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MULTIVARIATE ASSESSMENT OF VEGETATION ENVIRONMENT RELATIONSHIPS IN THE CENTRAL KARAKORAM NATIONAL PARK: INSIGHTS FOR CONSERVATION PLANNING

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Abstract

Thirty-two vegetation stands, comprising nine forested (gymnosperm-dominated) and twenty-three non-forested (angiosperm-dominated shrublands), were quantitatively analyzed in Central Karakoram National Park, Gilgit-Baltistan, Pakistan, using the Point-Centered Quarter method for trees and circular plots and quadrats for understorey, shrub, and herbaceous vegetation. Vegetation composition, community structure, and their relationships with environmental gradients (elevation, slope, and edaphic factors) were examined using multivariate techniques, including Ward's hierarchical cluster analysis and Detrended Correspondence Analysis (DCA). Ward's cluster analysis classified the vegetation into four major groups and one isolated stand. Group I represented conifer-dominated forests, primarily composed of *Picea smithiana* with *Pinus wallichiana* and *Juniperus excelsa*. Group II consisted mainly of angiosperm-dominated shrublands, while Group III comprised mixed communities of angiosperms and gymnosperms, with dominance of *Hippophae rhamnoides*. Group IV included angiosperm shrub vegetation with a distinct floristic composition. Stand 17 formed an isolated unit due to its unique species assemblage and higher elevation. Based on dominance and stability across environmental gradients, *Picea smithiana*, *Rosa webbiana*, and *Hippophae rhamnoides* were identified as climax communities of the region. Associated species included *Ribes orientale*, *Berberis lyceum*, and *Tamarix arceuthoides*/*T. leptostachya*, while *Juniperus excelsa* and *Pinus wallichiana* showed strong affinity with *Picea smithiana* forests.

Several rare species, including *Juniperus communis*, *Ribes alpestre*, *Artemisia brevefolia*, and *Urtica dioica*, were recorded, highlighting the conservation value of the park. Understorey vegetation was classified into six groups, with *Rosa webbiana* and *Hippophae rhamnoides* exhibiting the highest frequencies and widest ecological amplitudes.DCA ordination revealed strong correlations of Axis I with slope, soil conductivity, and total dissolved salts, indicating that topography and soil physico-chemical properties play a significant role in vegetation distribution. Weaker correlations observed for certain soil nutrients are attributed to habitat heterogeneity and anthropogenic pressures such as overgrazing, fuelwood extraction, and soil erosion, which disrupt natural species–environment relationships.

The study highlights pronounced vegetation differentiation along altitudinal and edaphic gradients and demonstrates the influence of natural and anthropogenic disturbances on forested and non-forested ecosystems. These findings provide valuable ecological insights into successional dynamics, conservation of climax and rare species, and habitat heterogeneity, offering a scientific basis for forest conservation, ecological restoration, and sustainable ecosystem management in Central Karakoram National Park under changing environmental conditions.

Key words: Multivariate; DCA; Forest; CKNP Vegetation

Introduction

Central Karakoram National Park (CKNP) is a national park located in Gilgit-Baltistan in Pakistan. Thirty-two stands were sampled from different locations of CKNP, Gilgit-Baltistan (Fig. 1). It encompasses some of the world's highest peaks and largest glaciers. Internationally renowned for mountaineering, rock climbing and trekking opportunities, it covers an area of about 10,000 sq. km and contains the greatest concentration of some of the highest mountains on Earth. It has four peaks over 8,000 m including K2 (8611 m), Gasherbrum-I (8068 m), Gasherbrum-II (8035m) and Broad Peak (8051 m), and sixty peaks higher than 7,000m. Due to its unique flora and fauna it has been declared as national park on 1993. Vegetation communities are complex systems influenced by a variety of ecological factors, and understanding their structure and dynamics is a key focus in vegetation ecology. Multivariate techniques, such as cluster analysis and ordination, have become essential tools for the quantitative analysis and description of plant communities (Siddiqui *et al*., 2011). These methods allow researchers to summarize large datasets and reveal underlying patterns in vegetation structure, providing insights into species distributions and environmental

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relationships (Wildi *et al*., 2017). Cluster analysis, in particular, is widely used to identify natural groupings within ecological data. Among the different clustering methods, agglomerative hierarchical clustering is a prominent approach, focusing on the calculation of similarities and dissimilarities among vegetation samples. This method includes several variations, such as nearest neighbor, farthest neighbor, and Ward's method, which has gained particular popularity for its robustness in ecological applications (Ward, 1963; Paal & Trei, 2004).

Ordination techniques, such as Detrended Correspondence Analysis (DCA), are also widely used to explore the relationships between species and their environment (Greigh-Smith, 1983; Chahouki, 2013). DCA, in particular, is well-suited for ecological datasets, helping to visualize patterns in species distribution along environmental gradients (Gauch, 1982). The use of DCA in vegetation studies has provided valuable insights into species-environment interactions and has been successfully employed in numerous ecological research projects (Wildi, 2018). Vegetation and communities of the coniferous forests of the northern Pakistan were quantitatively described by Ahmed *et al*., (2006) and Hussain *et al*., (2010; 2011; 2013).

In Pakistan, multivariate techniques have been applied to analyze the distribution and structure of vegetation across various regions, such as the work of Shaukat & Qadir (1971), who explored plant communities of calcareous hills around Karachi. However, despite the broad use of these methods in other regions, there remains a gap in the application of multivariate analysis within the Central Karakoram National Park (CKNP). This park is home to diverse vegetation types, including both forested and non-forested communities, which are facing significant degradation due to natural and anthropogenic factors. While local management agencies and non-governmental organizations have made efforts to protect these valuable ecosystems, their success has been limited due to the lack of modern scientific tools.

The present study aims to fill this gap by applying multivariate techniques to understand the vegetation dynamics of CKNP. By exploring the underlying group structures of vegetation, describing forested and non-forested communities, and examining the relationship between vegetation and environmental factors, this study seeks to provide insights into the factors contributing to vegetation degradation and inform future conservation efforts.

Material and Methods

Vegetation sampling: The Point Centre Quarter method (Cottam & Curtis, 1956) was used for forested vegetation, while a circular plot (1.5 m radius) was employed for understorey species (Sailas, 2021). According to Ahmed & Shaukat (2012), it has been widely and successfully used by various researchers for different vegetation all over the world including Pakistan. It is flexible, require little labour, computation and easily applied in thick vegetation with rugged topography like Gilgit-Baltistan.

The Quadrat method (Ellenberg & Mueller, 1974) was applied for sampling shrubs and herbaceous vegetation (Ahmed & Shaukat, 2012). A total of 9 forested and 23 non-forested stands were sampled. For multivariate analysis, density (ha-1) of trees, bushes, and herbs, along with the frequency of understorey vegetation, were considered. Twelve dominant species (top three of trees, herbs, and shrubs) and understorey species present in at least five stands (35 species from 65) were selected for analysis (Shaukat, 1989). Understorey vegetation was categorized into five frequency classes (1-20% Rare to 81-100% Very Abundant) following Tansley & Chipp (1926). Cluster analysis and ordination were applied to the vegetation data and correlated with environmental variables (Yılmaz, 2018; Ou, 2020).

Soil analysis: Soil samples were collected from each stand (4-5 samples per stand), mixed, and air-dried at 25-30°C. Physical and chemical properties of soil including pH, conductivity, salinity, total dissolved salts, and organic matter, were analyzed. Soil nutrients (Ca++, K+, Mg++, Co++, Mn+, Zn+, Fe++) were measured using an Atomic Absorption Spectrophotometer (Bilings & Harris, 1965). Maximum Water Holding Capacity (MWHC) was determined by Keen's method (1931).

