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Spatial Distribution and Population Structure of Himalayan Fir (*Abies pindrow* (Royle ex D.Don) Royle) in Moist Temperate Forests of the Kashmir Region

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Abstract: *Abies pindrow* is a keystone tree species of temperate forests in the Himalayan range with immense ecological significance. The current study was designed to investigate the spatial distribution, population structure, associated flora, and sustainability of *Abies pindrow* in the temperate forests of Azad Jammu and Kashmir (AJK), Pakistan. Vegetation data were collected from 48 forest sites distributed in six districts of AJK with respect to the geography, microclimates, and vegetation structure by employing a systematic quadrate-based methodology. *Abies pindrow* populations were characterized by an average stem density of 183.9 trees/ha with an average basal area cover of 789 cm. *A. pindrow* populations showed a regeneration value of 555.6 seedlings/ha. A digital elevation model revealed that *A. pindrow* exhibited a large extent of distribution in an altitudinal range of 1800–3400 m. GIS analysis identified that north-facing slopes with a moderate degree of slope steepness constitutes the preferred habitat of the species in the Kashmir mountains. A floristic analysis revealed that a total of 282 species from 74 plant families comprised the associated flora of *A. pindrow*-dominated forests with *Pinus wallichiana*, *Picea smithiana*, *Aesculus indica*, and *Viburnum grandiflorum* as codominant companion species. *A. pindrow* forests exhibited significant levels of species diversity and richness with average values of Simpson's diversity as 0.94, Shannon's diversity as 3.09, species richness as 1.45, and maturity index value as 45.9%. The *A. pindrow* populations in the study area were found to be subjected to significant deforestation pressure along with overgrazing and erosion impacts. Results provide valuable scientific information for the conservation management of *A. pindrow* populations, ensuring the sustainability of temperate forest ecosystems in the Western Himalayan region of Kashmir.

Keywords: Himalayan fir; Kashmir; population structure; temperate forests; western Himalayas; GIS

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Citation: Alam, N.M.; Shaheen, H.; Manzoor, M.; Tinghong, T.; Arfan, M.; Idrees, M. Spatial Distribution and Population Structure of Himalayan Fir (*Abies pindrow* (Royle ex D.Don) Royle) in Moist Temperate Forests of the Kashmir Region. *Forests* **2023**, *14*, 482. https://doi.org/10.3390/f14030482

Academic Editor: Mark Vanderwel

Received: 14 January 2023
Revised: 15 February 2023
Accepted: 22 February 2023
Published: 27 February 2023

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1. Introduction

Abies pindrow (Royle ex D.Don) Royle is a keystone gymnosperm tree species belonging to the Pinaceae family [1]. It is commonly recognized as Himalayan fir, distributed throughout the Himalayan mountains in Pakistan, India, and Nepal [2]. *A. pindrow* is an evergreen tall tree growing up to 30 m in height in a narrow pyramidal shape and bears needle-like leaves with a dark green color [3]. The species prefers cool, moist, and mountainous habitats and is generally distributed at elevations between 1800 and 3000 m in temperate forest ecosystems [4,5]. *A. pindrow* populations are gregarious in the western Himalayan range, usually found on the north-facing aspects, indicating its habitat preference and specialized ecological niche [6].

A. pindrow constitutes the main bulk of Himalayan mixed coniferous moist temperate forests, where it occurs abundantly in pure stands as well as with codominant conifer species including *Pinus wallichiana*, *Cedrus deodara*, and *Picea smithiana* [7]. Three more species of the *Abies* genus including *A. densa*, *A. spectabilis*, and *A. spectabilis* var. *langtanensis* are also reported in the Himalayas [8], but *A. pindrow* in the only *Abies* species in the Kashmir region [9].

A. pindrow holds vital ecological significance in the region, owing to the large number of ecosystem services it offers [10]. Being a keystone species, it constitutes the structure of temperate forest stands and furnishes immense levels of biological productivity in terms of vegetative growth, biomass yield, and habitat formulation [11,12]. Its wood is used as fuel, timber, for making agricultural tools, furniture, and pulp [13]. *A. pindrow* serves as an umbrella species by constituting the habitat for hundreds of associated temperate-zone plant species, insects, birds, and animals [14]. The leaves, oils, resin, bark, and wood parts of *A. pindrow* are also used to treat a large number of human and livestock diseases by the local Himalayan populations. It also possesses aesthetic and ornamental values in the region, closely linked with ecotourism in the Himalayan forest landscapes [10,15].

The state of Azad Jammu and Kashmir (AJK) in north Pakistan, located in the western Himalayas, is a regional biodiversity hotspot owing to its unique geography, great altitudinal gradient, climatic variability, and diverse vegetation types. This rugged mountainous region is mainly inhabited by temperate forest ecosystems weaved by coniferous species, among which *A. pindrow* is the most dominant one [11,16]. The investigation of the forest structure focusing on keystone species in the AJK region holds vital ecological significance.

A. pindrow habitats in the region are facing severe threats due to immense anthropogenic pressure in terms of deforestation, overgrazing, land use changes, and soil degradation [17]. Climate change scenarios are also predicted to impact the species distribution in the Himalayas [18]. Literature review reveals that there has been no detailed study on the distribution pattern, population dynamics, and conservation status of *A. pindrow* in the Kashmir region, which reflects a significant knowledge gap. This study was formulated to investigate the spatial distribution, population structure, species composition, diversity levels, and sustainability of *A. pindrow* in the western Himalayan state of AJK, north Pakistan. The specific objectives also include to quantify the regeneration status, deforestation pressure, and geographic analysis of the species habitat in the region.

2. Materials and Methods

2.1. Study Area

The state of AJK is located between longitudes east 73°–75°and latitudes north 33°–36° with an area of 13,297 km^2. AJK falls within the western Himalayan orogenic belt [16]. The *Abies pindrow*-dominated forests are spread throughout the moist temperate forest ranges of the AJK region. This zone is characterized by cold, humid conditions with mild summers and harsh snow-covered winters. Average summer temperatures are in the 12–16 °C range, whereas winters are freezing, with temperatures as low as −10 °C. The area receives an annual precipitation of about 1300 mm [19].

2.2. Vegetation Sampling

The current study was carried out in May–September during the years 2021–2022. A total of 48 temperate forest sites were sampled in 6 districts of AJK in an altitudinal range of 1800–3600 m with respect to the geography, microclimates, and vegetation structure (Figure 1). We employed a systematic quadrat method for vegetation sampling, with a total of 20 quadrates at each of the 48 sites. Rectangular quadrats of 400 m^2 (20 m × 20 m) were used for trees, 25 m^2 (5 m × 5 m) for shrubs, and 1 m^2 (1 m × 1 m) for herbs. Primary phytosociological attributes of the vegetation data including cover, frequency, and density were recorded at all the sampling sites for *Abies pindrow*, along with all the associated plant species, following standard methods [20,21]. The geographic attributes of the sites including latitude, longitude, altitude, aspect, and slope were recorded using

Global Positioning System (Garmin, Model Oregon 700, Fujimi, Japan). The recorded plant specimens were collected, preserved, and brought to the herbarium of the University of AJK for identification with the help of flora [22,23].

