis jacquemontiana* (70.3 IVI), *Indigofera heterantha* (41.7 IVI) and *Zanthoxylum armatum* (24.9 IVI). Among 55 herb species of PSP association 6 plant species were co-dominant of which *Ajuga bracteosa* (6.2 IVI), *Carex schlagintweitiana* (5.5 IVI), *Solena amplexicaulis* (5.2 IVI), *Veronica anagalis-aquatica* (5.2 IVI), *Impatiens edgeworthi* (4.8 IVI) and *Plantago lanceolate* (4.6 IVI). The loamy soil of PSP community contained 10.3-2.4% calcium carbonate, 133.4±113.57 mg/Kg potassium, 3.23-1.91 mg/Kg phosphorus, 0.29-0.14%nitrogen, 2.9-2.1% organic matter and EC 0.19-0.07 dSm^{-1}. Soil pH values were 6.2-4.5 with clay 7.3-2.4%, sand 29.7-15.3% and silt 39.6-33.7%. The community was affected by moderate grazing and deforestation.

3.7. Abies - Viburnum - Poa community (AVP)

This Plant community were found between 2198-2635m, latitude (35°08'15.10"- 35°09'34.94"N) and longitude (72°23'91.95" -72°21'59.83 "E). Based on 15 investigated sites this community contained a maximum number of 101 plant species including 10 trees, 22 shrubs and 69 herbs. The topmost dominant species of this plant community were *Abies pindrow* (107.1 IVI), *Viburnum cotinifolium* (54.3 IVI) and *Poa alpina* (38.9 IVI). The top most co-dominant herb species of AVP community were *Polygonum plebeium* (10.6 IVI), *Rumex nepalensis* (8.6 IVI), *Poa annua* (54.4 IVI), *Carex infuscate* (7.2 IVI), *Bromus japonicas* (7.1 IVI), *Potentilla nepalensis* (6.8 IVI), *Bergenia ciliate* (14.2 IVI), *Swertia ciliate* (5.8 IVI), *Potentilla atrosanguinea* (5.8 IVI), *Medicago polymorpha* (5.7 IVI), *Ajuga bracteosa* (5.4 IVI), *Ajuga bracteosa* (5.3 IVI), *Polygala abyssinica* (5.3 IVI), *Pimpinella stewartii* (5.3 IVI), *Poa bulbosa* (5.3 IVI) and *Origanum vulgare* (5.1 IVI). Among trees (supplementary material 3) *Picea smithiana* (76.6 IVI) were found second most dominant plant species. AVP plant community with co-dominant shrubby flora included *Sarcococca saligna* (22.3 IVI), *Rhamnus purpurea* (20.2 IVI), *Andrachne cordifolia* (19.2 IVI), *Salix acmophylla* (28.9 IVI) and *Buxus wallichiana* (15.5 IVI). The soil was silt loamy that contained 13.3-3.7% calcium carbonate, 139.05-88.23mg/Kg potassium, 2.67-1.82mg/Kg phosphorus, 0.2-0.11%nitrogen, 3.7-2.1% organic matter and EC 0.29-0.007 dSm^{-1}. Soil pH value were 4.9-4.1 with clay 5.8-3.3%, sand 32.4-17.7% and silt 57.5-38.4%. AVP community was under moderate deforestation (DP) and very low grazing pressure (GP).