Environmental variables: Elevation and slope of each stand were measured using a GPS device. Slope was categorized into four classes: gentle (0-15°), moderate (16-30°), steep (31-45°), and very steep (> 46°) following Siddiqui *et al*., (2011).

Ward's clustering method: Ward's agglomerative hierarchical method (Ward, 1963) was used for cluster analysis to classify mixed vegetation (trees, shrubs, herbs) and understorey species based on similarities (McCune & Grace, 2002; Pakgohar, 2021). CLUSTR program was employed to perform the analysis, which combines multiple attributes for optimal clustering (Landau & Ster, 2010).

DCA ordination: Detrended Correspondence Analysis (DCA) was used to ordain vegetation and analyze relationships between species and environmental variables (Hill & Gauch, 1980; Xia, 2023). DCA, implemented via PC-ORD (McCune & Mefford, 1999), provides a comprehensive understanding of vegetative and ecological patterns (McCune & Grace, 2002; Majeed *et al*., 2022).

Results

Ward's clustering method (forested and non-forested vegetation): Cluster analysis using Ward's agglomerative method (Fig. 2) divide the vegetation into 4 distinct groups and one isolated stand at a 75% information level (Euclidean distance = 1.9 x 10^6). The groups and their associated environmental variables are detailed in Tables 1 and 2.

Group I: Comprised 9 stands with dominant species *Picea smithiana* (97 ± 13 density ha-1), *Juniperus excelsa* (70 ± 23 density ha-1), and *Pinus wallichiana* (43 ± 17 density ha-1). The understorey had 33 species, with *Artemisia brevifolia* and *Taraxacum nigrum* as frequent species. This group was located at a high elevation (3362 ± 53 m) and very steep slope (52° ± 6). Soil was slightly acidic pH (5.6 ± 0.14) with low salinity, high conductivity (55.14 ± 6.87), and moderate organic matter (5.36 ± 0.63%).

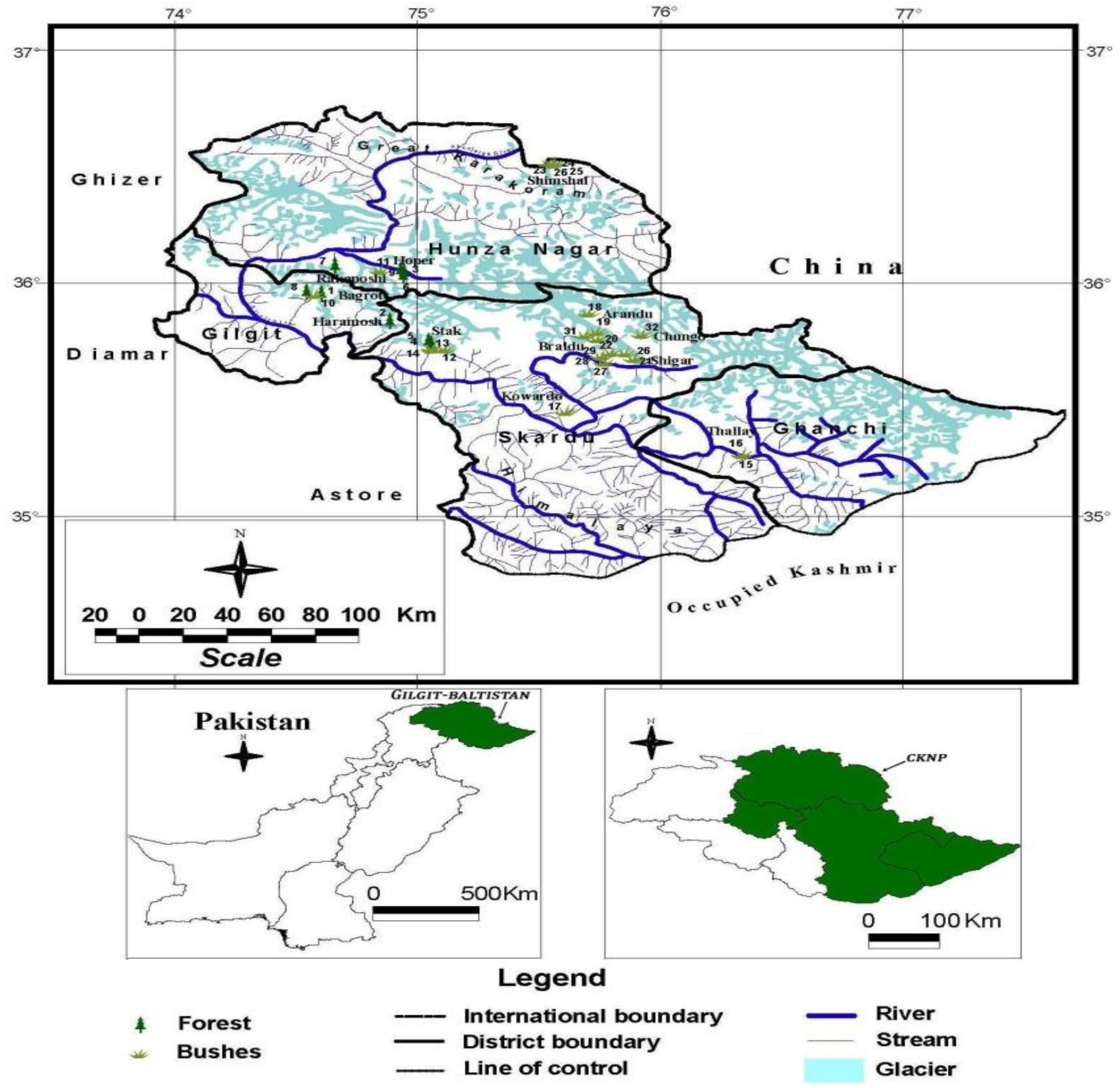

Fig. 1. Study area map (CKNP). Numbers indicating the sampling locations.

Group II: Comprised 9 stands, with *Rosa webbiana* (511 ± 40 density ha-1) as the dominant species. *Hippophae rhamnoides* and *Berberis lyceum* were also recorded. Understorey vegetation consisted of 29 species, with *Rosa webbiana* (52%) and *Hippophae rhamnoides* (47%) as dominant. This group was found at moderate elevation (2975 ± 87 m) and slope (27° ± 3°). Soil nutrients showed a higher concentration of K+, Ca++, and Mg++.

Group III: Comprised 7 stands, with *Rosa webbiana* (390 ± 62 density ha-1) and *Hippophae rhamnoides* (389 ± 20 density ha-1) as dominant species. The understorey included 24 species, with *Hippophae rhamnoides* (46%) and *Rosa webbiana* (43%) as frequent species. It occurred at a slightly higher elevation (2950 ± 99 m) and moderate slope (27° ± 4°). Soil was acidic pH (6.06 ± 0.21) with moderate MWHC (34.71 ± 2.48), and moderate organic matter (3.17 ± 0.56%).

Group IV: Comprised 6 stands with dominant species *Hippophae rhamnoides* (444 ± 47 density ha^{-1}), *Rosa webbiana* (338 ± 38 density ha-1), and *Tamarix indica?* (378 ± 33 density ha-1). Understorey vegetation consisted 25 species, with *Hippophae rhamnoides* (53%) and *Astragallus gilgitensis* (50%) being frequent. This group was found at slightly higher elevation (2940 ± 103 m) and gentle slope (13° ± 5°). Soil conditions showed medium conductivity (49.66 ± 3.37), slightly acidic pH (5.48 ± 0.06), and low organic matter (4.21 ± 0.90%).

