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Influence of Edaphic Properties in Determining Forest Community Patterns of the Zabarwan Mountain Range in the Kashmir Himalayas

Shiekh Marifatul Haq [1,2], Aqil Tariq [3,4,*,†], Qingting Li [5,*,†], Umer Yaqoob [6], Muhammad Majeed [7], Musheerul Hassan [1], Sammer Fatima [7], Manoj Kumar [8], Rainer W. Bussmann [2], Muhammad Farhan Ul Moazzam [9] and Muhammad Aslam [10]

1 Clybay Research Private Limited-560114, Bangalore, India; snaryan17@gmail.com (S.M.H.); musheer123ni@gmail.com (M.H.)
2 Department of Ethnobotany, Institute of Botany, Ilia State University, 0105 Tbilisi, Georgia; rbussmann@gmail.com
3 State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China
4 Department of Wildlife, Fisheries and Aquaculture, Mississippi State University, 775 Stone Boulevard, Mississippi State 39762, MS, USA
5 Airborne Remote Sensing Center, Aerospace Information Research Institute, Chinese Academy of Sciences, Beijing 100094, China
6 Zonal Educational office, Vehil, Shopian, Jammu and Kashmir 192303, India; umerraj6668@gmail.com
7 Department of Botany, University of Gujrat, Hafiz Hayat Campus, Gujrat 50700, Pakistan; m.majeed@uog.edu.pk (M.M.); sammer.fatima@uog.edu.pk (S.F.)
8 GIS Centre, Forest Research Institute, PO New Forest, Dehradun 248006, India; manojfri@gmail.com
9 Department of Civil Engineering, College of Ocean Science, Jeju National University, 102 Jejudaehakro, Jeju 63243, Korea; farhan.moazzam@gmail.com
10 School of Computing Engineering and Physical Sciences, University of West of Scotland, Paisley G72 0LH, UK; muhammad.aslam@uws.ac.uk
* Correspondence: aqiltariq@whu.edu.cn or at2139@msstate.edu (A.T.); liqt@radi.ac.cn (Q.L.)
† These authors contributed equally to this work.

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Abstract: The significance of edaphic factors in describing forest vegetation patterns is becoming more well acknowledged, with significant implications for the description of biogeographical regions and biome classification, as well as abundance and growth patterns at regional levels. The current study examines the vegetation association in the Zabarwan mountain range of the Western Himalayas and its association with edaphic factors. To collect data on forest types, we employed a systematic random sampling strategy in 60 plots (0.1 ha) across five forest types. We investigated data using ordination and cluster analysis approaches after calculating the important value index (henceforth IVI) for each plant species and edaphic data from forests. In total, 76 plant species from 39 different families were found in the area. The Rosaceae family was the most numerous, followed by Fabaceae and Asteraceae. Scrub forest types have lower diversity indices, while broad-leaved forest types have greater diversity indices. Two-way cluster analyses classified the forest vegetation of the Zabarwan mountain range into two plant communities on the basis of indicator plant species. The ordination analysis (canonical correspondence analysis) indicated that vegetation association tended to be influenced differently by distinct levels of soil parameters. The soil pH and calcium content were the main factors influencing the species distribution in the different forest types. The phytosociological features (basal area) were higher in coniferous forest type (74.49 m^2ha^{-1}) compared to broad-leaved (58.63 m^2ha^{-1}) and scrub forest type (15.4 m^2ha^{-1}). Overall, the goal of this research is to gain a better understanding of the impact of soil elements on forest composition and associations in order to develop scientifically based management options for forest ecosystem protection in the Himalayan region.

Keywords: soil; forest; biodiversity; protected area; Kashmir Himalayas

1. Introduction

Mountain regions have played a key role in the conservation of biodiversity throughout history, and they will serve an even bigger role in future initiatives to combat climate change [1]. Mountain ecosystems not only supply direct and indirect ecological resources for human life, but they also have a much broader impact since they provide ecological services to lowland ecosystems and humans [2]. Plants have long been used directly for medical purposes and as a source of fuel and fodder for cattle in the western Himalayan region [3–5]. Mountains are critical for the survival of human populations who rely on large river water bodies for domestic and agricultural water resources in this region, as well as throughout the south Asian countries [6,7]. The Himalayas are the source of several major rivers, and the economies of many south Asian countries rely significantly on their flow, which ensures food security by providing irrigation water for wheat and rice, two of the world's most important staple cereals [8]. The shrubby flora of these high-altitude mountain ecosystems also controls the avalanche movements and prevents soil erosion [9]. High-altitude biodiversity and habitats are now at risk of biodiversity loss as a result of global warming, which result in both geographical range reduction and the risk of extinction of mountain-top ecosystems [10]. Adequate assessment of biodiversity for resource management decisions that affect forest wealth is one of the most critical factors for the successful management of forest resources in protected areas [11].

Changes in population structure, diversity, abundance and distribution in the Himalayan-protected forest ecosystem are complex due to topographic heterogeneity (e.g., altitude, slope), forest productivity, biological interactions of the forest and evolutionary competition between different species [12,13]. The interaction of all these variables defines the unique environmental conditions of each group, including species richness, architecture and spatial association patterns, and thus can help with the assessment and quantification of vegetation [12]. The discontinuous distribution of many biotic/abiotic processes that operate on various geographical and temporal dimensions determines the structure and diversity of vascular plants [14]. Abiotic factors such as topography and soil composition have a substantial impact on plant physiognomic differentiation in a variety of habitats. For effective forest management and conservation of biodiversity, identifying these crucial characteristics is critical [15].

The importance of soil in explaining ecological patterns in forests is becoming more widely recognized, with important implications for biogeography domain and biome characterization [16] as well as abundance and growth patterns at regional and community levels [17]. The interaction between plant and soil at the small scale is linked to a wide range of important ecological processes in which conditions and resources can alter the community's features [16,17]. Through these interactions, plant populations are exposed to biogeochemical and hydrological cycles influenced by factors such as water availability, pH, growth necessary nutrients (N, K, C, P, Mg, Ca, S) and possibly toxic elements (Al, Pb, Mn, among others) [18]. Several studies suggest that local occurrence and variability filters can influence how resources become available for plant survival and growth. The soil may impact the successional process and functional/phylogenetic diversities through these influences, as well as play a part in species selection from the regional pool, as well as their patterns of establishment and growth [17,18].

The structure and function of habitats are influenced by a wide range of elements such as soil structure, erosion rates, terrain and hydrology, among others. Soil nutrient quality has been proven to influence tree height and basal area, and hence the composition of plant communities, among the edaphic influences [16]. Plant species diversity is positively linked to soil productivity as shown in several studies [17,18], while some studies published contradictory findings [19], necessitating the conduct of in-depth studies in diverse ecosystems. The soil–vegetation interaction in this diversified environment is critical for conservation biology because it specifies habitat choice, plant structure and diversity supported by each type of soil and habitat formation, that is, the habitat with the richest plant and soil [17].

While the Zabarwan mountain range of the Kashmir Himalayan region supports a diverse forest type [20], ecologists and foresters have generally overlooked this region for multivariate phytosociological analysis. Despite the fact that scientific understanding of protected forests is growing, significant information gaps around the world remain, particularly in the Global South. The Zabarwan mountain range in the Kashmir Himalayan region is a dry temperate Himalayan forest that has received little academic attention. As a result, broad-scale classification is critical for understanding regional dynamics of plant associations and habitat types, as well as forest conservation, planning and management. The current study was developed to answer the following research issues since the Zabarwan mountain range is so essential for biodiversity protection. (1) What is the floral composition of the Zabarwan mountain range's forest types? (2) What relationship do edaphic characteristics have on forest vegetation association? Our findings will help guide forest ecosystem management and conservation in the Himalayan region by providing a better understanding of the influence of soil variables on forest vegetation composition and association

2. Materials and Methods

2.1. Study Area

In the union territory of Jammu and Kashmir, India, the Zabarwan Range is a short (32 km) sub-mountain range located between the Pir-panjal and the Great Himalayan Ranges in the central part of the Kashmir Valley. The Zabarwan mountain range possesses great Himalayan features of rich forests in Dachigam National Park (DNP). DNP has a total size of 141 km^2 and is located between 34°05′ N and 34°11′ N and 74°54′ E and 75°09′ E. (Figure 1). The park has been a protected area since 1910, when it was first under the jurisdiction of the Maharaja of Jammu and Kashmir and later promoted and proclaimed a national park in 1981. The climate in DNP is temperate, with warm and pleasant summers and severe and harsh winters. The average precipitation in the area is 660 mm, but there is no such thing as a rainy season, as there is in other parts of the world. The average maximum temperature in the summer is 27 °C, while it is 2 °C in the winter (minimum). The park is dominated by deciduous and coniferous forests, with riparian vegetation intermingled (for a more detailed description of the vegetation and region, see [21].