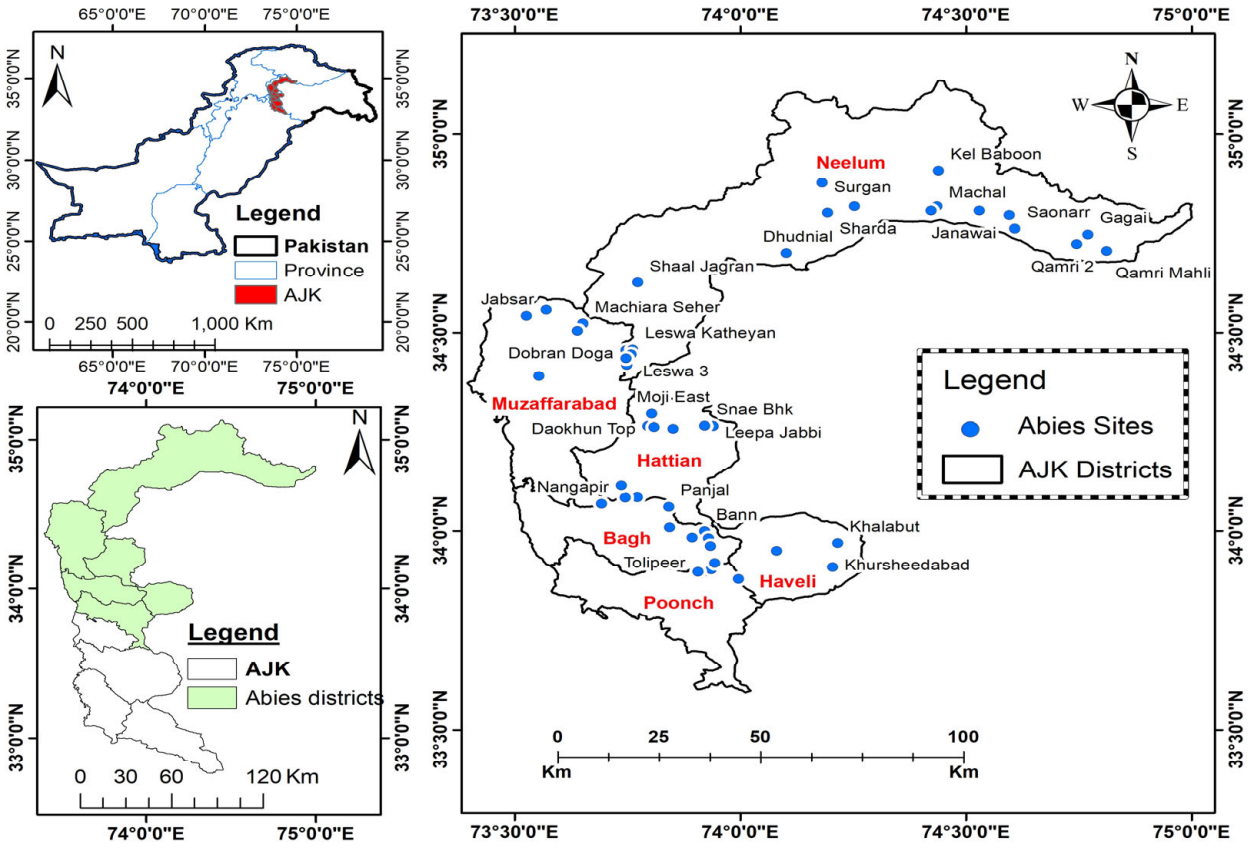


Figure 1. GIS map of the study area and spatial distribution of studied *Abies pindrow* populations in the state of AJK.

2.3. Diversity Indices

Analytical vegetation characters of the sampled *Abies pindrow* forest communities were measured using diversity indices. Importance Value Index (IVI) was calculated for all the recorded species in each population following [24] as IVI: Relative Density (RD) + Relative Cover (RC) + Relative Frequency (RF). Simpson's diversity index (D) was measured as D: $\sum$ni (ni−1)/N (N − 1) [25], where ni: Number of individuals of a species; N: Total number of individuals of all the species. Shannon–Wiener's index of diversity (H′) was measured as H′: $-\sum pi \log pi$ [26], where pi = ni N; N = $\sum$ni: Total number of individuals of all species; ni = number of individuals of a single species. Species evenness was measured as J′:H′/lnS (Pielou 1966), where H′: Shannon–Wiener's diversity index; S: Total number of species. Species richness was determined as D:S/$\sqrt{}$N [27], where S: Total number of the species; N: Total number of individuals of the species. Community maturity index was measured as MI: F/S [28], where S: Total number of species; F: Sum of frequency of all the species.

2.4. Statistical Analysis and GIS Mapping

The vegetation data were statistically analyzed through ordination analysis to find out the relationship between vegetation attributes and variables by employing multivariate techniques including cluster analysis (CA) and principal component analysis (PCA) [29,30]. Pearson's correlation and generalized linear regression models were applied on the species data set using software PAST (version 4.02). Geographic Information System software Arc GIS 10.8.2 was used for geospatial analysis of *A. pindrow* populations in AJK, including

mapping of study sites, generating a digital elevation model, aspect and slope class analysis, and distribution pattern of healthy/disturbed populations (Figure 2).

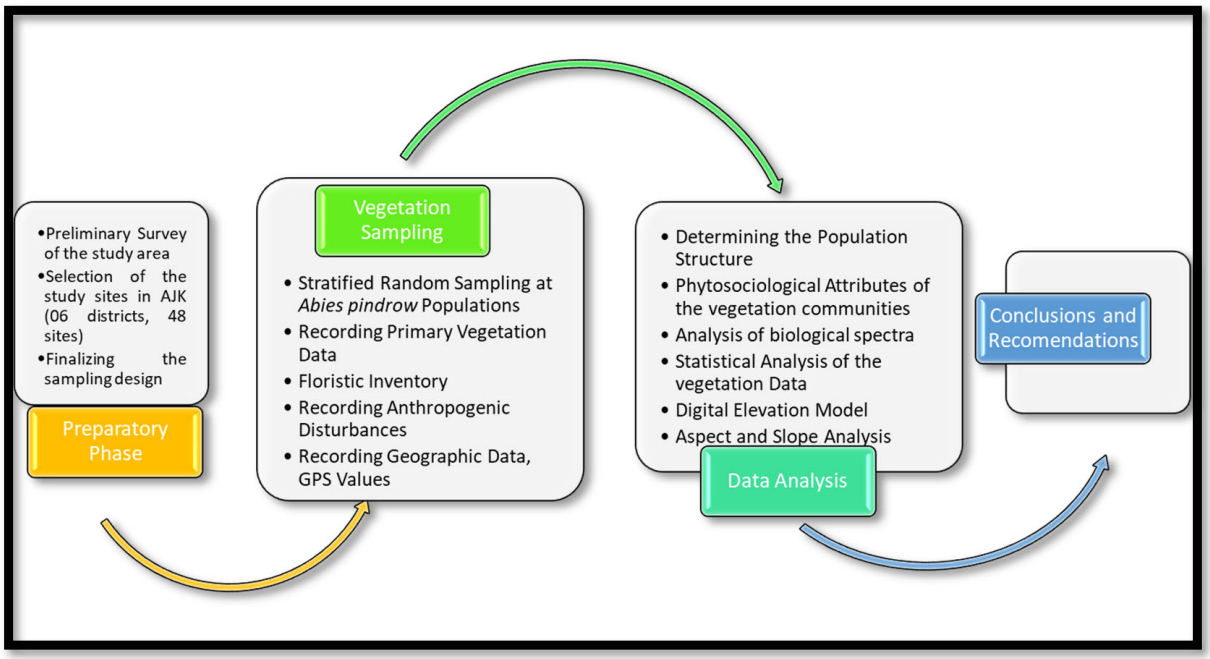


Figure 2. Flow chart of the methodology to investigate *A. pindrow* populations in AJK.