Isolated stand: Comprising 15 species with *Rosa webbiana* (1067 density ha-1), *Ribes orientale* (467 density ha-1), and *Berberis lyceum* (333 density ha-1) as dominant species. The understorey includes 15 species with *Rosa webbiana* (100%) as the most frequent. This stand occupied higher elevation (3559 m) with very steep slope (50°). Soil was slightly acidic pH (5.4) with low salinity (0.1), and low organic matter (1.3%).

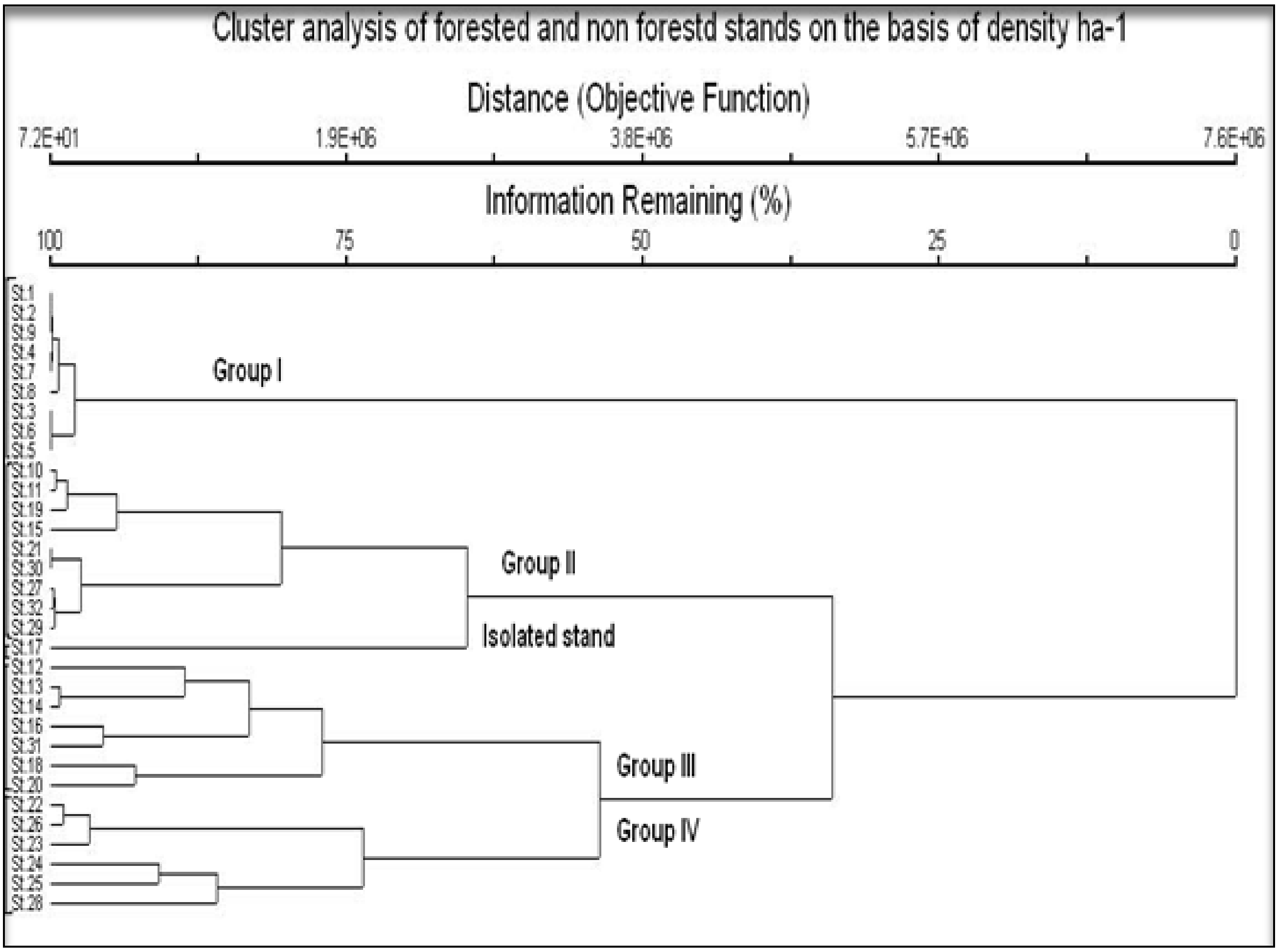

Fig. 2. Dendrogram, based on Information level and Euclidean distance of the 32 stands of forested and non-forested vegetation data representing four groups.

Ward's clustering method for understory vegetation: Ward's cluster analysis identified 6 distinct groups based on species composition and environmental factors (Fig. 3). These groups were categorized using an information level of 53% and Euclidean distance of ~1.2 × 10^5. The groups were associated with topographic, edaphic, and soil nutrient variables, summarized in Tables 3 and 4.

Group I: Comprising 5 stands and 34 species, *Artemisia brevefolia* (38%) is the dominant species, followed by *Impatiens balfourii* (33%) and *Silene vulgaris* (33%). Found at 3283 ± 92 m elevation and a 32 ± 9° slope, the soil was slightly acidic (pH 5.34 ± 0.09), with high conductivity (70.9 ± 5.75) and organic matter (6.52 ± 0.84%).

Group II: This group consists of five stands and 24 species. *Taraxacum nigrum* – please check doubtful – rare endemic (49%) dominated, with *Spiraea canescens* doubtful-*Spiraea affinis?* (38%) and *Leontopodium millefolium?* (35%) occuring at 3379 ± 65 m and a 62 ± 4° slope, the soil was acidic (pH 5.96 ± 0.14), with moderate conductivity (37.96 ± 1.91) and low organic matter (0.42 ± 0.30%).

Group III: Composed of 6 stands and 23 species, *Rosa webbiana* (58%) was the dominant species, found at 3051 ± 154 m elevation and a 23 ± 7° slope. The soil was slightly acidic (pH 5.52 ± 0.11), with moderate conductivity (29.45 ± 4.23) and low organic matter (2.16 ± 0.53%).

Group IV: The largest group having 7 stands and 24 species with *Rosa webbiana* (55%) was dominant, followed by *Hippophae rhamnoides* (53%) and *Berberis lyceum* (37%). The group was found at 2872 ± 13 m elevation and a 31 ± 3° slope. Soil was acidic (pH 6.17 ± 0.29), high conductivity (47.41 ± 5.46), and (6.88 ± 1.69%) organic matter.

Group V: It was the smallest group, with 3 stands and 17 species, dominated by *Hippophae rhamnoides* (60%), found at 3079 ± 9 m elevation with a gentle slope (5° ± 0). The soil was slightly acidic (pH 5.46 ± 0.08), with moderate conductivity (48.33 ± 0.88) and organic matter (4.7 ± 1.51%).

Group VI: Composed of 6 stands and 19 species, *Taraxacum baltistanicum* and *Berberis lyceum* (47%) were dominant occurring at 2988 ± 35 m elevation and a 31 ± 3° slope, the soil was acidic (pH 5.73 ± 0.19), with high conductivity (48.5 ± 3.03) and moderate organic matter (5.21 ± 2.25%).

DCA ordination was performed to examine the correlation between environmental variables (elevation and slope) and the forested and non-forested vegetation stands, based on species density (ha^{-1}) from 32 stands in the study area.