3.8. Viburnum - Taxus - Poa community (VTP)

A total of 24 sampling sites were clustered in this association by TWINSPAN. In comparison with other community types, VTP was a unique association with the highest recorded 141 plant species. The top 3 indicator species of this association were *Viburnum cotinifolium, Taxus wallichina* and, *Poa supine* with importance values of 42.1, 23.5 and 10 respectively. Co-dominant trees were *Ilex dipyrena* (21.5 VI), *Aesculus indica* (17.6 IVI) and *Pyrus pashia* (18.7 IVI), however *Diospyros lotus* (5.9 IVI), *Quercus dilatata* (5.9 IVI) and *Alnus nitida* (4.7 IVI) were rare species of this association. Co-dominant shrubs with high IVI values were *Parrotiopsis jacquemontiana* (23.9 IVI), *Indigofera heterantha* (23.6 IVI) and *Rhamnus purpurea* (22.8 IVI) while *H. nepalensis, R. alpestre, R. ellipticus* and *Z. armatum* were rare most shrubs of this community. Among 106 herbs second high IVI values were found for *Hypericum perforatum* (8.1 IVI), *Primula denticulate* (5.9 IVI) and *Cynodon dactylon* (5.0 IVI) while 28 plant species were lowest IVI values equal to 1of which *A. mutica*, *A. vulgaris*, *A. grahamianus*, *B. pectinatus*, *V.thapsus*, *T. minuta*, *S. laureola*, *S. auriculata*, *P. eriocarpa, P. eriocarpa* and *P. nepalensis* were prominent rare species. The soil were mostly loamy and slightly acidic (pH 5.2-4.3) with silt 36.1-31.1%, clay 7.6-4.9% and sand 35.5-13.3%. Soil also contained 5.7-2.3% organic matter, 12.3-3.5% calcium carbonate, EC 0.18-0.09 dSm^{-1}, 115.27-71.34mg/Kg potassium, 0.6-0.27% nitrogen, 3.03-1.72mg/Kg phosphorus. Grazing pressure was high with moderate deforestation.

3.9. Pinus -Viburnum -Lithospermum community (PVL)

This is a unique association with the greater number of 126 plant species which represents the best growth of vegetation. The community is situated at lower altitudes between 2000-2230m. The highest importance value 46.2 were recorded for *Pinus wallichiana* that stands 1st dominant among 14 tree species, 19.6 for *Viburnum grandiflorum* as 1st dominant among 23shrub species and 6.7 *Lithospermum arvense* as 1st dominant among 89 herb species. The 2nd most dominant tree species were *Pyrus pashia*(44.6 IVI), *Ficus carica*(29.6 IVI), *Ailanthus altissima* (27.3 IVI), *Diospyros lotus L.*(26.6 IVI) and *Platinus orientale*(26.6 IVI). 2nd most dominant shrubs with nearest importance values were 19.1,18.6,16.5,16.3,16.3 were recorded for *C. microphyllus, B. parkeriana, J. humile, S. saligna* and *S. canescens* respectively (supplementary material 3). Recorded 2nd dominant 6 herbs were *V. jatamansi*(5.9 IVI), *V. thapsus* (5.9 IVI), *G. ocillatum*(5.3 IVI), *S. urticifolia*(5.2 IVI), *T. royleanum*(5.1 IVI) and *S. auriculata*(5.0 IVI). Overall, 5 plant species *Anaphalis triplinervis, Arisaema flavum, Artemisia japonica, Arthraxon prionodes* and *Festuca gigantean* of PVL association type with lowest importance values were rare. PVL community contained silty loam soil that highly acidic (pH 3.7-4.6) and contained 3.9-2.5% organic matter, potassium 155.52-85.37mg/Kg, 7.9-3.5% calcium carbonate, phosphorous 2.1-1.23mg/Kg, nitrogen 0.37-0.24%, EC 0.26-0.11 dSm^{-1}. Silt, sand and clay values were 43.7-36.1%, 39.4-15.6% and 7.1-3.7% respectively. The community is under severe grazing and deforestation pressure(DP) however terrain cultivation was common to this community.