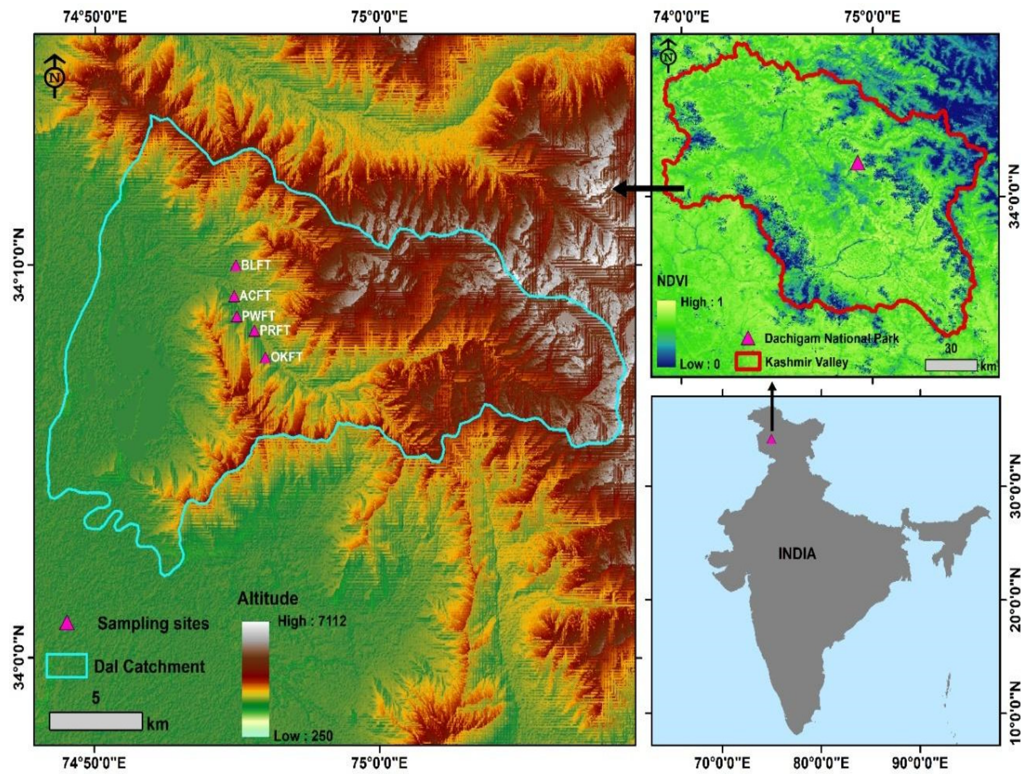

Figure 1. Map of the Zabarwan mountain range in Kashmir Himalayas, India and point showing the sampling forest types in Dachigam National Park.

2.2. Sampling and Data Analysis

Several field exploration investigations and botanical exploration trips were conducted in the Zabarwan Range between 2018 and 2021 to know more about the vegetation composition, topography, distribution and approachability of various forest types. *Pinus wallichiana* forest (PNFT), broad-leaved forest (BLFT), acacia forest (ACFT), oak forest (OKFT) and scrub forest (SRFT) are the main types of forests in the Zabarwan Range [21,22]. Voucher plant specimens were collected for the identification and future study following standard taxonomic procedures [23]. In each of the forest types, random vegetation sampling was carried out and twelve square plots of 0.1 ha were spread out in four different directions. Within each (0.1 hectare) plot, shrubs were sampled in four subplots (5 $\times$ 5 m^2). Finally, five 1 m^2 subplots were sampled for herbaceous diversity, one in each plot's corner and one in the center. In total, 60 (0.1 ha) plots for trees, 300 (60 plots $\times$ 5 forest types = 300) plots (1 m^2) for herbs and 120 (24 plots $\times$ 5 forest types = 120) plots (5 m^2) for shrubs were sampled in the current study. We calculated the importance value index (hereinafter IVI) for each plant species using the abundance, cover and the number of species from each quadrant (frequency). The IVI was chosen since it is a widely used ecological technique for determining the dominance of plant species in a given habitat [24].

From each (0.1 ha) plot, four different random soil samples were collected to study the different physicochemical parameters of the forest types for further analysis. Soil samples from each plot were taken and sieved via a 2 mm mesh screen. The pH was calculated using pH meter (Mettler Toledo pH meter) and electrical conductivity and salinity were calculated using electro meter (Conductivity TDS Tester–HI98129) meter (Conductivity TDS Tester–HI98129). The total nitrogen was estimated by modified Kjeldahl's method, phosphorous by Olsen's method and carbon by the Walkley and Black method [25]. The soil types are orthods, belonging to the spodosol suborder, with a coarse texture, being typically acidic and infertile, with reddish-brown or black subsoil.

2.3. Data Analysis

Plant IVI and stand-level soil data were calculated and analyzed using ordination techniques for multivariate analysis. To compare the relationships between the forest vegetation, we used detrended correspondence analysis (DCA), an ordination technique based on reciprocal averaging. Species scores represent the relative position of taxa in the reduced space in terms of how they change over time. The significance of DCA axes is then inferred by examining species' relative positions in relation to what is known about their distribution in environmental parameters. This is a completely qualitative process and its major purpose, as with any ordination approach, is to establish the environmental significance of the axes, and hence define the ecological area indicated by the ordination axes. Following that, the space specified by species is used to ordinate samples, and by plotting axis scores stratigraphically, it is feasible to deduce how the stated environmental factors evolved through time. We investigated the relationship between plant species and soil variables using canonical correspondence analysis (CCA) by extracting key gradients among combinations of explanatory variables. Following CCA, the Monte Carlo test was used to evaluate the influence of explanatory variables on vegetation composition [26]. PCORD version 5 was used to perform two-way cluster analysis on the presence/absence data [27]. The Rényi diversity profile was used with PAST software version 3.14 [28] to highlight disparities in diversity curves for all five forest types. PAST software version 3.14 was used to generate the generally used diversity indices [29]: Shannon–Wiener [30], Simpson [31], Margalef richness index, dominance index and evenness index [32].

3. Results

3.1. Plant Composition and Distribution

In this study, we have documented 76 plants belonging to 63 genera and 39 families. Herbaceous life forms have the most species (60%), followed by trees (24%), shrubs (13%) and climbers (3%) (Table 1). The perennial was the most common life span group, accounting for 87 percent of all species, followed by annual (9%) and biannual (4%) species (Table 1). Half of the collected plants belonged to just seven families: Rosaceae, Fabaceae, Asteraceae, Poaceae, Asparagaceae and Lamiaceae, while the other half belonged to thirty-two (32) families. The majority of the families (25) were monotypic (Table 1).

Table 1. Database of plant species with family, growth form, life span and IVI values recorded in forests in the Zabarwan mountain range of the Kashmir Himalayas.