Table 1. Four groups and one isolated stand obtained from Ward's cluster analysis of forested and non-forested species from 32 stands based on density ha^{-1} and environmental variable (elevation, slope).

S. No.	Name of species	Group 1	Group II	Group III	Group IV	Isolated stand (17)
1.	*Picea smithiana*	97 ± 13	*	*	*	*
2.	*Pinus wallichiana*	43 ± 17	*	*	*	*
3.	*Juniperus excels*	70 ± 23	*	*	*	*
4.	*Rosa webbiana*	*	511 ± 40	390 ± 62	333 ± 38	1067 ± 00
5.	*Hippophae rhamnoides*	*	452 ± 52	389 ± 20	444 ± 47	*
6.	*Berberis lyceum*	*	437 ± 33	133 ± 00	467 ± 00	333 ± 00
7.	*Ribes alpestere*	*	*	267 ± 67	*	*
8.	*Urtica dioca*	*	*	400 ± 00	*	*
9.	*Ribes orientale*	*	*	267 ± 00	600 ± 00	467 ± 00
10.	*Tamarix indica?*	*	*	0	378 ± 33	*
11.	*Artemesia brevefolia*	*	*	334 ± 67	*	*
12.	*Juniperus communis*	*	*	*	533 ± 00	*

*Absent

Table 2. Mean values ± SE of environmental variables (topographic, and edaphic) and soil nutrients based on forested and non-forested groups derived from Ward's cluster analysis using 32stands of CKNP. (Mean ± SE).

Mean ± SE	Mean ± SE	Mean ± SE	Mean ±SE	Mean ± SE	Mean ± SE
Variable	**Group I**	**Group II**	**Group III**	**Group IV**	**Isolated (17)**
	1. Topographic variables of soil				
Elevation (m)	3362 ± 53	2975 ± 87	2950 ± 99	2940 ± 103	3559 ± 00
Slope°	52 ± 6	27 ± 3	27 ± 4	13 ± 5	50 ± 00
	2. Edaphic variables of soil				
Conductivity	55.14 ± 6.87	44.58 ± 4.48	36.32 ± 5.33	49.66 ± 3.37	39 ± 00
Salinity	0 ± 0	0.03 ± 0.03	0.01 ± 0.01	0.08 ± 0.03	0.1 ± 00
pH	5.66 ± 0.14	5.77 ± 0.23	6.06 ± 0.21	5.48 ± 0.06	5.4 ± 00
MWHC	37.44 ± 4.98	33.66 ± 3.67	34.71 ± 2.48	29.16 ± 4.11	29 ± 00
TDS	26.41 ± 1.48	21.83 ± 2.57	16.95 ± 2.76	22.78 ± 2.54	15.3 ± 00
Organic matter %	5.36 ± 0.63	7.02 ± 1.87	3.17 ± 0.56	22.78 ± 2.54	15.3 ± 00
	3. Soil nutrients				
Ca (ppm	188.22 ± 13.48	186.44 ± 19.41	237.42 ± 35.13	205.5 ± 12.94	156 ± 00
Mg (ppm)	142.8 ± 5.98	132.33 ± 5.48	140.85 ± 6.78	139.3 ± 7.07	163 ± 00
K (ppm)	224.4 ± 21.7	250.88 ± 27.33	225.7 ± 18.44	265.83 ± 13.97	244 ± 00
Co (ppm)	0.58 ± 0.01	1.26 ± 0.05	1.47 ± 0.16	1.20 ± 0.03	1.26 ± 00
Mn (ppm)	10.14 ± 1.3	8.82 ± 0.96	6.06 ± 1.10	7.79 ± 0.87	5.91 ± 00
Zn (ppm)	0.09 ± 0.02	0.35 ± 0.14	0.09 ± 0.004	0.39 ± 0.25	0.42 ± 00
Fe (ppm)	5.36 ± 0.63	130.06 ± 5.23	148.92 ± 9.64	128.3 ± 5.93	179 ± 00

SE = Standard error; *= Absent

Ordination of forested and non-forested vegetation: Two-dimensional DCA ordinations among axes 1-2, 1-3, and 2-3 showed a discontinuous pattern, clearly separating forested and non-forested vegetation. No distinct groups were identified from these axes, and the plots did not form meaningful clusters.

The ordination between axes 1-3, however, revealed a more continuous pattern, identifying 4 groups and one isolated stand. Group I, located in the upper and lower left of the ordination plot, consisted of 9 forest stands, predominantly of *Picea smithiana*, with *Pinus wallichiana* and *Juniperus excelsa*. Group II, the largest, occupied the center of the ordination plane, overlapping with groups III and IV, dominated by *Rosa webbiana* with *Hippophae rhamnoides* and *Berberis lyceum*.

Group III, the second largest among non-forested vegetation, included 7 stands and 7 species, with *Rosa webbiana* and *Hippophae rhamnoides* as dominant species, alongside *Berberis lyceum*, *Urtica dioca*, *Ribes alpestre*, *Ribes orientale*, and *Artemisia brevefolium*. Group IV, overlapping with Group II, featured a discontinuous distribution pattern, with two stands (22 and 23) merging into Group III. *Hippophae rhamnoides* dominated this group, with *Rosa webbiana*, *Tamarix indica*, *Ribes orientale*, *Juniperus communis*, and *Berberis lyceum* but in lower densities.

An isolated stand (17), present between Groups II and III, consisted of only 3 species: *Rosa webbiana* (dominant), *Berberis lyceum*, and *Ribes orientale*.

Correlation of ordination axes with environmental variables and soil nutrients: The correlation between DCA ordination axes and environmental variables showed significant correlations for axis 1 (Table 5). Axis 1 was positively correlated with slope ($p<0.05$), TDS ($p<0.05$), conductivity ($p<0.05$), and Mn^{+}. However, no significant correlations were observed for axes 2 and 3 with any environmental variables or soil nutrients.