3.10. Abies - Berberis - Carex community (ABC)

ABC community was recognized in 18 sampling sites started in the lower elevation range of 1970m at Dunkacha area, with latitude(35°08'08.48" - 35°09'16.81"N) and reaches at higher elevation range at Julba area, with longitude (72°22'28.35" -72°21'06.09 "E). TWINSPANS clustered a total of 62 plant species for ABC plant community. The leading dominant tree species of this community were *Abies pindrow* (95.5 IVI) followed by a shrub specie *Berberis pseudoumbellta* (37.1 IVI) and the herb specie *Carex cardiolepis* (16.7 IVI). The topmost leading co-dominant 4 tree species with importance values were *Abies pindrow* (95.5 IVI), *Picea smithiana* (56.6 IVI), *Quercus semecarpifolia* (33.1 IVI) and *Pinus wallichiana* (32.2 IVI). Among shrubs *Parrotiopsis jacquemontiana* (36.1 IVI), *Viburnum cotinifolium* (32.6 IVI) and *Daphne mucronata* (26.9 IVI) were recorded as the top most co-dominant species. While *Plantago major* with IVI 14.6, *Oxalis corniculata* with IVI 13.2, *Heliotropium strigosum* IVI 12.9 and *Bergenia ciliate* with IVI 12.1 were stood second co-dominant herbs of this community. In overall recorded species of ABC community *A. pubiflora* with IVI 2.8 and *F. nubicola* with IVI 2.9 were highly rare (supplementary material 3). In this community the soil contained sand 31.5-15.3%, clay 5.3-2.9%, silt 44.6-31.9%, 5.3-4.8% calcium carbonate, 143.27-73.97mg/Kg potassium, 3.09-1.83mg/Kg phosphorus, 0.36-0.18%nitrogen, 4.6-2.9% organic matter and EC 0.26-0.11 dSm^{-1}. Soil were comparatively neutral with pH value of 7.3-4 while deforestation and grazing pressure was moderate with the high frequency of regenerates.

3.11. Pinus -Viburnum - Poa community (PVP)

Pinus -Viburnum - Poa community is located at altitude of 2000-2345m. *Pinus wallichiana* leading specie with 123.2 IVI value followed by *Viburnum cotinifolium* (35.1) and *Poa nemoralis*(22.6). The recorded 16 samplings sites of PVP plant community in the investigated area 3 tree species included *Quercus incana* (36.1 IVI), *Abies pindrow* (26.1 IVI), and *Aesculus indica* (22.1 IVI) while among shrubs *Parrotiopsis jacquemontiana* (26.4 IVI), Rubus ellipticus(22.5 IVI) and *Indigofera heterantha* (20.8 IVI) represents co-dominant species.Of total 65 herb species of PVP community type *Poa annua* (21.9 IVI) *Paeonia emodi*(10.2.4 IVI) and *Chrozophora tinctoria* (7.9 IVI) were the second co-dominant species. Moreover of total of 99 plant species *Sisymbrium orientale, Sigesbekia orientalis, Sambucus wightiana, Fumaria indica, Aquilegia pubiflora, Bidens tripartite* were the most commonly rare occurring species.The silty loam soil of *Pinus -Viburnum - Poa* community contained 13.5±5.6% calcium carbonate, 133.4-74.12mg/Kg potassium, 2.67-1.84mg/Kg phosphorus, 0.35-0.18%nitrogen, 6.7-2.3% organic matter and EC 0.25-0.13 dSm^{-1}. Soil was slightly acidic properties with a content of clay 6.7-2.9%, sand 35.5-15.7%, and silt 93.5-37.3%. The community were under low grazing and high deforestation pressure (Supplementary material 1).

3.12. Parrotiopsis- Picea- Poa community (PPP)

PPP is a unique community association with 15 sampling sites included 14 tree species,12 herbs and 39 shrubs located within altitudinal range of 2085-2920m, latitude(35°08'20.77" - 35°09'04.34"N) and longitude(72°22'48.75" -72°24'45.48 "E).Followed by TWINSPAN cluster analysis this community type is accompanied by dominant species *Parrotiopsis jacquemontiana, Picea smithiana,* and *Poa annua* with IVI values 70.3,68.1, and 54.1 respectively. Other 2nd leading co-dominant species of shrubs were *Zanthoxylum armatum* (27.3 IVI), *Andrachne cordifolia* (40.6 IVI) and Cotoneaster affinities (21.1 IVI) followed by 2 tree species were *Abies pindrow* (51.26 IVI) and *Taxus wallichina* (46.0 IVI). The topmost herb species including *Swertia chordata* (14.8 IVI), *Ajuga bracteosa* (12.1 IVI), and *Viola canescens* (11.1 IVI) were occurring as co-dominant of PPP association.