Family	Botanical Name	Abbreviation	Life Span	Growth Form	ACFT	BLFT	OKFT	PWFT	SRFT
Acanthaceae	*Strobilanthes attenuate* Nees (SMH 186)	Str_att	Perennial	Herb	0	0	6.03	0	0
	Strobilanthes wallichii Nees (SMH 188)	Str_wal	Perennial	Herb	0	0	10.61	5.98	4.32
Adoxaceae	*Viburnum grandiflorum* Wall. ex DC. (SMH 492)	Vib_gra	Perennial	Shrub	77.89	30.62	53.51	83.57	0
Amaranthaceae	*Achyranthes bidentata* Blume (SMH 264)	Ach_bid	Perennial	Herb	0	0	22.42	18.83	33.14
Asteraceae	*Arctium lappa* L. (SMH 185)	Arc_lap	Biennial	Herb	6.39	6.27	2.98	0	0
	Artemisia vulgaris L. (SMH 190)	Art_vul	Perennial	Herb	4.85	4.47	0	0	0
	Carpesiumabrotanoides L. (SMH 194)	Car_abr	Perennial	Herb	4.43	3.99	2.98	3.59	4.85
	Erigeron canadensis L. (SMH 192)	Eri_can	Annual	Herb	5.17	5.54	0	4.54	3.53
Asparagaceae	*Asparagus filicinus* Buch.-Ham. ex D.Don (SMH 210)	Asp_fil	Perennial	Herb	0	0	2.99	0	0
	Asparagus officinalis L. (SMH 211)	Asp_off	Perennial	Herb	0	0	0	4.37	3.53
	Polygonatum biflorum (Walter) Elliott (SMH 442)	Pol_bif	Perennial	Herb	0	0	5.97	4.27	5.15
	Polygonatum verticillatum (L.) All. (SMH 445)	Pol_ver	Perennial	Herb	0	0	0	2.35	3.21
Aspleniaceae	*Asplenium ofeliae* Salgado, A.E. (SMH 435)	Asp_ofe	Perennial	Herb	3.75	3.27	8.05	2.19	2.801
Apiaceae	*Daucus carota* L. (SMH 198)	Dau_car	Biennial	Herb	5.78	5.62	0	0	0
	Selinum wallichianum (DC.) Raizada& H.O. Saxena (SMH 212)	Sel-wal	Perennial	Herb	2.25	2.14	0	0	0
Araliaceae	*Hedera nepalensis* K.Koch (SMH 216)	Hed_nep	Perennial	Climber	11.24	11.71	13.12	14.09	16.51
Balsaminaceae	*Impatiens glandulifera* Royle (SMH 305)	Imp_gla	Annual	Herb	14.31	13.05	16.06	9.15	10.91
Berberidaceae	*Berberis lyceum* Royle (SMH 306)	Ber_lyc	Perennial	Shrub	59.07	76.29	0	0	0
Caprifoliaceae	*Lonicera webbiana* Wall. ex DC. (SMH 326)	Lon_web	Perennial	Shrub	69.29	0	0	0	0
Campanulaceae	*Asyneuma thomsonii* (C.B.Clarke) Bornm. (SMH 328)	Asy_tho	Perennial	Herb	0	0	0	2.35	2.36
Cannabaceae	*Celtis australis* L. (SMH 440)	Cel_aus	Perennial	Tree	33.71	42.68	15.28	45.75	46.75
Dioscoreaceae	*Dioscorea deltoidea* Wall. ex Griseb (SMH 441)	Dio_del	Perennial	Climber	10.91	10.46	9.86	5.21	6.16
Dryopteridaceae	*Dryopteris barbigera* (T.Moore ex Hook.) Kuntze SMH (443)	Dry_bar	Perennial	Herb	6.08	6.31	6.87	12.19	12.26
Fabaceae	*Robiniapseudoacacia* L. (SMH 219)	Rob_pse	Perennial	Tree	87.89	14.91	0	0	0
	Desmodium elegans DC. (SMH 449)	Des_ele	Perennial	Shrub	0	0	0	0	63.62
	Indigofera hebepetala Baker (SMH 243)	Ind_heb	Perennial	Shrub	0	0	0	0	97.27
	Trifolium pratense L. (SMH 507)	Tri_pra	Perennial	Herb	14.73	16.59	0	0	0
	Trifolium repens L. (SMH 508)	Tri_rep	Perennial	Herb	11.66	10.64	5.62	0	0
Fagaceae	*Quercus robur* L. (SMH 516)	Que_rob	Perennial	Tree	16.46	0	200.97	5.92	0
Geraniaceae	*Geranium nepalense* Sweet (SMH 517)	Ger_nep	Perennial	Herb	9.97	9.43	10.49	4.62	5.48
	Geranium pratense L. (SMH 356)	Ger_pra	Perennial	Herb	3.53	4.34	2.98	4.17	3.07
	Geranium wallichianum D.Don ex Sweet (SMH 357)	Ger_wal	Perennial	Herb	0	0	5.01	1.69	2.29
Hamamelidaceae	*Parrotiopsis jacquemontiana* (Decne.) Rehder (SMH 138)	Par_jac	Perennial	Shrub	0	65.93	116.73	170.91	154.44
Hypericaceae	*Hypericum perforatum* L. (SMH 175)	Hyp_per	Perennial	Herb	2.75	2.63	0	0	0
Iridaceae	*Iris hookeriana* Foster (SMH 382)	Iri_hoo	Perennial	Herb	3.51	3.27	9.57	0	0
Jugalandaceae	*Juglans regia* L. (SMH 326)	Jug_reg	Perennial	Tree	25.24	10.15	0	0	0
Lamiaceae	*Perilla frutescens* (L.) Britton (SMH 320)	Per_fru	Annual	Herb	7.71	7.67	0	0	0
	Salvia moorcroftiana Wall. ex Benth. (SMH 321)	Sal_moo	Perennial	Herb	0	0	2.23	2.35	3.21
	Prunella vulgaris L. (SMH 322)	Pru_vul	Perennial	Herb	0	0	2.02	0	0
Moraceae	*Morus alba* L. (SMH 334)	Mor_alb	Perennial	Tree	18.01	21.94	25.46	5.99	0
	Morus nigra L. (SMH 335)	Mor_nig	Perennial	Tree	26.44	21.95	6.95	0	0
Orchidaceae	*Cypripedumcordigerum* D.Don (SMH 328)	Cyp_cor	Perennial	Herb	0	0	3.87	3.2	2.81
Oxalidaceae	*Oxalis acetosella* L. (SMH 329)	Oxa_ace	Perennial	Herb	0	0	0	6.55	10.06
Pinaceae	*Pinus wallichiana* A.B.Jacks. (SMH 330)	Pin_wal	Perennial	Tree	0	0	0	184.44	0
Poaceae	*Cynodon dactylon* (L.) Pers. (SMH 331)	Cyn_dac	Perennial	Herb	0	0	0	38.96	21.17
	Oplismenus burmannii f. cristata (J. Presl) Hier. ex Peter (SMH 332)	Opl_bur	Annual	Herb	54.19	52.36	30.4	89.07	83.31
	Poa bulbosa L. (SMH 339)	Poa_bul	Annual	Herb	23.28	22.66	14.33	0	0
	Sorghum halepense (L.) Pers. (SMH 480)	Sor_hal	Perennial	Herb	0	0	6.86	0	0
	Stipa sibirica (L.) Lam. (SMH 481)	Sti_sib	Perennial	Herb	35.48	39.14	59.11	8.3	10.02
Polygonaceae	*Fagopyrum esculentum* Moench (SMH 483)	Fag_esc	Annual	Herb	5.81	6.99	3.39	0	0
	Polygonum amplexicaule D.Don (SMH 482)	Pol_amp	Perennial	Herb	1.74	1.64	3.19	0	0
	Polygonum hydropiper L. (SMH 489)	Pol_hyd	Annual	Herb	3.51	3.27	0	0	0
Plantaginaceae	*Digitalis purpurea* L. (SMH 486)	Dig_pur	Perennial	Herb	6.08	5.57	0	0	0
	Plantago major L. (SMH 479)	Pla_maj	Perennial	Herb	5.35	6.26	3.39	4.17	4.99
Pteridaceae	*Pteris cretica* L. (SMH 460)	Pte_cre	Perennial	Herb	4.19	3.84	0	3.82	4.18
Rosaceae	*Crataegus monogyna* Jacq. (SMH 462)	Cra_mon	Perennial	Tree	0	4.7	6.3	25.1	0
	Prunus persica (L.) Batsch (SMH 463)	Pru_per	Perennial	Tree	0	13.48	0	0	0
	Prunus armeniaca L. (SMH 340)	Pru_arm	Perennial	Tree	11.65	3.12	0	6.35	14.1
	Prunus avium (L.) L. (SMH 370)	Pru_avi	Perennial	Tree	21.26	16.72	0	0	0
	Prunus cerasus L. (SMH 371)	Pru_cer	Perennial	Tree	5.18	13.71	0	0	0
	Rosa webbiana Wall. ex Royle (SMH 204)	Ros_web	Perennial	Shrub	0	52.12	40.1	0	0
	Rubus ulmifolius Schott (SMH 350)	Rub_ulm	Perennial	Shrub	93.73	0	0	0	0
	Sorbaria tomentosa (Lindl.) Rehder (SMH 385)	Sor_tom	Perennial	Shrub	0	0	0	0	69.24
	Fragaria nubicola (Lindl. ex Hook.f.) Lacaita(SMH 450)	Fra_nub	Perennial	Herb	6.17	5.74	3.48	6.25	5.83
	Geum aleppicum Jacq. (SMH 472)	Geu_ale	Perennial	Herb	2.64	3.63	9.5	4.88	4.18

Table 1. *Cont.*

Family	Botanical Name	Abbreviation	Life Span	Growth Form	ACFT	BLFT	OKFT	PWFT	SRFT
	Geum urbanum L. (SMH 473)	Geu_urb	Perennial	Herb	10.21	9.77	6.22	4.63	5.12
	Prunus tomentosa Thunb. (SMH 474)	Pru_tom	Perennial	Shrub	0	75.03	89.63	45.51	0
Ranunculaceae	*Delphinium roylei* Munz (SMH 475)	Del_roy	Perennial	Herb	0	0	0	2.42	4.83
Salicaceae	*Populus alba* L. (SMH 476)	Pop_alb	Perennial	Tree	0	47.26	0	0	0
	Salix alba L. (SMH 477)	Sal_alb	Perennial	Tree	4.11	30.31	0	0	0
Sapindaceae	*Acer caesium* Wall. ex Brandis (SMH 478)	Ace_cae	Perennial	Tree	3.36	5.88	0	6.26	0
	Aesculus indica (Wall. ex Cambess.) Hook. (SMH 110)	Aes_ind	Perennial	Tree	3.76	15.33	30.55	6.57	0
Simaraubaceae	*Ailanthus altissima* (Mill.) Swingle (SMH 135)	Ail_alt	Perennial	Tree	37.04	19.41	14.46	5.9	46.84
Scrophulariaceae	*Verbascum thapsus* L. (SMH 511)	Ver_tha	Biennial	Herb	3.88	3.47	2.98	4.44	3.53
Ulmaceae	*Ulmus wallichiana* Planch. (SMH 525)	Ulm_wal	Perennial	Tree	5.82	18.37	0	7.68	37.86
Violaceae	*Viola odorata* L. (SMH 512)	Vio_odo	Perennial	Herb	8.30	8.11	7.26	20.25	17.06

3.2. Diversity and Phytosociological Attributes

Shannon diversity indices ranged from a high of 3.66 to a low of 3.092 for broad-leaved and scrub forest types. The Rényi diversity profiles revealed that the BLFT has much higher diversity than other forest types, as evidenced by the values (Figure 2). The decreasing order of species richness in forest types was as BLFT > ACFT > PNFT > OKFT > SRFT. The phytosociological features (basal area) were higher in coniferous forest type (74.49 m^2ha^{-1}) compared to broad-leaved (58.63 ± 21.57 m^2ha^{-1}) and scrub forest type (15.4 m^2ha^{-1}). In the case of tree density, the scrub forest type (1197.5 ± 199.56 N ha^{-1}) was denser than acacia forest (850 ± 204.61 N ha–^{1}) and coniferous (707.5 ± 148.18 N ha^{-1}) forest type (Table 2).