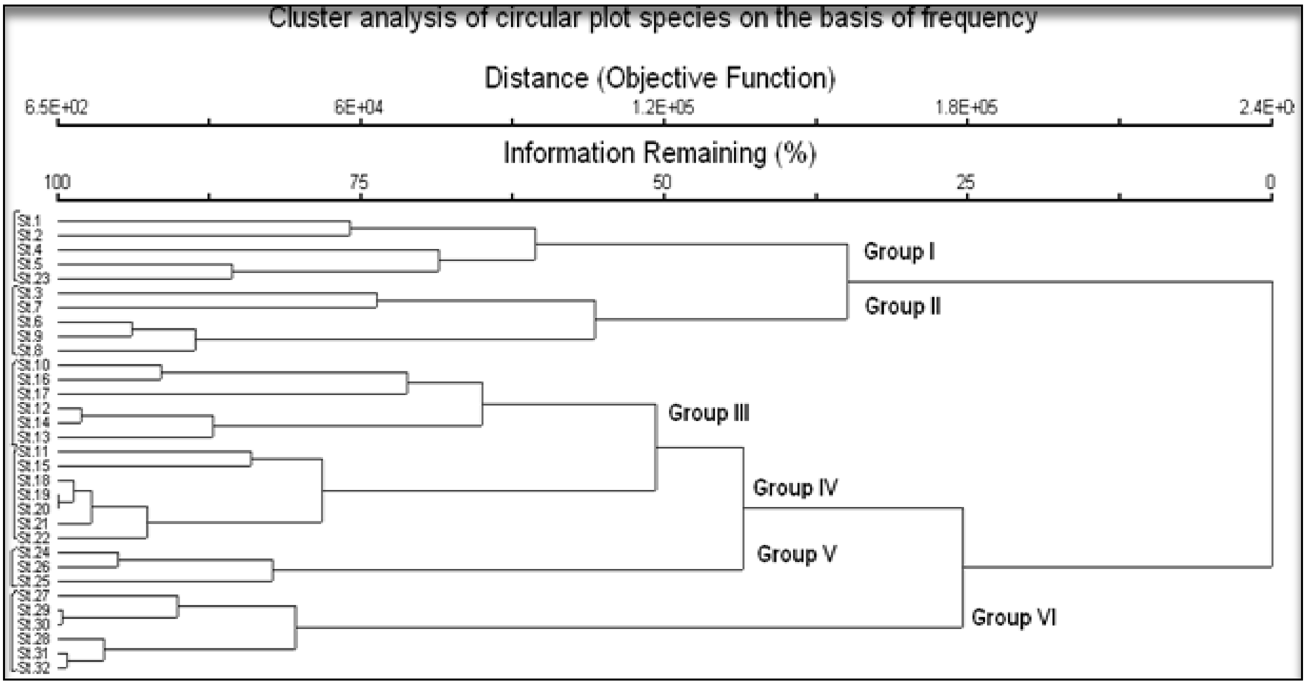

Fig. 3. The dendrogram resulting from cluster analysis based on frequency of the under storey vegetation data using Ward's method.

Table 3. Ward's cluster analysis means of groups of circular plot species (understorey vegetation) on the basis of frequency and environmental variables. Rephrase the head – not clear.

S. No.	Name of species	Group 1	Group II	Group III	Group IV	Group V	Group VI
1.	*Anaphalis verigata*	20	29	18	24	30	20
2.	*Artemesia brevifolia*	38	*	17	26	30	28
3.	*Astragallus zanskrensis*	27	*	*	20	*	30
4.	*Astrgallus gilgitensis*	27	34	10	*	*	*
5.	*Berberis orthobotrys*	20	19	20	*	*	*
6.	*Bistorta affinis*	30	29	30	*	27	35
7.	*Carum carvi*	16	25	*	*	20	15
8.	*Geranium neplensis*	15	*	18	20	*	*
9.	*Geranium pratens*	27	21	20	20	15	20
10.	*Hippophae rhamnoides*	30	*	48	53	60	40
11.	*Impatiens balfourii*	33	24	*	*	*	*
12.	*Juniperus communis*	23	29	*	*	40	*
13.	*Lentopodium lentopodinum*	20	30	*	10	*	25
14.	*Leontopodium linearifolium?* Doubtful identification	13	35	20	*	*	*
15.	*Lendopodium nanum*	20	27	*	30	*	*
16.	*Potentilla anserine*	21	33	*	*	10	20
17.	*Potentilla biflora*	10	*	25	*	*	20
18.	*Ribes orientale*	18	*	30	20	40	35
19.	*Rosa webbiana*	21	*	58	55	33	38
20.	*Rubus irritans*	31	20	14	20	30	30
21.	*Rubus ulmifolius*	12	34	*	20	*	*
22.	*Sedum pacycloides*	27	14	25	20	*	*
23.	*Rhodiola quadrifida*	10	22	23	15	20	13
24.	*Silene vulgaris*	10	23	*	20	50	*
25.	*Spiraea cannses?*	33	38	*	10	*	16
26.	*Tanactum artemisiodes*	18	26	*	*	*	*
27.	*Taraxacum baltistanicum*	15	*	22	26	*	47
28.	*Taraxacum indicum*	32	35	15	30	*	*
29.	*Taraxacum nigrum?*	23	49	20	30	47	*
30.	*Taraxacum xanthophylum*	25	20	20	*	0	*
31.	*Thymus linearis*	22	*	37	25	40	43
32.	*Trifolium repnes*	23	17	20	18	10	20
33.	*Urtica dioca*	20	21	33	10	*	*
34.	*Berberis lyceum*	*	*	30	37	*	47
35.	*Ribes alpestre*	30	*	33	10	30	*

Table 4. Mean values ± SE of environmental variables (topographic, and edaphic) and soil nutrients based on circular plot groups derived from Ward's cluster analysis using 32stands of CKNP. (Mean ± SE).

Mean ± SE	Mean ± SE	Mean ± SE	Mean ±SE	Mean ± SE	Mean ± SE	Mean ± SE
Variable	**Group I**	**Group II**	**Group III**	**Group IV**	**Group V**	**Group VI**
			1. Topographic variables of soil			
Elevation (m)	3283 ± 95.78	3378 ± 64.53	3051 ± 154.34	2872 ± 131.54	3079.33 ± 9.38	2987 ± 34.61
Slope °	31.6 ± 8.63	62.4 ± 3.93	23.3 ± 7.14	30.71 ± 2.54	5.0 0± 0.00	30.83 ± 3.00
			2. Edaphic variables of soil			
Conductivity	70.9 ± 5.75	37.96 ± 1.91	29.45±4.23	47.41 ± 5.46	48.33 ± 0.88	48.5 ± 3.03
Salinity	0.02 ± 0.02	0.0 ± 0.0	0.03±0.02	0.04 ± 0.04	0.13 ± 0.03	0.00 ± 0.00
pH	5.34 ± 0.09	5.96 ± 0.014	5.52±0.11	6.17 ± 0.29	5.46 ± 0.08	5.73 ± 0.19
MWHC	46.4 ± 5.90	25.6 ± 3.12	31.66±3.92	36 ± 4.56	23.33 ± 1.20	35.66 ± 1.25
TDS	28.6 ± 2.34	22.8 ± 0.73	13.56±2.63	23.64 ± 3.49	19.76 ± 0.32	23.61 ± 0.72
Organic matter %	6.52 ± 0.84	2.16 ± 0.30	2.16±0.53	6.88 ± 1.69	4.7 ± 1.51	5.21 ± 2.25
			3. Soil nutrients			
Ca (ppm	201.8 ± 22.61	188.6 ± 18.44	219.5 ± 45.54	190 ± 19.16	181.66 ± 7.79	213.16 ± 19.30
Mg (ppm)	142.4 ± 8.52	139.4 ± 8.53	154.3 ± 8.48	137.85 ± 8.09	135.66 ± 4.05	134.83 ± 5.60
K (ppm)	216.8 ± 26.12	247.4 ± 34.15	243.5 ± 19.26	278.71 ± 15.54	247.66 ± 0.66	203.5 ± 34.98
Co (ppm)	0.95 ± 0.10	0.84 ± 0.01	1.54 ± 0.18	1.29 ± 0.06	1.18 ± 0.03	1.15 ± 0.02
Mn (ppm)	11.13 ± 2.15	8.25 ± 1.18	5.81 ± 0.72	8.61 ± 1.30	9.34 ± 1.12	7.62 ± 1.16
Zn (ppm)	0.12 ± 0.02	0.07 ± 0.03	0.15 ± 0.06	0.25 ± 0.06	0.038 ± 0.01	0.61 ± 0.30
Fe (ppm)	131.6 ± 8.23	135.6 ± 4.50	145.5 ± 13.34	137.77 ± 7.78	125.33 ± 10.13	135.66 ± 2.25

SE = Standard error

DCA Ordination

Table 5. Relationship (correlation coefficients) of environmental variables (topographic variables and edaphic variables) and soil nutrients with 3 DCA ordination axes obtained by forested and non-forested vegetation data based on frequency.