Soil were slightly acidic with silt 47.8-36.1%,clay 4.7-3.4 and sand 21.5-15.1%. Soil chemical content were 3.5-2.1% organic matter, 6.7-2.4% calcium carbonate, EC.18-0.07, 98 dSm^{-1}. Major soil content were 23-61.56mg/Kg potassium, 0.6-.23% nitrogen, 2.89-1.91mg/Kg phosphorus (Supplementary material 1).

3.13. Plant community diversity parameters

Shannon's diversity index for all species shows significant differences among different plant associations and presents a gradual increase from lower altitude to higher altitudes. Values obtained from the analysis of Shannon-Wiener and Simpson indices were used for measurements of diversity among different plant communities presented in Table 2. Of the total eleven plant communities, *Picea- Indigofera- Poa, Quercus -Viburnum - Poa,* and *Berberis- Abies- Bergenia* represents the lowest Shannon diversity values 0.76, 1.2 and 1.50 respectively. Hence strength of diversity become increases for certain communities like *Abies- Parrotiopsis- Poa (2.42),* and *Abies- Viburnum- Poa(2.03), Viburnum- Taxus- Poa(2.50) and Pinus- Viburnum- Lithospermum(2.65).* However, four plant communities of the study site were significantly highest diversity values from 3.6 -3.99 for community types *Abies-Berberis-Carex, Parrotiopsis-Picea-Poa, Pinus-*

Table 2. Calculated values of Diversity indices from Lalkoo valley Swat.

Community	Altitudinal range	NR	NS	H	D	IVI	Species/ Community
Berberis- Abies- Bergenia (BAB-I)	2125±2240	06	47	1.50	0.96	35.02±3.25	47
Picea - Indigofera- Poa (PIP-II)	2125 ± 3045	21	67	0.76	0.95	49.95±1.93	67
Abies- Parrotiopsis- Poa(APP-III)	2092 ± 3095	15	73	2.42	0.91	64.09±3.08	73
Quercus -Viburnum - Poa. (QVP-IV)	2368 ±2920	15	47	1.21	0.93	74.03±3.04	47
Picea- Salix - Primula (PSP-V)	2087 ± 2865	13	81	3.99	0.97	76.06±2.11	81
Abies - Viburnum -Poa (AVP-VI)	2198 ± 2635	15	101	2.03	0.97	107.1±2.01	101
Viburnum -Taxus - Poa (VTP-VII)	2090 ± 2805	24	141	2.50	0.98	42.01±1.63	141
Pinus -Viburnum - Lithospermum (PVL-VIII)	2000 ± 2230	10	126	2.65	0.99	46.02±2.25	126
Abies-*Berberis-Carex (ABC-IX)*	1970 ± 2890	12	62	3.6	0.96	95.05±2.84	62
Pinus-Viburnum-Poa (BVP-X)	2000 ± 2345	16	99	3.79	0.94	123.2±2.18	99
Parrotiopsis-Picea-Poa (*PPP-XI*)	2085 ± 2920	15	65	3.11	0.87	70.03±3.26	65

NR: Number of releves; NS: Number of species; H: Shannon index; D: Simpson index; IVI: Importance values index.

Viburnum-Poa, and Picea- Salix - Primula that indicates overall potential diversity.

Simpson, s diversity index for all plant species shows the remarkable differences among distributed groups. These differences are indeed related to human interference like deforestation and grazing intensity. Concerning the vertical structure of the study area, this index shows a significant difference only in the *Pinus- Viburnum- Lithospermum* community with a maximum value D= 0.99 as presented in Table 1. However *Berberis-Abie- Bergenia*, *Abies- Parrotiopsis- Poa*(APP-III), *Viburnum- Taxus- Poa* (VTP-VII) and *Pinus- Viburnum- Poa* stands average Simpson, s diversity values from 0.99 - 0.91 .More Plant community *Parrotiopsis- Picea- Poa* stands the lowest value of Simpson, s diversity (0.87).