2.5. Quantification of Disturbance Factors

Soil erosion and grazing intensity were recorded at all the investigated forest sites. Visual indicators including trampling, hoof marks, browsed vegetation, and animal droppings were used to classify the sites into low, moderate, and over-grazed categories [13]. Similarly, the erosion intensity classes were determined as no/low, moderate, and highly eroded categories [31].

3. Results

3.1. Population Structure of Abies pindrow

A. pindrow populations were recorded at all 48 of the investigated moist temperate forest sampling sites across the whole state of AJK. The species exhibited a tree density of 183.9/ha in the forests of AJK, with a maximum value of 367 trees/ha and a minimum of 26/ha. The species showed a regeneration value of 555.31 seedlings/ha, ranging from a lowest density of 130/ha to a highest density of 959/ha in the AJK region. The populations showed an average basal area of 789.37 cm with huge variations, ranging from a minimum of 180 cm to a maximum of 1285 cm (Table S1).

3.2. Altitudinal Distribution and Habitat Geography

The digital elevation model (DEM) revealed that 35 out of 48 (72%) *A. pindrow* populations were distributed in an altitudinal range of 1800–2800 m, which comprises the temperate forest zone. About 13 sites (27%) were located in a higher elevation range in 2800–3400 m, located in subalpine forest zones (Figure 3). GIS analysis identified northeast facing slopes as the most preferred habitat of the species in the AJK region (Figure 4). Mountain slopes with moderately steep slope degree ranging from 30° to 60° comprised the majority of the species habitat (Figure 5). The zonal geometry analysis showed that more than 60% of the pixels of the investigated area fall into north-, northeast-, and east-facing aspects, and >50% of the area pixels have a moderately high degree of slope steepness (Figure 6).

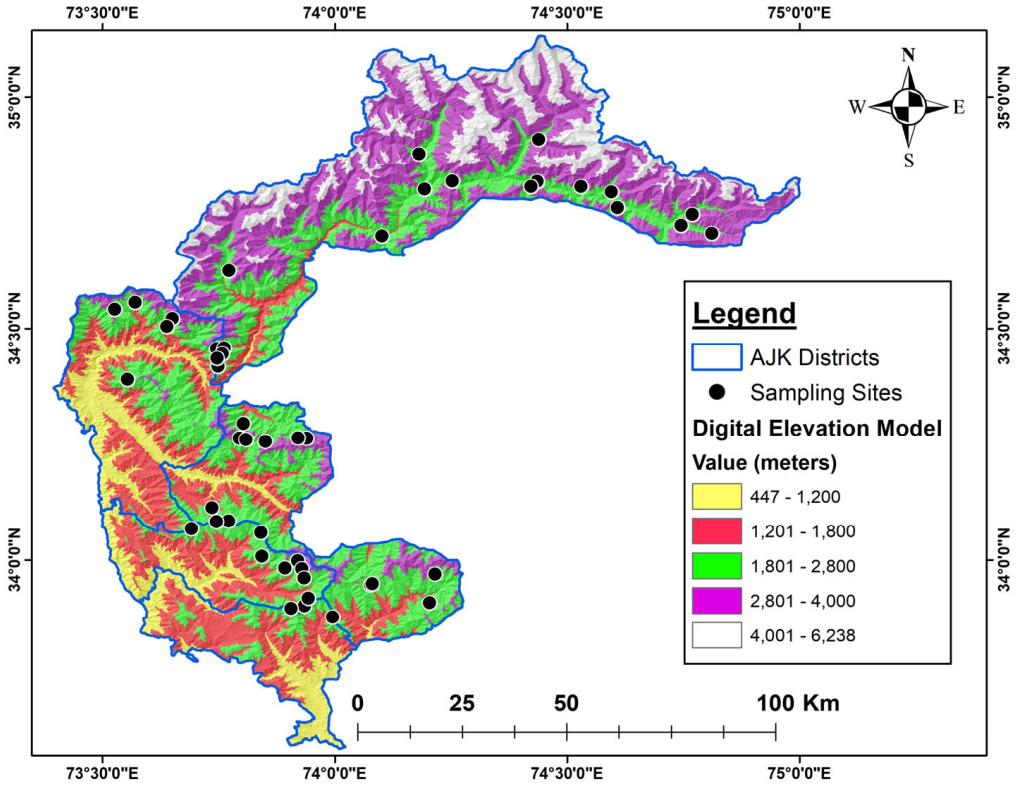


Figure 3. Digital elevation model showing the altitudinal distribution of *Abies pindrow* populations in AJK.

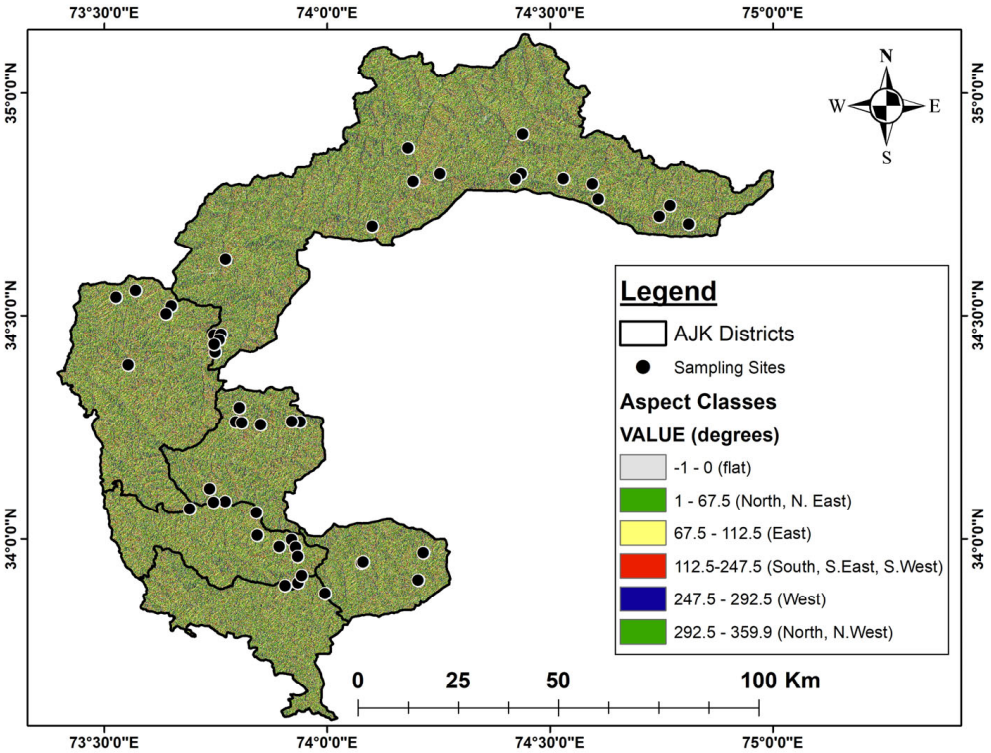


Figure 4. GIS map of aspect classification for *A. pindrow* populations.