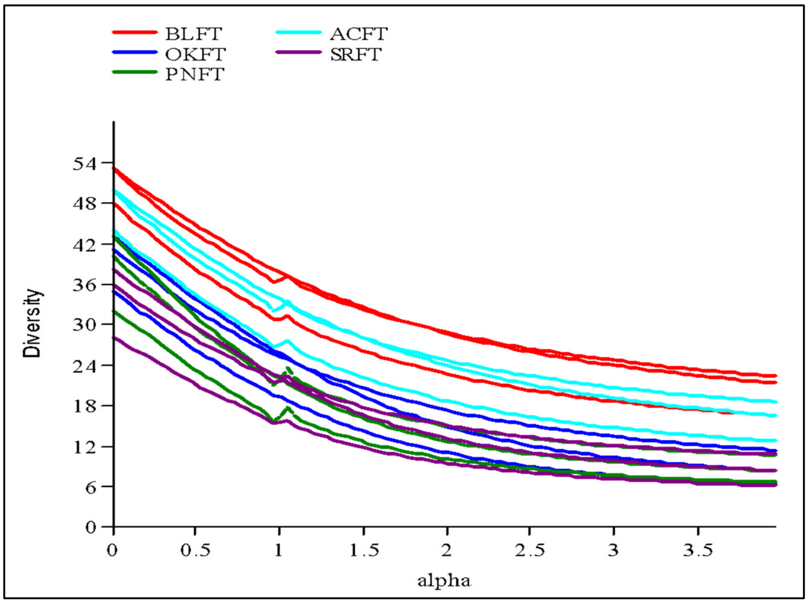

Figure 2. Rényi diversity profiles of the forest types in the Zabarwan mountain range of the Kashmir Himalayas. Broad-leaved forest (BLFT), Oak Forest (OKFT), *Pinus wallichiana* Forest (PNFT), Acacia Forest (ACFT), and Scrub Forest (SRFT).

Table 2. Multiple diversity, soil parameters and phytosociological attributes of different forest types in the Zabarwan mountain range of the Kashmir Himalayas.

Forest Types	ACFT	BLFT	OKFT	PNFT	SRFT
Species Richness	51	55	44	46	38
Dominance	0.041	0.033	0.066	0.075	0.076
Shannon	3.524	3.664	3.26	3.14	3.092
Simpson	0.958	0.966	0.933	0.924	0.923
Evenness	0.664	0.709	0.592	0.502	0.579
Fisher Alpha	16.33	16.63	14.89	16.62	15.03

Table 2. *Cont.*

Forest Types	ACFT	BLFT	OKFT	PNFT	SRFT
pH	6.56	6.5	5.9	5.51	6.66
Electrical Conductivity (µS/cm)	384	370	660	610	396
Organic Carbon (%)	4.14	5.18	5.44	4.5	5.04
Available Nitrogen(kg/ha)	0.08	0.13	0.16	0.12	0.13
Phosphorus (µg/g)	18.6	8.2	15.2	8.2	8.1
Potassium (µg/g)	147	129	463	230	339
Calcium (µg/g)	4.05	3.7	3.6	4.5	4.1
Salinity (ppm)	23.7	24.6	83.1	21.3	13.3
Density (mean ± SD; trees/ha^{-1})	850 ± 204.61	1057.5 ± 367.28	640 ± 140.95	707.5 ± 148.18	1197.5 ± 199.56
Basal Area (mean ± SD; m^{2}ha^{-1})	46.82 ± 14.73	58.63 ± 21.57	41.41 ± 3.81	74.49 ± 12.09	15.40 ± 6.20

3.3. Vegetation Ordination Approaches

3.3.1. DCA Ordination

We found that the 76 plant species found in the five forest types grouped differentially on the positive and negative sides of the DCA axis during DCA ordination (Figure 3). The maximal species had a positive connection with both axis 1 and 2. The following plant species, *Asplenium ofelia*, *Conyza canadensis*, *Dioscoreadeltoidea*, *Dryopteris barbigera*, *Fragaria nubicola*, *Impatiens glandulifera*, *Geranium nepalense*, *Quercusrobur*, *Trifloium repens*, *Rubus ulmifolius*, *Pteris cretica*, and *Viburnum grandiflorum*. *Delphinium roylei*, *Aesculus indica*, *Cynodon dactylon*, *Celtis australis*, *Geranium wallichianum*, *Morus alba*, *Populus alba*, *Rosa webbiana*, *Pinus wallichiana*, *Ulmus wallichiana* and *Prunus tomentosa*, were among the species clusters that showed differences in forest types on the negative side of both axes in ordination space. Table 3 shows a detailed summary of the total inertia (sum of all eigenvalues).

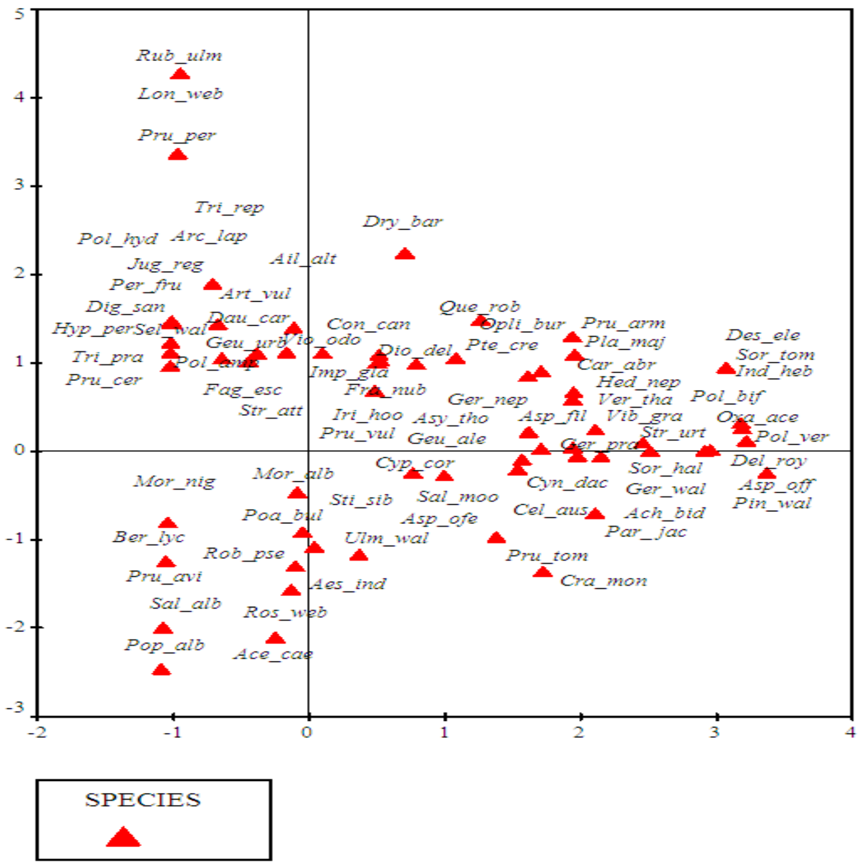

Figure 3. DCA vegetation ordination in the Kashmir Himalayan Zabarwan mountain range.

Table 3. Summary of the four axes of the DCA for vegetation data (using the importance value index) in the Kashmir Himalayan Zabarwan mountain range.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.81	0.42	0.28	0.04
Accumulative explained variation	17.6	26.8	32.9	33.9
Gradient length	6.84	3.04	2.44	2.07
Total inertia	4.603			

3.3.2. Role of Soil Parameters in Vegetation Patterns

The CCA ordination indicated that species were differently distributed along different soil variables (Figure 4). The species that are sensitive to Ca include *Asyneuma thomsonii*, *Crataegus songarica*, *Celtis australis*, *Delphinium roylei*, *Desmodium elegans*, *Oplismenus burmannii*, *Pinus wallichiana* and *Viburnum grandiflorum*. Other elements such as N, K, EC and P have an impact on species distribution; however plant species that are positively connected with their values include *Carpesium abrotanoides*, *Parrotiopsisjacquemontiana*, *Verbascum thapsus* and *Polygonatum acuminatifolium*. The species impacted by pH include *Artemisia vulgaris*, *Acer caesium*, *Conyza canadensis*, *Berberis lyceum*, *Fragarianubicola*, *Digitalis purpurea*, *Geum urbanum*, *Hypericum perforatum*, *Salix alba*, *Populus alba*, *Juglans regia* and *Ulmus wallichiana*. The species that were found to be sensitive to OC include *Asparagus filicinus*, *Prunella vulgaris* and *Quercus robur* (Figure 5). In the species data, the total variation (inertia) was 4.10. All axes had pseudo-canonical correlations of 0.98. For all axes, the Monte Carlo test yielded an eigenvalue of 0.75, a F-ratio of 0.977 and a p-value of 0.028 (Table 4).