3.14. Canonical correspondence analysis

For investigation, the effects of eleven environmental variables(EV) on the distribution patterns of plant communities Canonical correspondence analysis (CCA) was used (Figures 4-6). Analysis of CCA model (11-Environmental variables) revealed variation of 3.8 Axis -1, 3.3 Axis -2, and 2.9 Axis -3 alone of total unexplained variance (Figure 4 and supplementary material 2). The total variance ("inertia") of CCA data was 8.578. The main patterns in plant community distribution in the overall data set of CCA reflect on silt, altitude, and calcium carbonate. Silt represents a strong positive correlation on *Parrotiopsis - Picea – Poa* (PPP) community and a negative with *Berberis- Abies- Bergenia* (BAB) along Axis-2. Interestingly PPP community shows potential growth toward high altitudes (2920m) while BAB community towards lower altitudes (2085m) as presented in Figure 5. While *Abies- Parrotiopsis- Poa*(APP) shows a strong negative correlation with Axis -1 influenced by calcium carbonate. Similarly, *Picea- Indigofera- Poa* community affected by altitude shows a strong positive correlation with Axis -1. Most of the plant communities were clustered around the center of the ordination axis

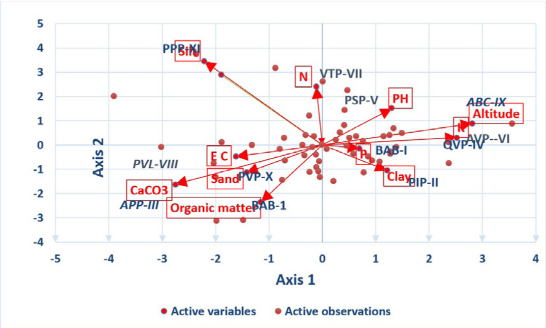

Figure 4. Results of CCA joint biplot showing results for eleven plant communities' correlation with environmental variable. BAB-I: *Berberis- Abies- Bergenia*; PIP-II: *Picea-Indigofera- Poa*; APP-III: *Abies- Parrotiopsis- Poa,QVP-IV:Quercus-Viburnum-Poa,PSP-V:Picea-Salix-Primula,AVP-VI:Abies-Viburnum -Poa*; VTP-VII: *Viburnum-Taxus-Poa*; PVL-VIII: *Pinus-Viburnum-Lithospermum*; ABC-IX: Abies-*Berberis-Carex*; PVP-X: *Pinus-Viburnum-Poa*; and PPP-XI: *Parrotiopsis-Picea-Poa* represents community types.

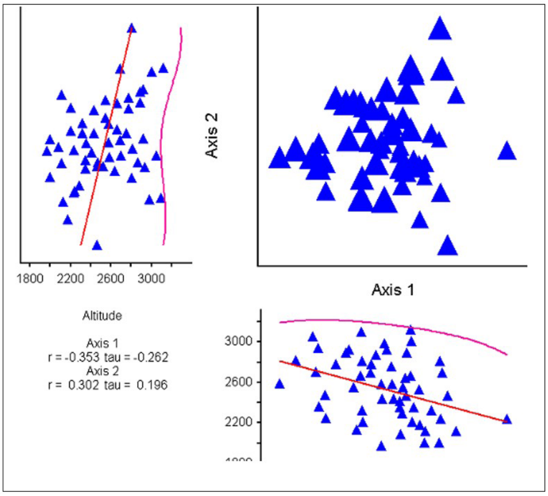

Figure 5. CCA plot Analysis of illustrating the influence of elevation on spreading pattern of plant communities in Lalkoo valley Swat.