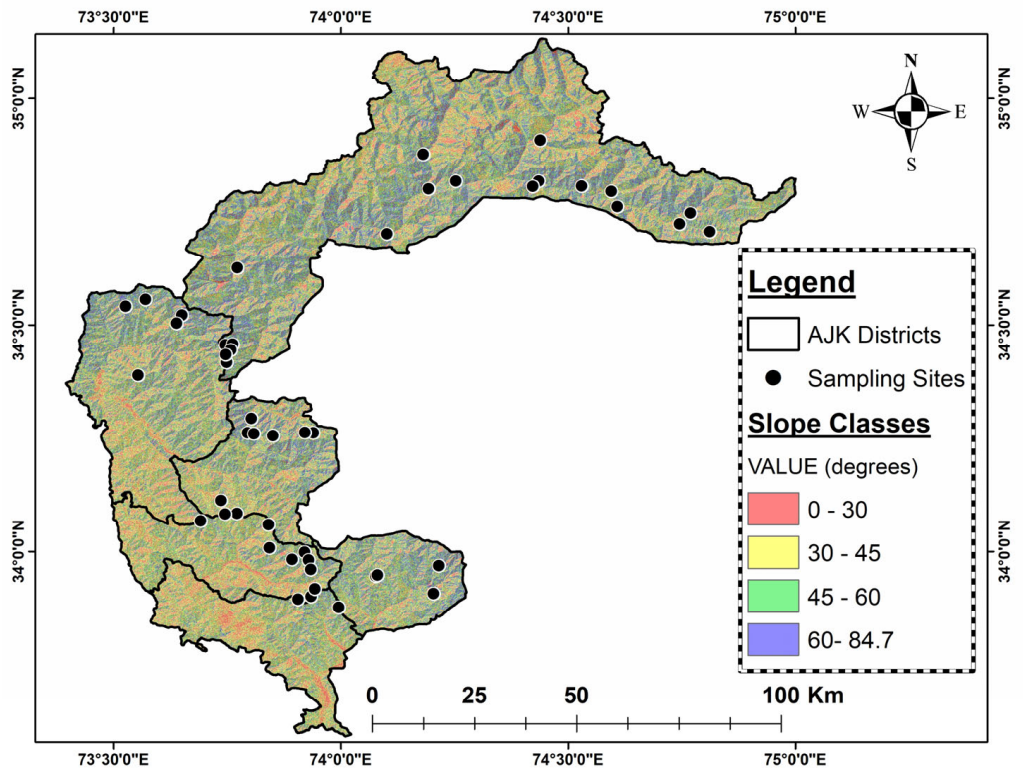


Figure 5. GIS map of slope steepness classes for the investigated *Abies pindrow* habitats.

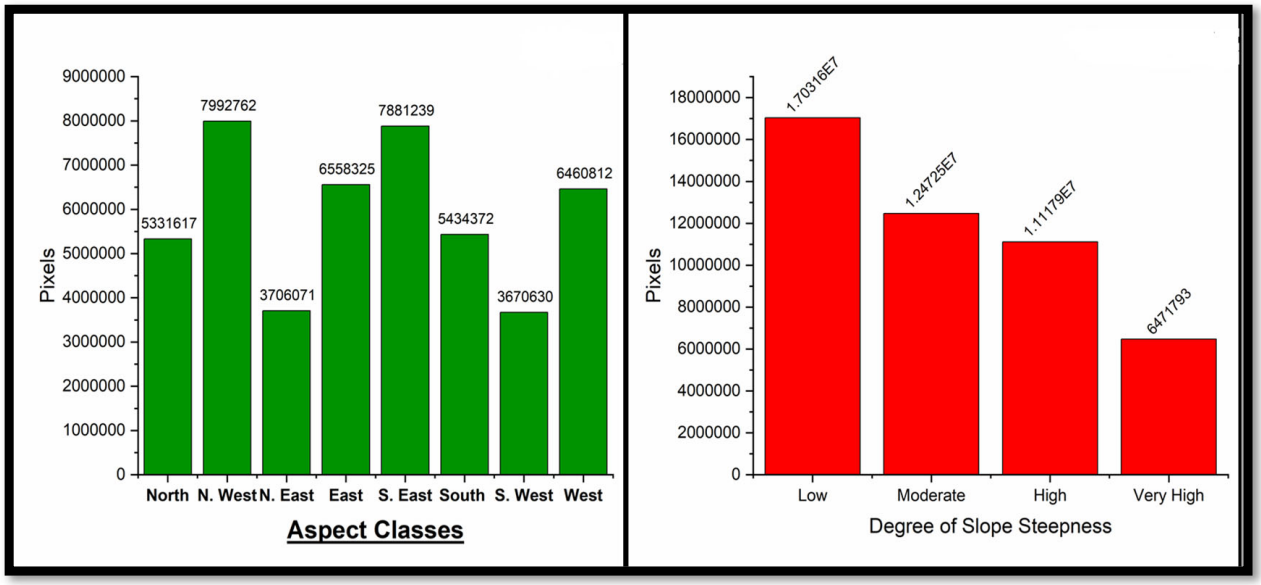


Figure 6. Number of pixels for aspect and slope classes extracted from the *A. pindrow* habitat map.

3.3. Associated Flora of A. pindrow Populations

A. pindrow populations were recorded to harbor high levels of floral diversity. A total of 282 species from to 73 plant families were recorded as the Abies-associated flora from the region. The study area showed an average of 45.4 plant species per site. Herbaceous species constituted the bulk of the recorded flora, making up 83%, whereas trees and shrubs contributed 8.5% each. Abies pindrow was recorded as the most abundant species, with an importance value of 39.36. The codominant species recorded abundantly and consistently with A. pindrow included Pinus wallichiana, Picea smithiana, Cedrus deodara, Aesculus indica (trees), Viburnum garndiflorum, Skimmila laureola (Shrubs), Poa alpina,

Fragaria nubicola, Viola odorata, Dryopteris stewartii, Sinopodophyllum hexandrum, Rumex nepalensis, Geranium nepalense, Oxalis corniculata, and Senecio chrysanthemoides (herbs) (Table S2).

3.4. Biological Spectrum of the Flora

The analysis of the biological spectrum revealed that Therophytes were the dominant life form, with 88 species, making up 32% of the Abies pindrow-associated flora. They were followed by Geophytes (25%) and Hemicryptophytes (20%) as the codominant life forms, whereas Nanophanerophytes were recorded as 10%. Mesophanerophytes (5%), Chameophytes (3%), Megaphanerophytes (2%), and Lianas (1%) were the least frequent lifeform classes (Figure 7). The leaf size classification revealed Microphylls as the dominant leaf size, comprising 38%, followed by the Nanophylls (24%) and Leptophylls (17%) as the codominant groups. Mesophylls (14%) and Megaphylls (6%) were the rarest classes (Figure 8).