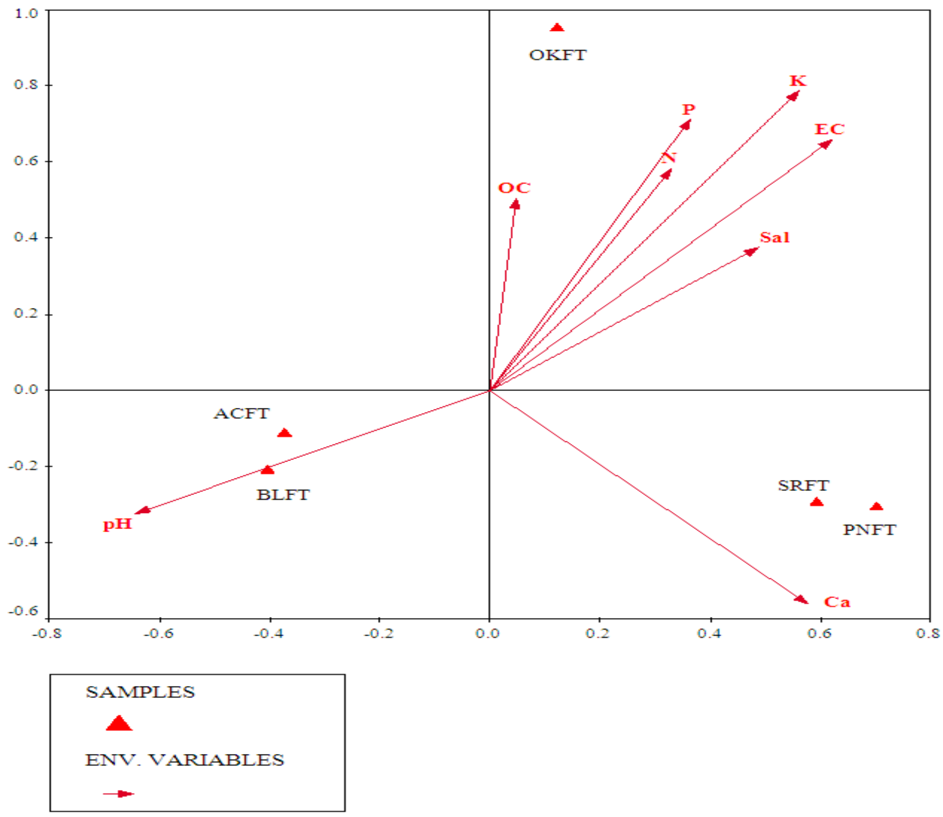

Figure 4. In the Kashmir Himalayan Zabarwan mountain range, a CCA diagram depicts the distribution of soil characteristics. P = Phosphorus, K = Potassium, Sal = Salinity, N = Available Nitrogen, Ca = Calcium, EC = Electrical Conductivity, OC = Organic Carbon and Sal = Salinity.

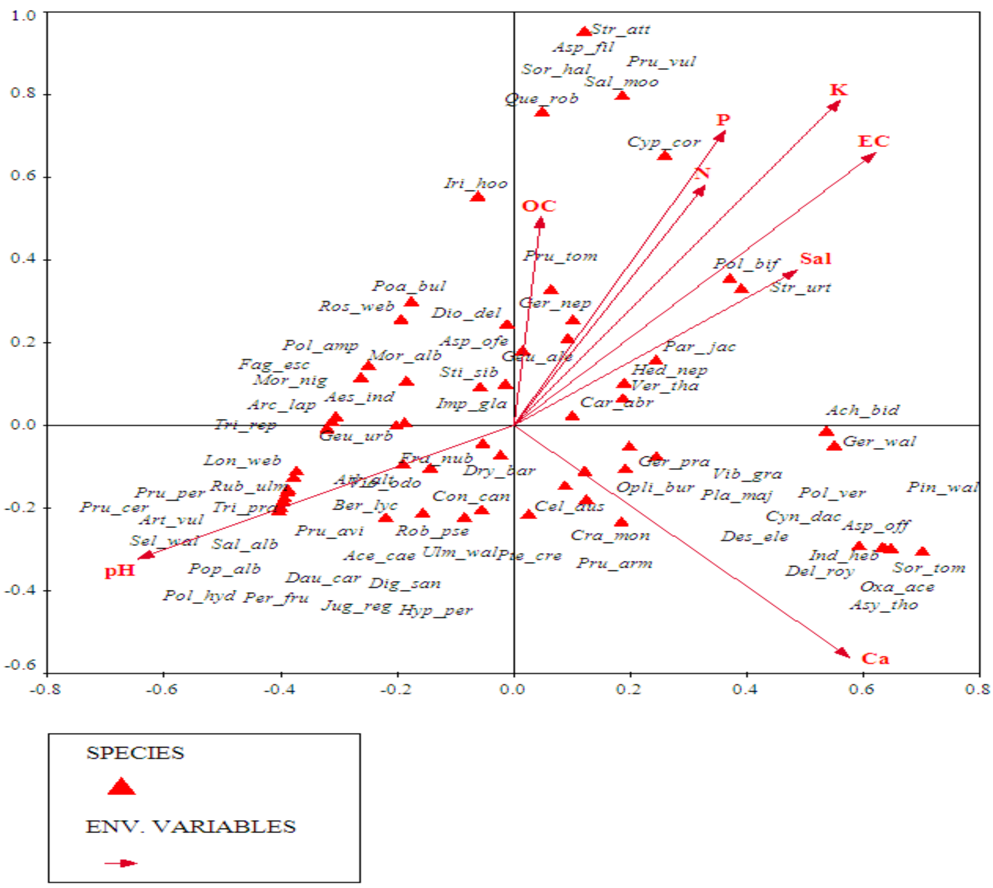

Figure 5. In the Kashmir Himalayan Zabarwan mountain range, a CCA diagram depicts the distribution of plant species along soil characteristics. P = Phosphorus, K = Potassium, Sal = Salinity, N = Available Nitrogen, Ca = Calcium, EC = Electrical Conductivity and OC = Organic Carbon.

Table 4. CCA results of vegetation data according to soil variables included in the analysis of the Kashmir Himalayas' Zabarwan mountain range.

Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.736	0.446	0.388	0.347
Explained variation	17.9	28.7	38.2	46.6
Pseudo-canonical correlation	0.984	0.958	0.980	0.962
Explained fitted variation	31.5	50.6	67.2	82.7
Total inertia		4.109		

3.3.3. Vegetation Classification

From the investigations of five forest types and 76 plant species, two-way clustering resulted in the establishment of two major plant groups. The BLFT and ACFT forest types are more similar and make up one leg of the cluster, whereas the OKFT, PNFT and SRFT forest types are similar in composition and make up the second. The white boxes represent the absence of a plant species in the forest types, whereas the black boxes represent the presence of a plant species (Figure 6).

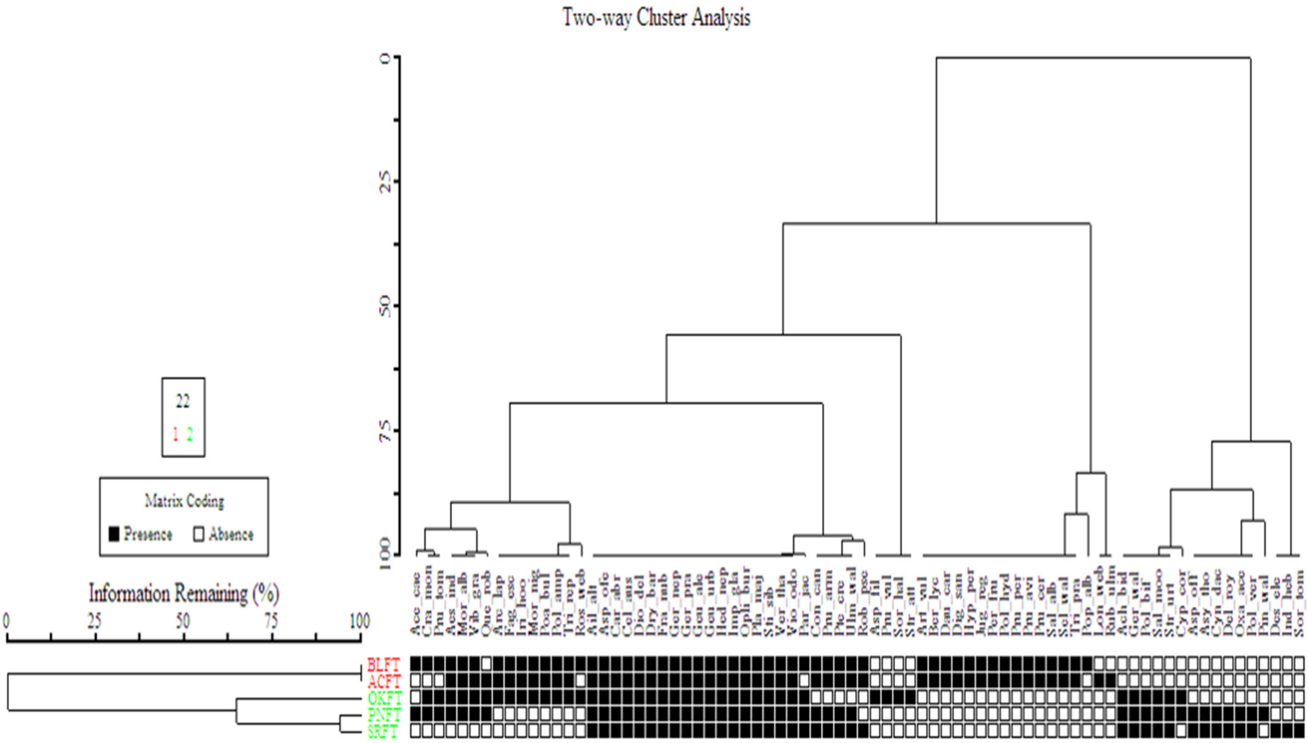

Figure 6. Two-way cluster analysis of 76 plant species and 5 forest types in the Kashmir Himalayan Za-barwan mountain range based on Sorenson's similarity index.

4. Discussion

Mountains are unquestionably the world's most rugged, yet fragile ecosystems and biodiversity-rich areas. However, these fragile environments are particularly vulnerable, and even the tiniest disturbance can place many species that live in these areas at risk. As a result, it is important to learn about the flora of these delicate mountain habitats so that conservation efforts can be prioritized. In this investigation, we identified 76 plants from five forest types in the Zabarwan mountain range. The number of plant species found in the research area is comparable to those found in previous studies in the Himalayan region and elsewhere. For example, Shaheen et al. [33] and Bokhari et al. [34] recorded 72 and 75 species from Pakistan's Himalayan woodlands, respectively. Deka et al. [35] and Borah et al. [36] found 71 and 88 species, respectively, in Assam's woodlands. From the forests of Jammu, India, Sharma and Kant [37] and Sharma and Raina [38] identified 112 and 63 species, respectively.