S. No.	Variables	Axis 1		Axis 2		Axis 3	
		r	Prob. Level	r	Prob. Level	r	Prob. Level
				1. Topographic variables			
1.	Elevation	-0.074	ns	0.01	Ns	-0.008	Ns
2.	Slope	0.65	p<0.05	-0.10	Ns	0.17	Ns
				2. Edaphic variables			
1.	TDS	0.39	p<0.05	-0.03	Ns	-0.09	Ns
2.	PH	-0.08	ns	0.17	Ns	0.10	Ns
3.	WHC	0.19	ns	0.009	Ns	-0.20	Ns
4.	Salinity	-0.28	ns	0.004	Ns	-0.01	Ns
5.	Conductivity	0.34	p<0.05	-0.04	Ns	-0.18	Ns
6.	Organic matter	0.06	ns	-0.004	Ns	-0.09	Ns
				3. Soil nutrients			
1.	Ca	-0.13	ns	0.004	Ns	-0.28	Ns
2.	Mg	0.12	ns	0.11	Ns	0.13	Ns
3.	K	-0.16	ns	-0.16	Ns	0.09	Ns
4.	Co	-0.66	ns	-0.00068	Ns	-0.02	Ns
5.	Mn	0.35	p<0.05	-0.07	Ns	-0.11	Ns
6.	Zn	-0.24	ns	-0.04	Ns	-0.05	Ns
7.	Fe	-0.09	ns	-0.26	Ns	-0.03	Ns

Key to abbreviations: r = Correlation coefficient, ns = Non-significant and Prob. Level = Probability level

Ordination of understory vegetation: DCA stand ordination of understory vegetation, based on axes 1-2, 2-3, and 1-3, is illustrated in Fig. 4. The groups derived from Ward's cluster analysis aligned well with the ordination on axes 1-2 and 1-3. The distribution pattern of stands on axes 1-2 and 1-3 was continuous, while the 2-3 axis showed a discontinuous pattern, making rather unsuitable for ordination of understory vegetation.

On axis 1-2, Group I was centrally located, comprising 5 stands. Group II was positioned near Group I, also consisting of 5 stands. Group III situated on the left side of the ordination space with 6 stands, overlapped with Group IV. Group IV, the largest group, consisting of 7 stands and overlapped with Group III. Group V, located between Group I and Group IV, was small, with 3 stands only. Group VI occupied an isolated position below Groups III and IV, and included 6 stands.

On axis 1-3, Group I and II were placed on the left, while Groups III and IV overlapped to the left side of the ordination space. Group V was situated centrally below Groups I and II, and Group VI was positioned left of the ordination space.

Correlation of ordination axes with environmental variables and soil nutrients (understory vegetation): The correlation of DCA ordination axes with environmental variables is presented in Tables 6 and 7. Axis 1 showed a significant positive correlation (p<0.01) with slope. Other variables, including elevation, TDS, MWHC, salinity, conductivity, organic matter, and pH, did not show significant correlations with axis 1. Axis 2 only showed a significant positive correlation with salinity (p<0.05), while axis 3 did not show significant correlations with topographic or edaphic variables.

Soil nutrients also showed limited significant correlations with the ordination axes. Calcium (Ca++) exhibited a significant correlation (p<0.02) with axis 2, while magnesium (Mg++) had a significant relationship with axis 1 (p<0.05). Other nutrients such as potassium (K+), cobalt (Co++), manganese (Mn+), zinc (Zn+), and iron (Fe+) did not show significant correlations with any of the axes.

Univariate analysis of variance (forested and non-forested vegetation): Ward's clustering analysis identified 4 groups and one isolated stand. ANOVA of environmental variables revealed significant differences in elevation (F = 5.86, p<0.01) and slope (F = 9.27, p<0.001) (Table 8). Total dissolved salts (F = 4.22, p<0.05) also showed significance, while MWHC, conductivity, salinity, organic matter, and pH were not significant. Soil nutrients including cobalt (Co) (p<0.001) and iron (Fe) (p<0.05) also showed significant differences.

Univariate analysis of variance (understory vegetation): For understory vegetation, 6 groups were identified. ANOVA revealed significant differences in elevation (F = 3.005, p<0.05) and slope (F = 9.76, p<0.001) (Table 9). Edaphic factors such as TDS (F = 4.22, p<0.01), pH (F = 2.54, p<0.05), MWHC (F = 3.45, p<0.01), conductivity (F = 9.48, p<0.001), and salinity (F = 2.15, p<0.05) were significant, while organic matter was not. Soil nutrients cobalt (Co) (p<0.01) and zinc (Zn) (p<0.05) also showed significant differences.

Table 6. Relationship (correlation coefficients) of environmental variables (topographic variables and edaphic variables) and soil nutrients with 3 DCA ordination axes obtained by understorey vegetation data based on frequency.

S. No.	Variables	Axis 1		Axis 2		Axis 3	
		r	Prob. Level	r	Prob. Level	r	Prob. Level
				1. Topographic variables			
1.	Elevation	-0.01	ns	0.16	ns	0.29	Ns
2.	Slope	0.49	p<0.01	-0.30	ns	-0.01	Ns
				2. Edaphic variables			
1.	TDS	0.25	ns	-0.41	ns	-0.13	Ns
2.	PH	-0.14	ns	0.14	ns	0.15	Ns
3.	WHC	-0.10	ns	-0.59	ns	0.17	Ns
4.	Salinity	-0.13	ns	0.41	p<0.01	-0.02	Ns
5.	Conductivity	0.13	ns	-0.42	ns	-0.11	Ns
6.	Organic matter	-0.12	ns	-0.13	ns	-0.10	Ns
				3. Soil nutrients			
1.	Ca	0.20	ns	0.31	p<0.05	-0.07	Ns
2.	Mg	0.30	p<0.05	0.16	ns	0.05	Ns
3.	K	-0.20	ns	-0.21	ns	-0.36	Ns
4.	Co	0.11	ns	0.06	ns	-0.15	Ns
5.	Mn	0.19	ns	0.09	ns	0.25	Ns
6.	Zn	-0.29	ns	-0.14	ns	-0.06	Ns
7.	Fe	0.09	ns	0.15	ns	-0.10	Ns

Key to abbreviations: r = Correlation coefficient, ns = Non-significant and Prob. Level = Probability level

Table 7. Intra-set correlation among different environmental variables.

	Elevation	Slope	Conductivity	Salinity	pH	MWHC	TDS	OM	Ca	Mg	K	Co	Mn	Zn	Fe
Elevation	1														
Slope	-0.24	1.00													
Conductivity	-0.25	0.09	1.00												
Salinity	-0.07	-0.39	0.01	1.00											
pH	-0.23	0.19	-0.11	-0.13	1.00										
MWHC	-0.26	0.07	0.75**	0.03	-0.02	1.00									
TDS	-0.29	0.33*	0.86**	0.03	0.00	0.72**	1.00								
OM	-0.21	-0.04	0.21	-0.02	-0.13	0.08	0.13	1.00							
Ca	-0.16	-0.19	-0.02	-0.21	-0.10	0.04	-0.07	-0.01	1.00						
Mg	-0.24	0.18	0.00	-0.18	-0.20	0.15	0.00	-0.06	0.19	1.00					
K	0.23	-0.17	-0.37*	0.10	-0.04	-0.50**	-0.31	0.28	-0.14	-0.36	1.00				
Co	0.05	-0.43*	-0.51**	0.03	-0.04	-0.22	.59**	-0.04	0.01	0.01	0.08	1.00			
Mn	-0.03	0.13	0.53**	0.04	0.22	0.40*	0.45*	0.08	-0.17	-0.05	-0.21	-0.48	1.00		
Zn	-0.01	-0.06	-0.05	-0.06	-0.23	0.07	0.09	-0.11	0.10	0.13	0.03	-0.02	0.30*	1.00	
Fe	-0.18	0.10	-0.06	-0.21	0.25	-0.01	-0.15	-0.12	0.46	0.06	-0.04	0.05	-0.10	-0.13	1