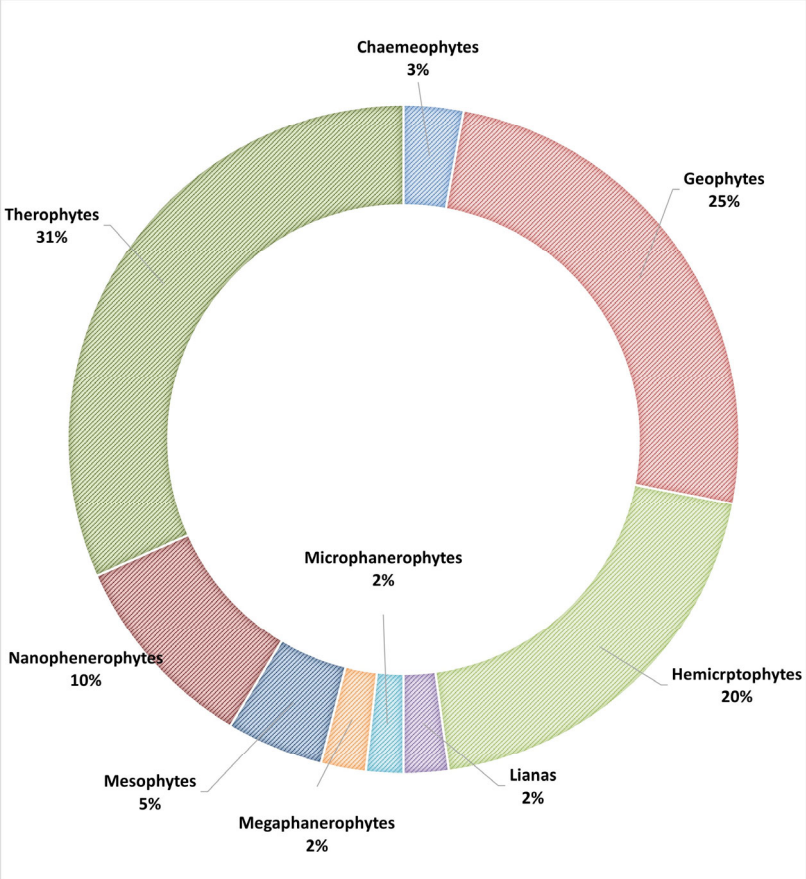


Figure 7. Raunkiaer's life form classification of the recorded temperate forest flora.

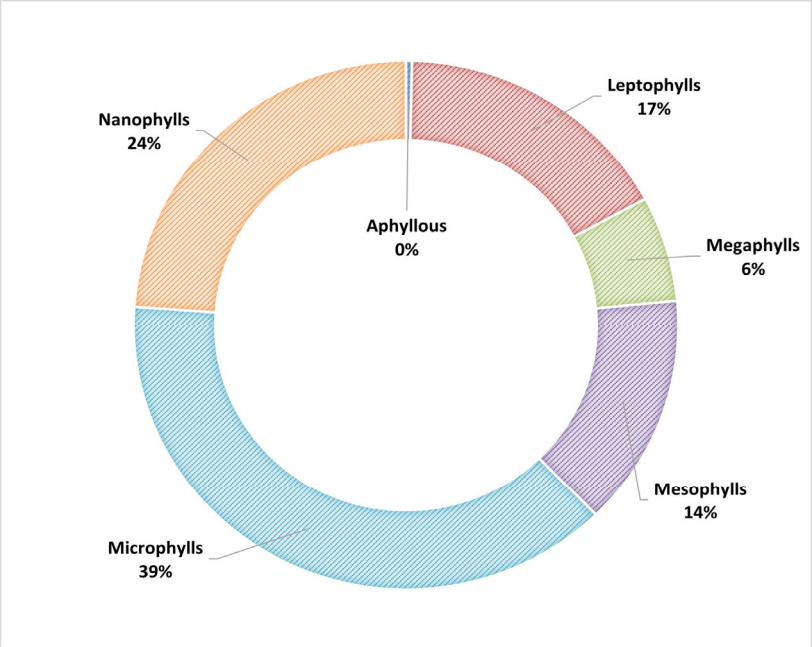


Figure 8. Leaf size classification of the recorded plant species of *Abies*-associated flora.

3.5. Phytosociological Attributes of the Fir dominated Forests

Abies pindrow-dominated forest stands were found characterized with significant levels of diversity and species richness. Simpson's diversity values averaged 0.94, with nonsignificant variations among the investigated populations. However, Shannon's diversity index values averaging as 3.09 showed broad variations ranging from 0.57 to 4.3. Species richness averaged 1.45, exhibiting great variations, ranging from a minimum of 0.4 to a maximum of 3.48. Forest stands were found to be characterized by a low degree of community maturity index, averaging 45.9%, with none of the communities having a benchmark value $\geq$60% (Table S1).

3.6. Deforestation, Overgrazing, and Soil Erosion Disturbances

Significant deforestation pressure was recorded in the A. pindrow forest stands in the region. Populations were found subjected to a deforestation intensity of 114.1 stumps/ha in the study area, with a minimum of 47 stumps/ha to and a maximum of 175 stumps/ha. More than 80% of the study sites were found subjected to significant levels of grazing pressure, about 60.1% of sites (29 out of 48) exhibited moderate grazing pressure, and 22% of sites (11/48) showed intense grazing. Moderate levels of soil erosion were recorded in 72% sites, whereas only 10% of sites showed intense erosion. Overall, less than 20% of sites were found undisturbed by grazing and erosion effects (Table S1).

3.7. Multivariate Ordination Analyses

The principal component analysis explained more than 90% of the variance in the data set in its first 04 axes. PCA identified the most dominant keystone species, i.e., Abies pindrow, placed distinctly on the x-axis. The closely associated plant species with consistent occurrence with A. pindrow were also placed in close proximity, including Oxalis corniculata, Galium aparine, Viola odorata, Poa annua, and Sinopodophylum hxandrum. PCA also segregated other dominant plant species sharing the same habitat sites but with their independent occurrence not closely linked with A. pindrow, which include Cedrus doodara, Isodon rogosus, Berberis kasmiriana, Fragaria nubicola, Viburnum grandiflorum, and Sarcococca saligna along the y-axis (Figure 9). Cluster analysis was applied on the diversity values and structural attributes of the forest sites. A prominent divisive clustering was revealed, splitting the sites into three major groups. Cluster A

comprised four sites with maximum values of regeneration and diversity components, and lower deforestation pressure. Cluster B comprised 23 sites further split into B-1 (3 sites) and B-2 (20 sites) groups. These sites were identified as the healthier populations of A. pindrow, characterized by higher values of stem density and regeneration, as well as diversity and richness. A large cluster, C, comprised 21 forest sites that had lower values of diversity, i.e., richness, diversity, and evenness, as well as stem density and regeneration, mostly including the sites with disturbed forest structure (Figure 10). Pearson's correlation test was applied on diversity indices values, which revealed a strong negative correlation ($p < 0.05$) between the community maturity index and the number of species and richness. A strong positive correlation ($p < 0.05$) was recorded between richness values and the number of species and Shannon's diversity (Figure 11).