The distribution of plants in specific families reflects the underlying effects of abiotic and biotic processes. Species composition and abundance, on the other hand, appear to be linked to environmental plant traits. The preponderance of Rosaceae and Fabaceae groups shows that the studied region has a less disturbed environment. Similar observations were made by Haq et al. [23,39,40], who reported Rosaceae as the leading family in the Kashmir Himalayas, India.

The floristic analysis reported that the species richness values of the present study are more or less similar with several phytosociological related investigations in the Himalayas. Similar results were noticed by Gairola et al. [41] where the authors reported species richness ranges between 31 and 58 from the Western Himalayas. Shaheen and Shinwari [42] reported 29 to 38 species from Chitral, Hindukush Himalayas. Ummara et al. [43] reported 19–32 species from the vegetation of the Shogran valley, Pakistan. Comparatively low species richness of 10–17 was reported by Nazir et al. [44] from phytosociological studies from the Pakistani Himalayas. The greater species richness was observed in broad-leaved and coniferous-dominated forest types compared to scrub forest type. A similar pattern was observed by Sharma and Kant [37] and Dar and Sundarapandian [45] from forest communities of the Western Himalayas. The phytosociological attributes of coniferous forest types were greater than those of broad-leaved and scrub forest types. The coniferous forest has a higher basal area due to slow-growing, long-lived tree species and old natural forest stands [2].

The tree basal area was reported to be between 15.4 and 74.49 m^2ha^{-1}. Dar and Sundarapandian [45] (19.4–51.9 m^2ha^{-1}) and Haq et al. [46] (71–92 m^2ha^{-1}) from India, Shaheen and Shinwari [40] (42.3–105.2 m^2ha^{-1}) from Pakistani Himalayas and Haq et al. [47] (6.7–104 m^2ha^{-1}) from the central Himalayas all agreed on the current findings. Scrub forest types were thicker than broad-leaved and coniferous forest types in terms of tree density. Because the research region is a protected area, the high density of the scrub forest is a result of no deforestation. The tree density was observed in a range of 640 to 1197 N ha^{-1}. The current findings matched those published by Ahmed et al. [48] from the Pakistani Himalayas 530–940 N ha^{-1}. Sreejith et al. [49] and Supriyadevi and Yadava [50] found tree density of 625–850 N ha^{-1} in Northern Kerala and 534–620 N ha^{-1} in Northeast India, respectively. It is conceivable that this is owed to the fact that no human activity is permitted within the park. As a result, protected forests, as hypothesized, have a greater tree density due to less anthropogenic disturbances.

Multivariate analyses (two-way cluster analyses, DCA and CCA) were adopted for the classification and ordination of plant associations in forest types. Two-way cluster analysis classified the forest vegetation of the Zabarwan mountain range into two plant communities on the basis of indicator plant species. Similar classifications were also carried out by previous researchers such as Siddiqui et al. [51], Rahman et al. [52] and Bano et al. [53] from the Pakistani Himalayas, Shahid and Joshi [54] and Shahid and Joshi [55] from the Garhwal Himalayas, India, three plant groups by Wang et al. [56] from China, Moradi and Vacik [57] from the southern forests of Iran and Sainge et al. [58] from the montane forest in Cameroon. The CCA diagram (bi-plot) revealed that variations in environmental and biotic interactions were reflected in the diversity, distribution and relationship of plant species. In addition, each change in soil characteristics has a major impact on plant population growth [12].

The results of this study demonstrated that the soil physicochemical parameters of different forest types differ significantly. Due to terrain, climate, weathering processes, plant cover and microbiological activity [59,60], as well as a range of other biotic and abiotic factors [61–64], forest soil physicochemical parameters fluctuate through time and location. Soil quality varies over short distances based on parent rocks, vegetation cover and land use. In Himalayan landscapes, bioclimatic conditions fluctuate fast and can vary over short distances, resulting in a remarkable variety of soil types and their chemical, physical and biological properties [65–68], as well as fluctuating vegetation patterns [68–71]. We found that, in addition to climactic factors such as temperature and precipitation, edaphic elements such as soil texture and chemistry emerged as key determinants of plant community composition. Other studies have proposed similar relationships between soil edaphic properties and plant species composition, which can be explained by the fact that local edaphic properties affect the resource availability of water and nutrients in different soil types, thereby selecting plant communities with varied ecological functions [69–73].

Other mountain forest habitats around the world have also discovered the role of soil structure on species zonation [69–74]. These findings differ from ours in that they were conducted in non-protected woodland habitats. Furthermore, it was revealed that the mildly acidic pH of the soil has an impact on the growth of diverse plant species in this habitat. The first axes were largely associated with soil pH and Ca, while the second axes were mostly connected with phosphorus, electrical conductivity and potassium contents, according to CCA's ecological gradient processes for both forest types and species. These findings match those of Khan et al. [75] and Khan et al. [12], all of whom conducted their research in Pakistan's Himalayan forests. The CCA bi-plot also showed that organic carbon, electric conductivity and phosphorus were determinants in shaping the composition, diversity and distribution of flora, as species are highly sensitive to these soil parameters. Hussain et al. [76,77], Majeed et al. [78], Rahman et al. [79] and Malik et al. [80] recorded a positive association between edaphic factors and plant structure and distribution trends, which supports our findings. The results reveal the potential role of edaphic parameters in shaping the various forest communities at a regional scale.

5. Conclusions

The present study brings new contributions about the soil impacts on forest plant communities within the Zabarwan mountain range of the Kashmir Himalayas, which are under threat from a variety of factors and are regarded as one of the world's most endangered forests. In this investigation, we recorded 76 plants, the majority of which (60%) are found in herbaceous life forms. According to the Rényi diversity profiles, the BLFT has much higher diversity than other forest types. The sequence of decreasing species richness in forest types was BLFT > ACFT > PNFT > OKFT > SRFT. The phytosociological characteristics (basal area) of coniferous forest type were greater than those of broad-leaved forest type and scrub forest type. Based on multiple-factor categorization and multivariate analyses, these findings reveal the link between forest types and soil parameters. As expected, species diversity and composition varied across spatial scales with higher values in BLFT. Soil variables such as Ca, N, K, EC, P and soil pH, on the other hand, tended to influence vegetation association in diverse ways. Furthermore, the conservation biology model has changed to put a greater focus on multi-scale approaches to biodiversity preservation; certain abiotic influences were involved in deciding what processes work at a given spatial scale to induce variations in population structure and species diversity. Our findings will provide a better understanding of forest community composition and related soil characteristics, which will guide forest ecosystem management and conservation in the Himalayan region.

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References

1. Perrigo, A.; Hoorn, C.; Antonelli, A. Why mountains matter for biodiversity. *J. Biogeogr.* **2020**, *47*, 315–325. [CrossRef]
2. Haq, S.M.; Khuroo, A.A.; Malik, A.H.; Rashid, I.; Ahmad, R.; Hamid, M.; Dar, G.H. Forest ecosystems of Jammu and Kashmir State. In *Biodiversity of the Himalaya*; Springer: Singapore, 2020.
3. Bargali, K.; Beena, J.; Bargali, S.S.; Singh, S.P. Diversity within Oaks. *Inter. Oaks* **2014**, *25*, 57–70.
4. Gosain, B.G.; Negi, G.C.S.; Dhyani, P.P.; Bargali, S.S.; Saxena, R. Ecosystem services of forests: Carbon Stock in vegetation and soil components in a watershed of Kumaun Himalaya, India. *Int. J. Ecol. Environ. Sci.* **2015**, *41*, 177–188.
5. Rana, S.; Bargali, K.; Bargali, S.S. Assessment of plant diversity, regeneration status, biomass and carbon stock in a Central Himalayan cypress forest. *Int. J. Biodiv. Conserv.* **2015**, *7*, 321–329.
6. Manandhar, P.; Rasul, G. The role of the Hindu Kush–Himalayan (HKH) mountain system in the context of a changing climate: A panel discussion. *Mt. Res. Dev.* **2009**, *29*, 184–187. [CrossRef]
7. Bargali, S.S.; Awasthi, P.; Bargali, K. Composition, structure and productivity of the herbaceous vegetation of five forest stands varying in soil moisture and nitrogen in Central Himalaya, India. *Euras. J. For. Sci.* **2021**, *9*, 29–42. [CrossRef]