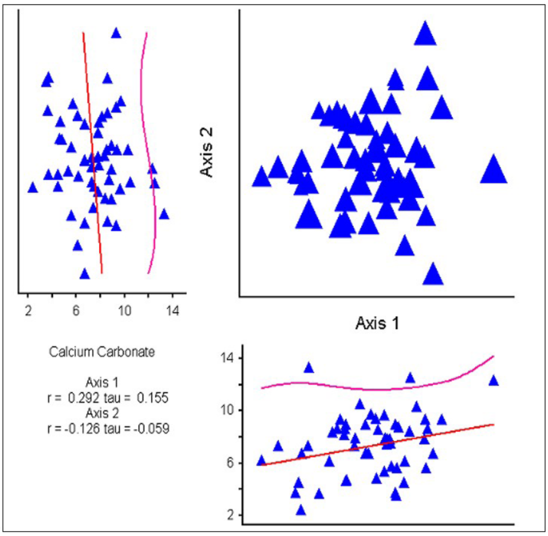

Figure 6. Analysis of CCA plot illustrating correlation between calciumcarbonate and plant communities along axis-1 and 2.

(Figure 4 and supplementary material 2) while among all environmental variables phosphorous was found negligible influence on the distribution of plant communities.

Our study also revealed that, *Quercus dilatata, Abies pindrow, Pinus wallichiana* and *Picea smithiana* had high dominance trees in terms of IVI while in shrubs were *Berberis lyceum, Indigofera heterantha*, and *Viburnum cotinifolium* and herbs were *Poa alpina*, and *Poa annua* (Table 1).

4. Discussion

Multivariate analysis was carried out to examine the distribution and classification of plant communities that vary greatly in Lalkoo Hindukush mountainous range Pakistan. The most important factors controlling this variation is elevation, soil texture, soil organic matter, soil pH, soil electrical conductivity, soil chemical nature topography, and so on among which elevation is a key factor that affect community distribution (Keddy, 1992; Rahman et al., 2021).

The systematic classification of plant communities is a basic tool used in vegetation ecology that is subjected for various purposes like conservation, land planning and management data reduction and synthesis that were used by scientists up to date (Diamond, 1975; Götzenberger et al., 2012; Oyola-Guzman and Oyola-Morales, 2018) however traditional classification of plant communities is typically constructed on general features of species assessed by personal experience (Yong-Chang, 2004; Qin et al., 2016). The methods applied in the present analysis provide a baseline for users to provide multiple classification procedures of plant communities for accurate information in future perspectives. The study identified 264 species of vascular plants that were classified in to eleven plant community types (clusters) with different diagnostic species in Lalkoo mountainous forest. Differences among dominant species and forest plant community compositionindicate an influence of environmental, anthropogenic, and topographic factors (Wiens and Donoghue, 2004; Khan, 2012; Idowu et al., 2020; Ohler et al., 2020; Rahman et al., 2021). The dominant plant species of the study area in all communities (1-11) are *Berberis, Picea smithiana, Abies pindrow, Abies pindrow, Viburnum grandiflorum Pinus wallichian,* and *Parrotiopsis jacquemontiana* which were also reported for adjacent temperate and moist temperate forests of Pakistan as dominant species in most of the plant communities (Khan, 2012; Habib et al., 2016; Shaheen et al., 2017). *Indigofera,* Salix, *Taxus, Bergenia, Poa, Carex, Lithospermum,* and *Primula* is representing typical leading species of the study area that have been reported in different plant communities connected to moist temperate forests (Khan et al. 2020).

One of the basic parameters for measurement of plant community structure and composition is the importance value index (IVI), Species with the same IVI have the same or similar population structure (Lamprecht, 1989; Hundera and Gadissa, 2008) resulting in maximum IVI values ascribed to some species. In comparison to this approach, all studied species showed different ecological importance and difference in relation to their recorded values of IVI. This indicates that these nine plant species are highly ecological significance that is adapted to high ecological amplitude, disturbance, and influence of local communities in Lalkoo moist temperate forest.