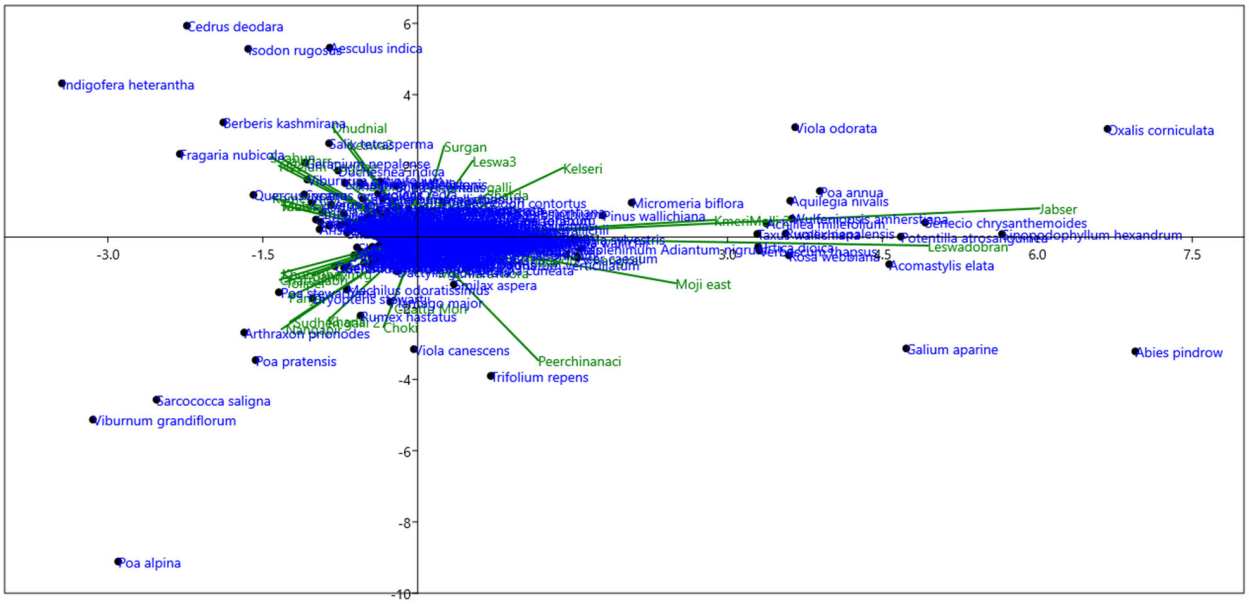


Figure 9. Principal component analysis biplot of species data set.

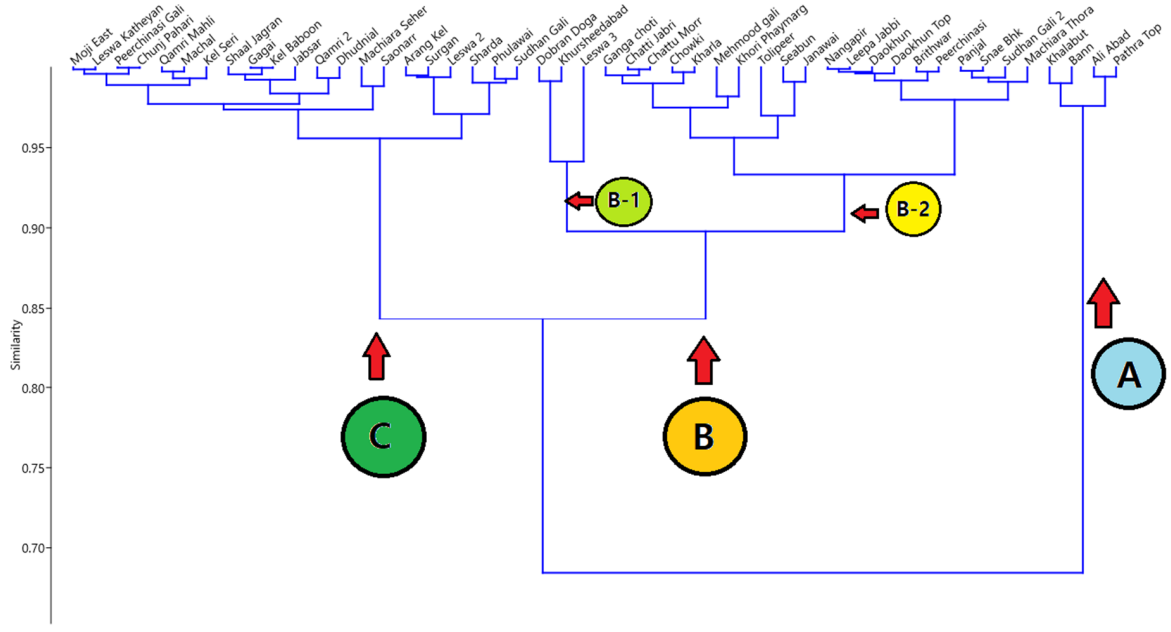


Figure 10. Cluster analysis dendrogram of sites data set based on diversity components and phytosociological values.

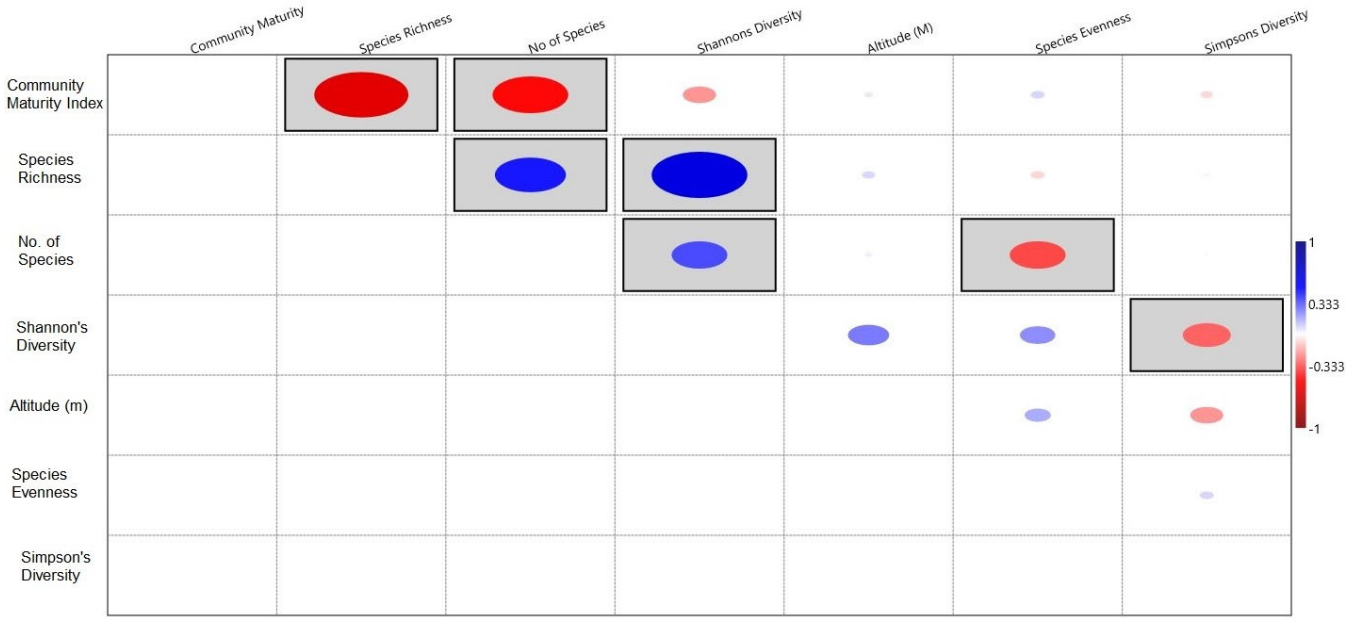


Figure 11. Pearson's linear correlation applied on diversity component values.

4. Discussion

A. pindrow holds vital importance in terms of biomass production, maintenance of soil organic matter, moisture, fertility, erosion control, microclimate regulation, and habitat construction of the Himalayan temperate forest ecosystems [32,33]. The sustainability and conservation management of *A. pindrow* forests is critical to ensure the forest ecosystem function and the sustainability of the ecosystem services in the Himalayan region [34].

The current study was carried out in temperate forests in the Himalayan state of AJK (Pakistan) to investigate the spatial distribution and community structure of *Abies pindrow* in the study area. *A. pindrow* holds vital ecological significance, as it builds the physical structure of the moist temperate forests in the Himalayan region as a keystone species [35]. An average stem density value of *Abies pindrow* was recorded to be 183.9/ha, significantly lower compared to the values >250 trees/ha recorded in temperate Himalayan regions in Nepal, India, and China [36–38]. Populations possessed a low tree density despite having fair tree girth sizes and regeneration (Figure 12).