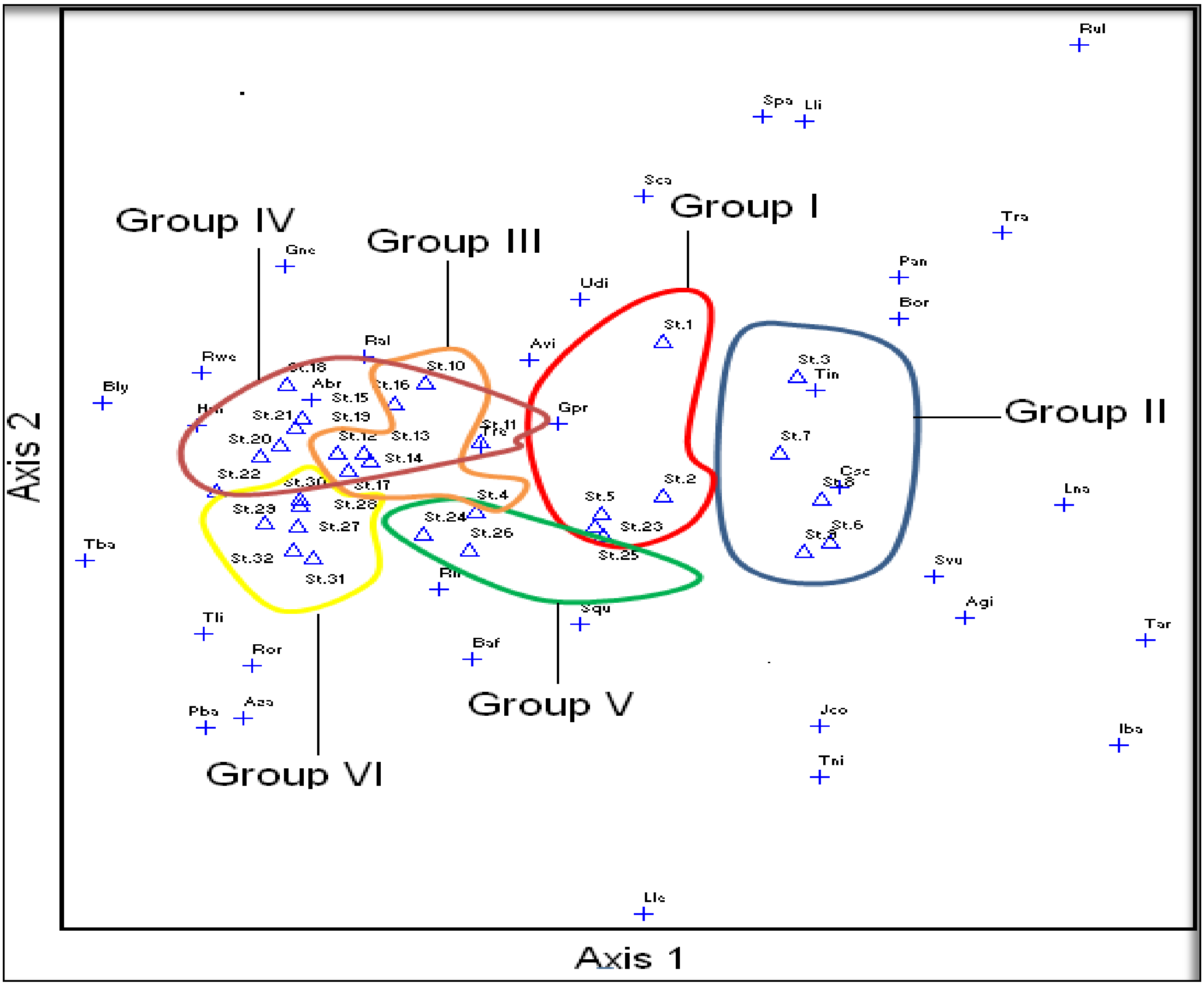

Fig. 4. DCA among axis 1 and 2 of understory vegetation data based on frequency.

Discussion

The mean density (ha-1) of species such as *Picea smithiana* (97±13), *Pinus wallichiana* (43±17), and *Juniperus excelsa* (70±23) in the present study was comparable to findings of Ahmed (2011) – missing see ref. list -, who reported densities of *Picea smithiana* (21±12), *Pinus wallichiana* (92±31), and *Juniperus excelsa* (24±14) in the Hindu Kush and Himalayan ranges of Pakistan. Additionally, Wahab *et al*., (2008) recorded similar densities of *Picea smithiana* (77 density ha-1) and *Pinus wallichiana* (41 density ha-1) in Afghanistan. Khan *et al*., (2011) also observed *Pinus wallichiana* and *Juniperus excelsa* communities, with ground flora species such as *Artemisia brevefolia*, *Trifolium repens*, *Urtica dioca*, and *Juniperus communis*, which were also common in the current study. Similarly, Siddiqui *et al*., (2010) reported *Picea smithiana* and *Pinus wallichiana* in the moist temperate areas of Pakistan, with common ground flora species like *Thymus linearis*, *Rosa webbiana*, and *Berberis lyceum*.

The elevation of the study area, ranging from 2872m to 3379m, was notably higher than the elevations (1503-1753m) reported by previous studies, which might explain the differences in vegetation. Non-forested vegetation was found in groups II, III, and IV, with common species such as *Rosa webbiana*, *Hippophae rhamnoides*, and *Berberis lyceum*. Group III showed dominance of *Hippophae rhamnoides*, with *Tamarix indica?* and *Rosa webbiana* as associated species. The isolated stand (17) located at higher elevation was dominated by *Rosa webbiana* and *Ribes orientale*.

Understory vegetation across all groups included species such as *Anaphalis virgata*, *Rosa webbiana*, *Ribes orientale*, *Artemisia brevefolia*, *Geranium pratens*, *Rhodiola quadrifida*, *Taraxacum baltistanicum*, and *Thymus linearis*, with *Rosa webbiana* showing the highest frequency (100%). Other species like *Hippophae rhamnoides* and *Berberis lyceum* had average frequencies of 53% and 50%, respectively. Previous studies by Ahmed *et al*., (2010) also recorded *Rosa webbiana* and *Berberis lyceum* in ground flora, however, differences in species composition may be due to the variation in elevation.

The DCA ordination results supported the findings from cluster analysis, with a continuous and somewhat discontinuous distribution pattern, likely due to variations in elevation. As noted by McCune & Grace (2002), ordination techniques helped in revealing vegetation patterns along environmental gradients. The study suggests that anthropogenic disturbances, though not explicitly reported in prior studies, may influence vegetation types in the area.

Climax communities like *Picea smithiana*, *Rosa webbiana*, and *Hippophae rhamnoides* are tolerant to local environmental conditions and contribute to the area's spatial structure and diversity. These results are consistent with the findings of Wazir *et al*., (2008). The understorey vegetation, consisting of perennial herbs and shrubs such as *Rosa webbiana*, *Hippophae rhamnoides*, *Berberis lyceum*, and *Astragallus gilgitensis*, played a crucial role in reflecting site quality and forest productivity. However, these species face challenges such as competition, overgrazing, soil erosion, and severe wind conditions. Connell & Slatyer *et al*., (1977) noted that fast-growing species dominated in early stages of community development, but eventually are replaced by species that are more competitive.