8. Rasul, G. The role of the Himalayan Mountain systems in food security and agricultural sustainability in South Asia. *Int. J. Rural Mgt.* **2010**, *6*, 95–116. [CrossRef]
9. Hester, A.; Brooker, R. Threatened habitats: Marginal vegetation in upland areas. *Issues Environ. Sci. Technol.* **2007**, *25*, 107–134.
10. Mondoni, A.; Rossi, G.; Orsenigo, S.; Probert, R.J. Climate warming could shift the timing of seed germination in alpine plants. *Ann. Bot.* **2012**, *110*, 155–164. [CrossRef]
11. Foxcroft, L.C.; Richardson, D.M.; Pyšek, P.; Genovesi, P. Invasive alien plants in protected areas threats, opportunities, and the way forward. In *Plant Invas Protect Areas*; Springer: Dordrecht, The Netherlands, 2013.
12. Khan, M.; Khan, M.S.; Ilyas, M.; Alqarawi, A.A.; Ahmad, Z.; Abd-Allah, F.E. Plant species and community's assessment in interaction with edaphic and topographic factors; an ecological study of the mount Eelum District Swat, Pakistan. *SJBS* **2017**, *24*, 778–786.
13. Saima, S.; Altaf, A.; Faiz, M.H.; Shahnaz, F.; Wu, G. Vegetation patterns and composition of mixed coniferous forests along an altitudinal gradient in the Western Himalayas of Pakistan. *Austr. J. Forens. Sci.* **2018**, *135*, 159–180.
14. Arruda, D.M.; Schaefer, C.E.; Corrêa, G.R.; Rodrigues, P.M.; Duque-Brasil, R.; Ferreira-JR, W.G.; Oliveira-Filho, A.T. Landforms and soil attributes determine the vegetation structure in the Brazilian semiarid. *Folia Geobot.* **2015**, *50*, 175–184. [CrossRef]
15. Ehrlich, P.R. Conservation in temperate forests: What do we need to know and do? *For. Ecol. Mgt.* **1996**, *85*, 9–19. [CrossRef]
16. Becknell, J.M.; Powers, J.S. Stand age and soils as drivers of plant functional traits and aboveground biomass in secondary tropical dry forest. *Can. J. Forest Res.* **2014**, *44*, 604–613. [CrossRef]
17. Dybzinski, R.; Fargione, J.E.; Zak, D.R.; Fornara, D.; Tilman, D. Soil fertility increases with plant species diversity in a long-term biodiversity experiment. *Oecologia* **2008**, *158*, 85–93. [CrossRef] [PubMed]
18. Neri, A.V.; Schaefer, C.E.G.R.; Silva, A.F.; Souza, A.L.; Ferreira-Junior, W.G.; Meira-Neto, J.A.A. The influence of soils on the floristic composition and community structure of an area of Brazilian Cerrado vegetation. *Edinb. J. Bot.* **2012**, *69*, 1–27. [CrossRef]
19. Fischer, C.; Leimer, S.; Roscher, C.; Ravenek, J.; de Kroon, H.; Kreutziger, Y.; Baade, J.; Beßler, H.; Eisenhauer, N.; Weigelt, A.; et al. Plant species richness and functional groups have different effects on soil water content in a decade-long grassland experiment. *J. Ecol.* **2019**, *107*, 127–141. [CrossRef]
20. Nadeau, M.B.; Sullivan, T.P. Relationships between plant biodiversity and soil fertility in a mature tropical forest, Costa Rica. *Int. J. For. Res.* **2015**, *2015*, 732946. [CrossRef]
21. Champion, H.G.; Seth, S.K. *A Revised Survey of the Forest Types of India*; Manager of Publications: Delhi, India, 1968.
22. Haq, S.M.; Hamid, M.; Lone, F.A.; Singh, B. Himalayan hotspot with alien weeds: A Case study of biological spectrum, phenology, and diversity of weedy plants of high-altitude mountains in district kupwara of J&K Himalaya, India. *Proc. Natl. Acad. Sci. India Sect. B Biol. Sci.* **2021**, *91*, 139–152.
23. Haq, S.M.; Malik, A.H.; Khuroo, A.A.; Rashid, I. Floristic composition and biological spectrum of Keran-a remote valley of northwestern Himalaya. *AES* **2019**, *39*, 372–379. [CrossRef]
24. Haq, S.M.; Rashid, I.; Khuroo, A.A.; Malik, Z.A.; Malik, A.H. Anthropogenic disturbances alter community structure in the forests of Kashmir Himalaya. *Trop. Ecol.* **2019**, *60*, 6–15. [CrossRef]
25. Gupta, P.K. *Soil Plant Water and Fertilizer Analysis*; Agrobios: Jodhpur, India, 2017.
26. TerBraak, C.J.F.; Smilauer, P. *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (Version 4.5)*; Microcomputer Power: Ithaca, NY, USA, 2002; Available online: http://www.canoco.com (accessed on 17 May 2021).
27. Leps, J.; Smilauer, P. *Multivariate Analysis of Ecological Data Using CANOC*; Cambridge University Press: Cambridge, UK, 2003.
28. Altaf, A.; Haq, S.M.; Shabnum, N.; Jan, H.A. Comparative assessment of Phyto diversity in Tangmarg Forest division in Kashmir Himalaya, India. *AES*, 2021, *in press*.
29. Sajad, S.; Haq, S.M.; Yaqoob, U.; Calixto, E.S.; Hassan, M. Tree composition and standing biomass in forests of the northern part of Kashmir Himalaya. *Vegetos* **2021**, *34*, 857–866. [CrossRef]
30. Shannon, C.E. A mathematical theory of communication. *Bell. Syst. Tech. J.* **1948**, *27*, 379–423. [CrossRef]
31. Simpson, E.H. Measurement of diversity. *Nature* **1949**, *163*, 688. [CrossRef]
32. Pielou, E.C. *An Introduction to Mathematical Ecology*; Wiley-Interscience: New York, NY, USA, 1969.
33. Shaheen, H.; Qureshi, R.A.; Shinwari, Z.K. Structural diversity, vegetation dynamics and anthropogenic impact on lesser Himalayan subtropical forests of Bagh district, Kashmir. *Pak. J. Bot.* **2011**, *43*, 1861–1866.
34. Bokhari, T.Z.; Ahmed, M.; Siddiqui, M.F.; Khan, Z. Forest communities of Azad Kashmir, Pakistan. *Fuuast J. Biol.* **2013**, *3*, 137–145.
35. Deka, J.; Tripathi, O.P.; Khan, M.L. High dominance of *Shorea robusta* Gaertn. in alluvial plain Kamrupsal forest of Assam, NE India. *Int. J. Ecosyst.* **2012**, *2*, 67–73. [CrossRef]
36. Borah, N.; Athokpam, F.D.; Garkoti, S.C.; Das, A.K.; Hore, D.K. Structural and compositional variations in undisturbed and disturbed tropical forests of Bhuban hills in south Assam, India. *Int. J. Biodiv. Sci. Ecosyst. Ser. Mgt.* **2014**, *10*, 9–19. [CrossRef]
37. Sharma, N.; Kant, S. Vegetation structure, floristic composition and species diversity of woody plant communities in sub-tropical KandiSiwaliks of Jammu, J & K, India. *Int. J. Basic Appl. Sci.* **2014**, *3*, 382.
38. Sharma, J.; Raina, A.K. Quantitative analysis, distributional pattern and species diversity of woody plant species of Lamberi Forest Range, Rajouri, J&K, India. *J. Appl. Nat. Sci.* **2018**, *10*, 522–527.
39. Haq, S.M.; Malik, A.H.; Khuroo, A.A.; Rashid, I. Contribution to the Flora of Keran Valley in Kashmir Himalaya, India. In *Ethnobotany and Biodiversity Conservation*; Indus Book Services Prvt. Ltd.: New Delhi, India, 2020; ISBN-10-938675657.