Low tree density correlated with a significant deforestation intensity prevailing across the study area. Local forests in the Kashmir region are subjected to immense tree-felling pressures due to fuel, wood, and timber demands of local rural mountain populations [39,40]. Due to the harsh climatic conditions of the Himalayan mountains, unavailability of alternate energy sources, overpopulation, and poverty, locals heavily rely on the *A. pindrow* forests, resulting in disturbed forest structure [41].

A. pindrow populations showed good regeneration potential, with values >500 seedlings/ha. However, due to consistent grazing and deforestation pressure, the probability of seedling survival and maturity is low [42]. Generalized linear models revealed a very strong negative correlation of deforestation with regeneration and species richness (Figures 13 and 14).

These results validate the devastating impacts of prevailing anthropogenic disturbance stimuli on the structure and sustainability of the temperate forest ecosystems, severely impacting the ecosystem functioning and natural balance [43].

A. pindrow prefer cold, moist, and slopy mountain areas in temperate regions across the northern hemisphere [44]. GIS analysis identified the north-facing mountain slopes with a moderate–high degree of steepness as the preferred habitats of the species in the AJK region. Results correspond with the habitat specificity and highly specialized ecological niche of the species [45]. North-facing slopes characterized by lower solar insolation exhibit thick, healthy soil layers with higher moisture contents constitute the optimum

microclimatic conditions required by *A. pindrow* [46]. Studies have indicated the direct effect of aspect variations on soil moisture availability, which in turns defines the habitat ranges for cold–moist-preferring tree species such as firs and spruces [47].

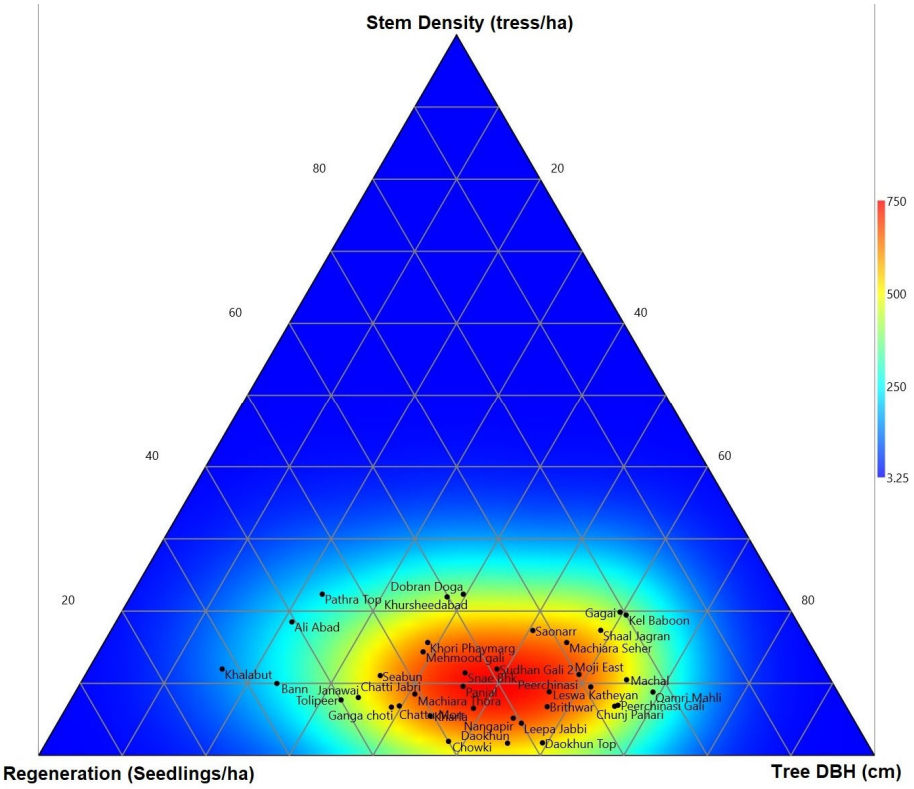


Figure 12. Ternary plot of tree density, regeneration, and diameter values.

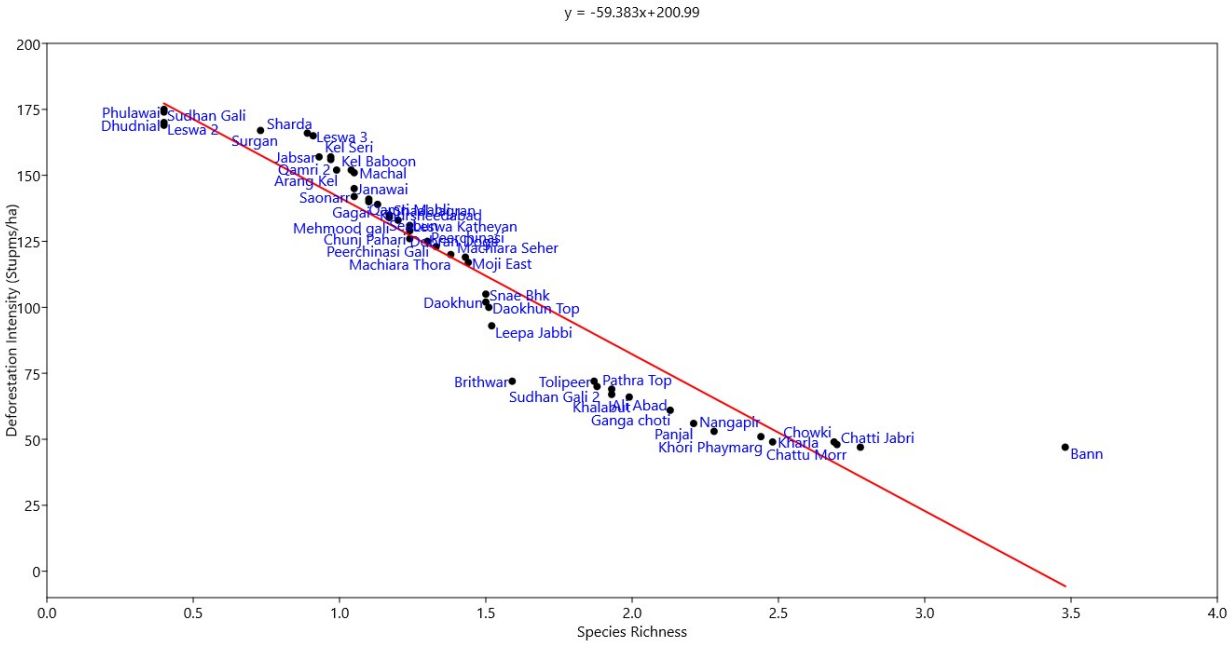


Figure 13. Generalized linear model regression plot of deforestation intensity vs. species richness.