The analysis of edaphic factors, including elevation, TDS, conductivity, and salinity, showed significant correlations with ordination axes. Soil nutrients like cobalt, calcium, and magnesium were also correlated with ordination axes, while other nutrients showed weaker correlations. These findings suggest that anthropogenic disturbances, as described by Siddiqui *et al*., (2010), Khan *et al*., (2011), and Wahab (2011), may be contributing to the weak correlations observed – what do you mean? explain. Moreover, 60% of Pakistan's forests are deteriorating due to illegal cutting and overgrazing, which significantly affect plant communities (Bai *et al*., 2008; Shaltout *et al*., 2008). This study underscores the need for further research and focused conservation efforts to address these issues.

Table 8. Analysis of variance of individual environmental variables (topographic and edaphic) and soil nutrients. Four groups were derived by Ward's cluster analysis using forested and non-forested vegetation data of 32 stands of CKNP Gilgit-Baltistan, Pakistan.

ANOVA: Single Factor

Source of variation	SS	df	MS	F	P-level
			1. Topographic variables		
1. **Elevation**					
Between Groups	1280395	4	320098.7	5.869504	
Within Groups	1472469	27	54535.9		
Total	2752864	31			
2. **Slope**					
Between Groups	6457.056	4	1614.264	9.277552	
Within Groups	4697.913	27	173.9968		
Total	**11154.97**	**31**			
			2. Edaphic variables		
1. **TDS**					
Between Groups	401.9303	4	100.4826	2.35307	
Within Groups	1152.974	27	42.70275		
Total	1554.905	31			
2. **PH**					
Between Groups	1.290568	4	0.322642	1.166236	
Within Groups	7.469619	27	0.276653		
Total	8.760188	31			
3. **MWHC**					
Between Groups	276.4846	4	69.12116	0.529216	
Within Groups	3526.484	27	130.6105		
Total	3802.969	31			
4. **Salinity**					
Between Groups	0.031845	4	0.007961	1.838722	
Within Groups	0.116905	27	0.00433		
Total	0.14875	31			
5. **Conductivity**					
Between Groups	1546.006	4	386.5015	1.633361	
Within Groups	6388.999	27	236.6296		
Total	7935.005	31			
6. **Organic matter**					
Between Groups	78.78	4	19.69	1.65321	
Within Groups	321.07	27	11.89		
Total	**399.86**	**31**			

Table 8. (Cont'd.)

Source of variation	SS	df	MS	F	P-level
			3. Soil nutrients		
1. **Ca**					
Between Groups	14809.48	4	3702.36	1.02	
Within Groups	97094.66	27	3596.11		
Total	111904.5	31			
2. **Mg**					
Between Groups	1507.55	4	376.88	1.47	
Within Groups	6644.19	27	255.54		
Total	8151.74	31			
3. **K**					
Between Groups	8684.59	4	2171.14	0.54	
Within Groups	107985.4	27			
Total	116670	31	3999.45		
4. **Co**					
Between Groups	1.67	4	0.419	7.85	
Within Groups	1.44	27	0.053		
Total	3.12	31			
5. **Mn**					
Between Groups	75.30	4	18.82	1.91	
Within Groups	265.52	27	9.83		
Total	340.82	31			
6. **Zn**					
Between Groups	0.62	4	0.15	1.16	
Within Groups	3.63	27	0.13		
Total	4.25	31			
7. **Fe**					
Between Groups	3742.58	4	935.64	2.89	
Within Groups	8727.43	27	323.23		
Total	**12470.02**	**31**			

Key to abbreviations: SS = Sum of square, MS = Mean square, F = F ratio, df = Degree of freedom, P level = Probability level and ns = Non-significant

Table 9. Analysis of variance of individual environmental variables (topographic and edaphic and) and soil nutrients. Six groups were derived by Ward's cluster analysis using understorey vegetation data of 32 stands of CKNP, Gilgit-Baltistan, Pakistan.

ANOVA: Single Factor

Source of variation	SS	df	MS	F	P-level
			1. Topographic variables		
1. **Elevation**					
Between Groups	1008230	5	201646.1	3.005099	
Within Groups	1744634	26	67101.3		
Total	2752864	31			
2. **Slope**					
Between Groups	7278.974	5	1455.795	9.765405	
Within Groups	3875.995	26	149.0767		
Total	**11154.97**	**31**			
			2. Edaphic variables		
1. **TDS**					
Between Groups	697.2392	5	139.4478	4.22734	
Within Groups	857.6655	26	32.98713		
Total	**1554.905**	**31**			
2. **PH**					
Between Groups	2.881333	5	0.576267	2.548614	
Within Groups	5.878855	26	0.22611		

Table 9. (Cont'd.)

Source of variation	SS	df	MS	F	P-level
Total	**8.760188**	**31**			
3. **MWHC**					
Between Groups	1519.235	5	303.8471	3.459259	
Within Groups	2283.733	26	87.8359		
Total	3802.969	31			
4. **Salinity**					
Between Groups	0.043607	5	0.008721	2.156658	
Within Groups	0.105143	26	0.004044		
Total	**0.14875**	**31**			
5. **Conductivity**					
Between Groups	5125.582	5	1025.116	9.487014	
Within Groups	2809.422	26	108.0547		
Total	7935.005	31			
6. **Organic matter**					
Between Groups	88.20	5	17.64	1.47	
Within Groups	311.66	26	11.98		
Total	**399.86**	**31**			
			3. Soil nutrients		
1. **Ca**					
Between Groups	5679.46	5	1135.89	0.27	
Within Groups	106225	26	4085.57		
Total	111904.5	31			
2. **Mg**					
Between Groups	439.78	5	87.95	0.25	
Within Groups	8866.09	26	341		
Total	9305.87	31			
3. **K**					
Between Groups	21690.87	5	4338.17	1.18	
Within Groups	94979.1	26	3653.04		
Total	**116670**	**31**			
4. **Co**					
Between Groups	1.69	5	0.33	6.15	
Within Groups	1.42	26	0.054		
Total	3.12	31			
5. **Mn**					
Between Groups	83.91	5	16.88	1.6	
Within Groups	256.91	26	9.88		
Total	340.82	31			
6. **Zn**					
Between Groups	1.19	5	0.23	2.03	
Within Groups	3.06	26	0.11		
Total	4.25	31			
7. **Fe**					
Between Groups	997.90	5	199.58	0.45	
Within Groups	11472.12	26	441.23		
Total	12470.02	31			

Key to abbreviations: SS = Sum of square, MS = Mean square, F = F ratio, df = Degree of freedom, P level = Probability level and ns = Non-significant

Conclusion

In Central Karakoram National Park, Gilgit-Baltistan, nine forested and 23 non-forested vegetation stands, along with understory vegetation, were classified using Ward's clustering method. Four groups and one isolated stand were identified for forested and non-forested vegetation, while 6 groups were found for understory vegetation. These groups were linked to topographic and edaphic gradients, particularly elevation and slope.

In forested vegetation, Group I, dominated by *Picea smithiana*, included *Pinus wallichiana* and *Juniperus excelsa*. The study's findings differed from earlier studies due to the region's dry temperate climate and topography, where topographic factors were significant compared to edaphic factors. In understory vegetation, all edaphic factors, except salinity, showed significant differences, underlining the role of both topography and edaphics in vegetation distribution.

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