40. Tariq, A.; Shu, H.; Siddiqui, S.; Imran, M.; Farhan, M. Monitoring Land use and land cover changes using geospatial techniques, a case study of Fateh Jang, Attock, Pakistan. *Geogr. Environ. Sustain.* **2021**, *14*, 41–52. [CrossRef]
41. Haq, S.M.; Calixto, E.S.; Kumar, M. Assessing biodiversity and productivity over a small-scale gradient in the protected forests of Indian Western Himalayas. *J. Sust. For.* **2021**, *40*, 675–694. [CrossRef]
42. Gairola, S.; Sharma, C.M.; Ghildiyal, S.K.; Suyal, S. Live tree biomass and carbon variation along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya (India). *Curr. Sci.* **2011**, *100*, 1862–1870.
43. Ummara, U.; Bokhari, T.Z.; Siddiqui, M.F. Quantitative description of understory vegetation of Shogran valley, Pakistan. *Fuuast. Biol.* **2015**, *5*, 63–70.
44. Tariq, A.; Riaz, I.; Ahmad, Z. Land surface temperature relation with normalized satellite indices for the estimation of spatio-temporal trends in temperature among various land use land cover classes of an arid Potohar region using Landsat data. *Environ. Earth Sci.* **2020**, *79*, 40. [CrossRef]
45. Dar, J.A.; Sundarapandian, S. Patterns of plant diversity in seven temperate forest types of Western Himalaya, India. *J. Asia Pac. Biodiv.* **2016**, *9*, 280–292. [CrossRef]
46. Tariq, A.; Shu, H. CA-Markov chain analysis of seasonal land surface temperature and land use land cover change using optical multi-temporal satellite data of Faisalabad, Pakistan. *Remote Sens.* **2020**, *12*, 3402. [CrossRef]
47. Haq, S.M.; Calixto, E.S.; Rashid, I.; Srivastava, G.; Khuroo, A.A. Tree diversity, distribution and regeneration in major forest types along an extensive elevational gradient in Indian Himalaya: Implications for sustainable forest management. *For. Ecol. Mgt.* **2022**, *506*, 119968. [CrossRef]
48. Ahmed, M.; Husain, T.; Sheikh, A.H.; Hussain, S.S.; Siddiqui, M.F. Phytosociology and structure of Himalayan forests from different climatic zones of Pakistan. *Pak. J. Bot.* **2006**, *38*, 361–383.
49. Sreejith, K.A.; Chandrashekara, V.M.; Nirmesh, T.K.; Sreekumar, V.B. Tree species composition and distribution pattern in a Myristica swamp of Northern Kerala, India. *Curr. World Environ.* **2016**, *11*, 743–750. [CrossRef]
50. Tariq, A.; Shu, H.; Saddiqui, S.; Mousa, B.G.; Munir, I.; Nasri, A.; Waqas, H.; Baqa, M.F.; Lu, L. Forest fire Monitoring using spatial-statistical and Geo-spatial analysis of factors determining Forest fire in Margalla Hills, Islamabad, Pakistan. *Geomat. Nat. Hazards Risk* **2021**, *12*, 1212–1233. [CrossRef]
51. Siddiqui, M.F.; Moinuddin, A.; Nasrullah, K.; Khan, I.A. A quantitative description of moist temperate conifer forests of Himalayan region of Pakistan and Azad Kashmir. *Int. J. Biol. Biotech.* **2010**, *7*, 175–185.
52. Tariq, A.; Shu, H.; Siddiqui, S.; Munir, I.; Sharifi, A.; Li, Q.; Lu, L. Spatio-temporal analysis of forest fire events in the Margalla Hills, Islamabad, Pakistan using socio-economic and environmental variable data with machine learning methods. *J. For. Res.* **2021**, *13*, 12. [CrossRef]
53. Bano, S.; Khan, S.M.; Alam, J.; Alqarawi, A.A.; Abd_Allah, E.F.; Ahmad, Z.; Hashem, A. Eco-Floristic studies of native plants of the Beer Hills along the Indus River in the districts Haripur and Abbottabad, Pakistan. *Saud. J. Biol. Sci.* **2018**, *25*, 801–810. [CrossRef] [PubMed]
54. Shahid, M.; Joshi, S.P. Pytosociological assessement and distribution pattern of tree species in forest of doon valley Shivalik Hills of lower Himalaya. *Trop. Pant Res.* **2016**, *3*, 263–271.
55. Tariq, A.; Shu, H.; Li, Q.; Altan, O.; Khan, M.R.; Baqa, M.F.; Lu, L. Quantitative analysis of forest fires in South- eastern Australia using SAR data. *Remote Sens.* **2021**, *13*, 2386. [CrossRef]
56. Wang, J.; Chen, C.; Li, J.; Feng, Y.; Lu, Q. Different ecological processes determined the alpha and beta components of taxonomic, functional, and phylogenetic diversity for plant communities in dry land regions of Northwest China. *Peer J.* **2019**, *6*, 6220. [CrossRef]
57. Tariq, A.; Shu, H.; Gagnon, A.S.; Li, Q.; Mumtaz, F.; Hysa, A.; Siddique, M.A.; Munir, I. Assessing burned areas in wildfires and prescribed fires with spectral indices and SAR images in the margalla hills of Pakistan. *Forests* **2021**, *12*, 1371. [CrossRef]
58. Sainge, M.N.; Lyonga, N.M.; Mbatchou, G.P.; Kenfack, D.; Nchu, F.; Peterson, A.T. Vegetation, floristic composition and structure of a tropical montane forest in Cameroon. *Bothalia. Afr. Biodiv. Conser.* **2019**, *49*, 1–12. [CrossRef]
59. Paudel, S.; Sah, J.P. Physico chemical characters of soil in tropical soil (*Shorearobusta* Gaertn.) forests in eastern Nepal. *Himal. J. Sci.* **2003**, *1*, 107–110.
60. Bargali, K.; Manral, V.; Padalia, K.; Bargali, S.S.; Upadhyay, V.P. Effect of vegetation type and season on microbial biomass carbon in Central Himalayan forest soils, India. *Catena* **2018**, *171*, 125–135. [CrossRef]
61. Bargali, S.S.; Joshi, M.; Bargali, K. Seasonal pattern of total soil respiration in age series of eucalypt plantation and mixed broad-leaved forest in Tarai belt of Kumaun Himalaya. *Oecol. Mont.* **1992**, *2*, 7–11.
62. Bargali, S.S.; Singh, R.P.; Joshi, M. Changes in soil characteristics in eucalypt plantations replacing natural broad-leaved forests. *J. Veg. Sci.* **1993**, *4*, 25–28. [CrossRef]
63. Hussain, S.; Lu, L.; Mubeen, M.; Nasim, W.; Karuppannan, S.; Fahad, S.; Tariq, A.; Mousa, B.G.; Mumtaz, F.; Aslam, M. Spatiotemporal variation in land use land cover in the response to local climate change using multispectral remote sensing data. *Land* **2022**, *11*, 595. [CrossRef]
64. Khan, A.M.; Li, Q.; Saqib, Z.; Khan, N.; Habib, T.; Khalid, N.; Majeed, M.; Tariq, A. MaxEnt Modelling and impact of climate change on habitat suitability variations of economically important chilgoza pine (*Pinus gerardiana* Wall.) in South Asia. *Forests* **2022**, *13*, 715. [CrossRef]
65. Bargali, S.S.; Padalia, K.; Bargali, K. Effects of tree fostering on soil health and microbial biomass under different land use systems in Central Himalaya. *Land. Degrad. Dev.* **2019**, *30*, 1984–1998. [CrossRef]

66. Manral, V.; Bargali, K.; Bargali, S.S.; Shahi, C. Changes in soil biochemical properties following replacement of Banj oak forest with Chir pine in Central Himalaya, India. *Ecol. Proc.* **2020**, *9*, 30. [CrossRef]
67. Padalia, K.; Bargali, S.S.; Bargali, K.; Manral, V. Soil microbial biomass phosphorus under different land use systems. *Trop. Ecol.* **2021**, *63*, 30–48. [CrossRef]
68. Bargali, K.; Joshi, B.; Bargali, S.S.; Singh, S.P. Oaks and the biodiversity they sustain. *Int. Oaks* **2015**, *26*, 65–76.
69. Hegazy, A.K.; El-Demerdash, M.A.; Hosni, H.A. Vegetation, species diversity and floristic relations along an altitudinal gradient in south-west Saudi Arabia. *J. Arid. Environ.* **1998**, *38*, 3–13. [CrossRef]
70. Wang, Y.; Singh, M.P. Trust representation and aggregation in a distributed agent system. In Proceedings of the Twenty-First National Conference on Artificial Intelligence and the Eighteenth Innovative Applications of Artificial Intelligence Conference, Boston, MA, USA, 16–20 July 2006; AAAI: Menlo Park, CA, USA, 2006; Volume 6, pp. 1425–1430.
71. Davies, R.G.; Barbosa, O.; Fuller, R.A.; Tratalos, J.; Burke, N.; Lewis, D.; Gaston, K.J. City-wide relationships between green spaces, urban land use and topography. *Urban Ecosyst.* **2008**, *11*, 269–287. [CrossRef]
72. Khan, S.M.; Page, S.; Ahmad, H.A.; Shaheen, H.; Harper, D.M. Vegetation dynamics in the Western Himalayas, diversity indices and climate change. *Sci. Tech. Dev.* **2012**, *31*, 232–243.
73. Tariq, A.; Siddiqui, S.; Sharifi, A.; Hassan, S.; Ahmad, I. Impact of spatio-temporal land surface temperature on cropping pattern and land use and land cover changes using satellite imagery, Hafizabad District, Punjab, Province of Pakistan. *Arab. J. Geosci.* **2022**, *15*, 1045. [CrossRef]
74. Haq, S.M.; Calixto, E.S.; Malik, A.A.; Rashid, I.A.H.; Kumar, M.; Khuroo, A. Anthropogenic pressure and tree carbon loss in the temperate forests of Kashmir Himalaya. *Bot. Lett.* **2022**, *12*, 1–13.
75. Khan, N.; Shaukat, S.S.; Ahmed, M.; Siddiqui, M.F. Vegetation-environment relationships in the forests of Chitral district Hindukush range. *Pak. J. For. Res.* **2013**, *24*, 205–216. [CrossRef]
76. Tariq, A.; Mumtaz, F.; Zeng, X.; Baloch, M.Y.J.; Moazzam, M.F.U. Spatio-temporal variation of seasonal heat islands mapping of Pakistan during 2000–2019, using day-time and night-time land surface temperatures MODIS and meteorological stations data. *Remote Sens. Appl. Soc. Environ.* **2022**, *27*, 100779. [CrossRef]
77. Hussain, M.; Khan, S.M.; ABD_ALLAH, E.F.; UlHaq, Z.; Alshahrani, T.S. Assessment of plant communities and identification of indicator species of an ecotonal forest zone at Durand line, district Kurram, Pakistan. *Appl. Ecol. Environ. Res.* **2019**, *17*, 6375–6396. [CrossRef]
78. Majeed, M.; Tariq, A.; Haq, S.M.; Waheed, M.; Anwar, M.M.; Li, Q.; Aslam, M.; Abbasi, S.; Mousa, B.G.; Jamil, A. A detailed ecological exploration of the distribution patterns of wild Poaceae from the Jhelum District (Punjab), Pakistan. *Sustainability* **2022**, *14*, 3786. [CrossRef]
79. Rahman, I.U.; Hart, R.E.; Ijaz, F.; Afzal, A.; Iqbal, Z.; Calixto, E.S.; Abd_Allah, E.F.; Alqarawi, A.A.; Hashem, A.; Al-Arjani, A.B.F.; et al. Environmental variables drive plant species composition and distribution in the moist temperate forests of Northwestern Himalaya, Pakistan. *PLoS ONE* **2022**, *17*, e0260687. [CrossRef]
80. Malik, Z.A.; Haq, S.M.; Bussmann, R.W.; Bhat, J.A.; Bhatt, A.B. Altitudinal variation in soil properties with reference to forest structure and composition in Western Himalaya. *Indian For.* **2021**, *147*, 288–301. [CrossRef]