Assessment of plant communities -environmental correlation multivariate technique CCA was applied. Of the environmental variables, Altitude, Clay, Silt, Sand, pH, Organic Matter, Calcium Carbonate, Nitrogen, Phosphorus Potassium, and Electrical Conductivity affect the plant community's classification and distribution. This is also documented that a species with the high cumulative percentage of variance (3.8) and environmental correlation on the ordination scale was exhibited along axis 1 . However of the total measured environmental variable used in CCA analysis the most influential factors were Calcium

Carbonate looked to be the cause for the distribution pattern of the community of *Abies- Parrotiopsis- Poa*, silt for *Parrotiopsis- Picea- Poa* community and altitude (Shaheen et al., 2011b) for *Picea- Indigofera- Poa* community. Likewise, outcomes were also described by Khan et al. (2019), and Ahmad et al. (2016).

Altitudinal variation is a significant factor controlling plant community structure. In mountainous forests altitudinal gradient limits species distribution and plant community types (Chawla et al., 2008; Rahman et al., 2022). In this context, a lot of studies were carried out on the variation of the diversity of species along elevation gradient in mountainous forests (Lomolino, 2001). In Lalkoo hills we found a lot of indicator species with different altitudinal preferences for example *Abies pindrow* was found from 1900-2920m, *Picea smithiana* was of common occurrence in the elevation range of 2215-3045m, *Pinus wallichiana* most abundantly recorded from 2000-2345m, *Parrotiopsis jacquemontiana* ranged from lower elevation 2085m was distributed at high elevation 3095m. *Quercus dilatata* is distributed from mid-elevation (2368m) but shows its peak of dominancy towards high elevations (2920m). Dominant indicator shrubs *Berberis lyceum* and *Indigofera heterantha* herbs *Poa annua and Primula rosea* were found in range from 2000-3045m. All plant species showed significant floristic and structural heterogeneity with local ecological variables. Other studies in the Hindu Kush–Himalayas have documented similar elevation ranges for temperate ecosystems (Shaheen et al., 2012; Rahman et al., 2021).

Present findings revealed that Lalkoo forest is a potentially complex region, chiefly in terms of wide spread range of biodiversity and important portable natural resources. The area is under heavy anthropogenic and biotic pressure which needs conservation strategies for the complete restoration of Lalkoo forest. The present investigation also suggests that if human pressure remains exists in the study area, the established natural plant resources may be disappeared and will follow rapid extinction as observed in the nearby Hindukush mountainous forests of District Swat, commonly Girbanr hills Miandam hills (Hussain et al., 1997), Qalagai hills (Ilyas et al., 2012; Ali et al., 2018). Our description of plant communities, species and environmental variables is an integrated way to study diversity in the ecosystem.

5. Conclusion

Current work investigated 11 plant communities with potential indicator plant species in sub-alpine natural mature forests of Lalkoo Valley, Hindukush mountains Pakistan. These indicators will be helpful in the future for monitoring variations in response to ecological fluctuations that affect plant community structure and composition (Conti et al., 2017). Altitude and edaphic factors (silt, organic matter, and calcium carbonate) played a vital roles in determining the plant communities. These forests provide carbon storage, a better environment, biodiversity, and other natural resources to the indigenous communities. Our analysis also revealed that several anthropogenic and edaphic factors like deforestation, overgrazing, wood extraction, expansion of agriculture fields by the destruction of soil cover, and soil erosion are serious threats to the vegetation in the investigated area Lalkoo valley. It is strictly recommended that conservation strategies are essential to deal with restoration plans, rangeland management, fuel alternatives sources, and local community awareness for restoration of existing natural biodiversity.

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Supplementary Material

Supplementary material accompanies this paper.

Supplementary Material 1. Description of plant communities with their respective values of environmental variables

Supplementary Material 2. Results of Canonical correspondence analysis illustrating relationship of various parameters among species of community and environmental variables (EV).

Supplementary Material 3. Dominant and Rare plant species of each community

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