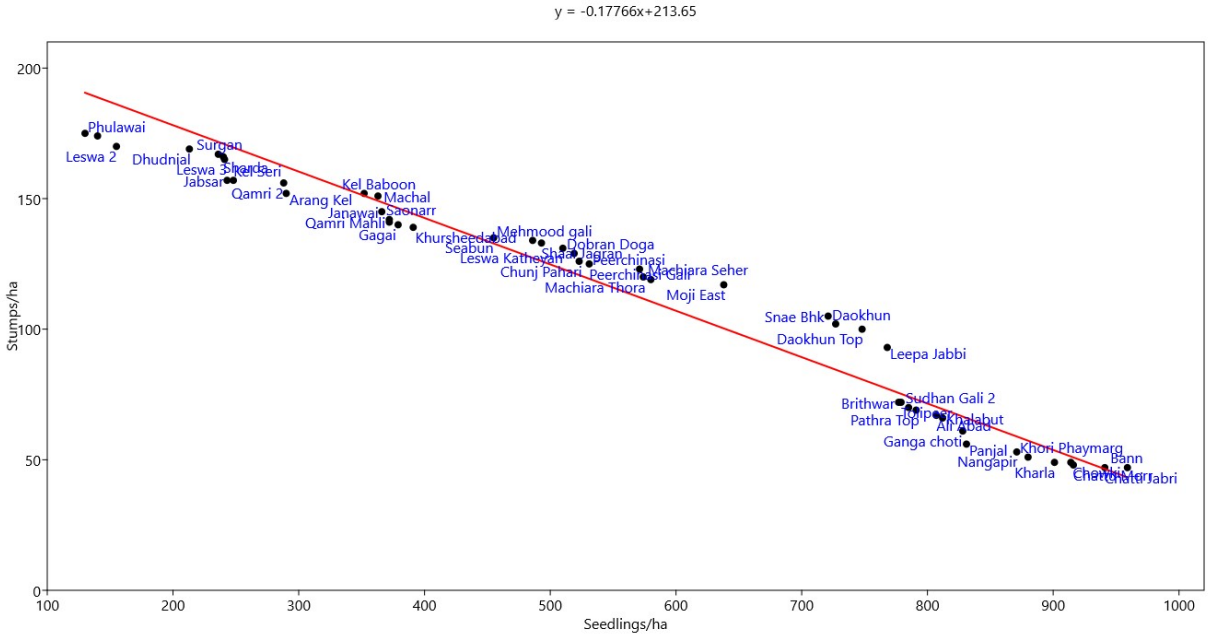


Figure 14. Generalized linear model regression plot of deforestation intensity vs. regeneration of *Abies pindrow*.

The digital elevation model revealed that *A. pindrow* populations were well distributed in a broad altitudinal range of 1800–3400 m in the high, moist, temperate forest zone of the region with a large extent of occurrence. Findings supports our hypothesis that *A. pindrow* species are significant indicators of temperate forests at higher altitudes [48].

Vegetation diversity in the Himalayan mountain forests is widely reported to decrease with increasing altitude [49]. However, contrary to this, our data set revealed a moderately increasing trend in the Shannon's diversity values with increase in altitude. This may be attributed to a decreasing level of anthropogenic disturbances with increasing altitudes, resulting in higher diversity [40]. The altitudinal range of 2000–3000 m in the Himalayan temperate forests exhibits higher precipitation and healthier soils compared to the lower subtropical zones with less hospitable, dry, and hot climates, which results in higher diversity levels [40,50].

Pearson's correlation test indicated significant ($p < 0.05$) correlation between diversity and richness values as, logically, the higher species number results in a higher diversity level [51]. Plant communities with lower species counts are characterized by evenly spaced distribution patterns, which is a community-level adaptation ensuring efficient resource utilization as well as avoiding competition [11]. More diverse communities show low evenness and maturity values attributed to high species density and competition [52].

The floristic analysis showed that *A. pindrow* forests harbor high levels of species diversity, evident from a total of 291 species recorded as associated flora. This reflects the fact that *A. pindrow* acts as an umbrella species that is vitally important for a large number of lower plant taxa, providing them specific microclimates in terms of shade, higher moisture availability, protection from snow, and strong solar radiations [41,53]. Composite, Poaceae, Rosaceae, and Lamiaceae were recorded as the abundant plant families in the region in terms of species count. The dominance of these families in the Himalayan mountain forests is attributed to generalized ecological niches and environmental tolerance of the taxa, which have the best fits in the temperate forests [54]. Life form and leaf size spectra dominated by the *Therophytic microphyllous* flora significantly corresponded to the prevailing physical habitat and climatic condition of the Himalayan region. These groups show efficient adaptations to the harsh climatic conditions of the Himalayan regions through faster growth cycles and reduced surface area [55]. Small leaves are an adaptive strategy for higher moisture retention [56].

Researchers have previously worked on the composition and structure of coniferous forests in the Kashmir region, but their scope remained limited, as they were conducted either at small local scales or targeted few growth parameters [57,58]. An in-depth, detailed analysis of keystone species at a regional level still remained missing [59]. The current study focusing on *A. pindrow* has successfully bridged the existing knowledge gap, providing significant results at regional level in the western Himalayas.

The investigated *Abies* populations showed poor regeneration attributed to uncontrolled grazing, soil degradation, and less protective cover of bigger trees due to deforestation [60]. This appears to be a challenge for the sustainability of the species populations in the region. The lack of alternate fuelwood and construction resources adds in aggravating the deforestation pressure on the *A. pindrow*-dominated temperate forests [61]. Our results reflect the need for an immediate conservation management strategy for the disturbed *A. pindrow* populations in the state of AJK. Pressure on the species can be reduced by introducing alternate fast-growing fuel wood tree species, controlling the grazing regimes, and ensuring seedlings' survival by protection [62]. This should be a comprehensive integrated effort which fulfills the needs of locals and reduces the pressure on local *Abies pindrow* trees, along with the restoration of degraded forest soils and reforestation efforts in the region.

5. Conclusions

The current study provides valuable scientific data on the spatial distribution, population structure, diversity, and sustainability of *Abies pindrow* in temperate forest zones of the state of AJK. Forest stands showed a heterogenous population structure with a high degree of inter-site variations in terms of tree density, regeneration, and basal cover. Results showed that *A. pindrow* forests exhibit significant levels of species richness, providing a habitat for a large number of associated plant species. Populations are subjected to significant levels of deforestation and soil degradation disturbances, posing a serious threat to the sustainability of the temperate forest ecosystems. Forest managers in the state of AJK need to devise immediate conservation management plans for the *A. pindrow* populations based on controlling deforestation, overgrazing, and soil loss disturbances, provision of alternate fuel and timber resources, seedling protection, and reforestation at the forest sites, along with integrating community-level participation for conservation to ensure the sustainability of western Himalayan temperate forest ecosystems in the Kashmir region.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f14030482/s1, Table S1: Values of diversity components, erosion, grazing, deforestation, and structural attributes of *Abies pindrow* populations recorded from the temperate forests of AJK; Table S2: Floristic inventory and average importance values of the plant species recorded as *Abies pindrow*-associated flora.

Author Contributions: Conceptualization, N.M.A. and H.S.; methodology, H.S.; software, M.A.; validation, T.T., M.M. and N.M.A.; formal analysis, H.S.; investigation, M.I.; resources, M.A.; data curation, M.M.; writing—original draft preparation, N.M.A.; writing—review and editing, M.A.; visualization, M.I.; supervision, M.A.; project administration, H.S.; funding acquisition, T.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China project: Grant Nos. 32160086 and 31900271; Key Project of Natural Science Foundation of Guizhou Province: Grant No. 2019-1455; The Key Laboratory Project of the Department of Science and Technology of Guizhou Province: Grant No. [2020]2003. PhD Research Start-Up Foundation of Tongren University, Tongren 554300, China: Grant No. trxyDH1806.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: We are thankful to Department of Botany, University of Azad Jammu and Kashmir 13100, Muzaffarabad Pakistan for providing administrative and technical support.

Conflicts of Interest: The authors declare that they have no conflict of interest.

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