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Diversity, Distribution and Vegetation Assessment of Woody Plant Species in the Cold Desert Environment, North-Western Himalaya, India

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Abstract: The species richness, distribution and community structure in cold desert regions across the world are poorly understood because of their inaccessibility and remoteness. Similarly, the structure and composition of forest resources, including other management units (i.e., agroforestry and forestry systems), have hardly been studied in the cold desert of the Lahaul valley. However, such information is a prerequisite to understanding the trends and changes in the vegetation distribution under global climate change scenarios, especially considering the sensitivity of plant species in high-altitude areas of the Himalayan region. High anthropogenic activity has exerted tremendous pressure on available forest resources, including other management units in the cold desert of the Lahaul valley. Standard ecological methods were used to obtain an ecological (i.e., status, structure, composition and vegetation patterns) understanding of the region for biodiversity conservation and environmental sustainability. The present study was aimed at understanding the trend, structure and composition of plant species in the cold desert region of the western Himalaya. A total of 64 species (27 trees and 37 shrubs) of vascular plants were recorded in the present study. Tree diversity demonstrated greater variation along the gradients and slope aspects. *Salix fragilis* trees, with a 102 tree ha^{-1} density and a few trees of *Populus nigra*, were found to be sparsely distributed under the agroforestry system on the south-facing slopes in Khoksar. In Jahlma, *Salix fragilis* grew in an agroforestry system with a density of 365 tree ha^{-1}. However, in Hinsa, *Juniperus polycarpos* was a dominant tree species in the agroforestry system, with a density of 378 tree ha^{-1}. On the north-facing slopes in Kuthar, a higher number of trees and bushes were present due to natural regeneration maintained by farmers along the edges of terraced agricultural fields. The south-facing slopes showed a relatively lower species richness and diversity as compared to north-facing slopes at similar locations due to relatively less favourable growth conditions under sun-exposed, extremely xeric soil conditions. The highest level of species turnover was found between the altitudes of 2400 m and 3000 m. *Betula utilis* showed the highest adaptability at higher altitudes (>3500 m). The vegetation analysis results and information generated in the present study are useful for gaining an ecological understanding of the cold desert ecosystem in the Lahaul valley. Sustainable forest resource management, including other management units (e.g., agroforestry and forestry systems), is crucial for improving the vegetation pattern, structure and function of the cold desert ecosystem, thereby contributing to climate change mitigation, adaptation, biodiversity and ecosystem service conservation.

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1. Introduction

The Trans-Himalayan zone lies in the shadow of the main Himalayan range and is usually described as a 'High Altitude Cold Desert' [1]. The region remains completely snowbound for months and exhibits extreme climatic conditions, i.e., a temperature range of −45 °C in winter to 40 °C in summer, rainfall < 60 mm, etc. Asia encompasses the largest area of cold desert in the world, extending through Afghanistan, India, China, Kyrgyz Republic, Iran, Mongolia, Pakistan, Russia and Tajikistan [1,2]. The 'High-Altitude Cold Desert Zone' of the Indian Trans-Himalaya (ITH) is spread over an area of 98,980 km^2 across three biogeographic zones: (a) Ladakh mountains (Kargil, Nubra and Zanskar) in Jammu and Kashmir and Lahaul-Spiti and Kinnaur in Himachal Pradesh; (b) Tibetan plateau (Changthang region of Ladakh and parts of northern states of Uttarakhand); and Sikkim plateau [3,4]. Owing to the high velocity of winds, poor soil nutrients and harsh climatic conditions, plants in cold deserts tend to become prostrate, thick, woody, cushion-forming and bushy, with long, deep roots and small leaves [5–8]. Thus, the vegetation found in these areas is broadly segregated into alpine forests (extension of temperate forests), dry alpine scrub, alpine meadows and alpine stony deserts. Nonetheless, cold desert regions have rarely been at the forefront of biodiversity and sustainability research due to their inherently low levels of species richness, inhospitable climate and socio-economic marginality [1]. The species richness, distribution and community structure in cold desert regions across the world are poorly understood because of their inaccessibility and remoteness [9,10].

Cold deserts occupy 2.3% (74,809 km^2) of the total geographic area of India, covering the Leh and Kargil districts of Jammu-Kashmir and the Lahaul-Spiti district and parts of the Kinnaur and Chamba districts of Himachal Pradesh [11]. They occupy approximately 35% of the total geographic area of the state of Himachal Pradesh and are mainly found in the district of Lahaul-Spiti, in which 25% of the cold deserts of Himachal Pradesh are situated [5]. Cold deserts are vulnerable ecosystems due to their extreme ecological conditions and climate change, where plants have to withstand the effects of drought, low temperatures, wind and erosion. Due to low temperatures and large snow deposits, however, sapling establishment and growth are poor, and the establishment of plantations has usually been unsuccessful except in some valleys, such as the Pattan valley [12]. Today, many hill slopes are denuded and barren. Although agroforestry provides, to some extent, fuelwood and fodder to meet local requirements, pressure on relict forests continues to exist due to a great demand for subsistence resources [13,14].

Most of the conspicuous changes in plant community composition in the cold desert are related to differences in climatic conditions, i.e., precipitation, temperature, humidity and altitude. The cold desert has an ultra-varied topography, a factor that fosters species diversity and endemism [9,10,15]. In this region, along the altitudinal transect, distinct spatial and temporal changes in the distribution, density and species composition are apparent in the vegetation [2,8,15,16]. The floristic altitudinal zonation found along the altitudinal gradient corresponds to the influence of physiographic factors that determine a characteristic type of vegetation [17]. In the Himalayas, vegetation is determined by altitudes and bio-geography and is characteristically developed in more hilly/mountain tracts [9]. The western Himalayan montane temperate forests and alpines seem to be best classified by precipitation during the season of vegetative activity, which is generally during the months with a mean temperature over 13 °C [18]. The cold desert of the Himalaya is endowed with patches of relict forests on a predominantly barren landscape. Scanty rainfall, massive snowfall, early frost damage, high wind velocity, reduced oxygen concentration, a short growing season, and low and fluctuating temperatures are some of the ambient factors determining the life forms and vegetation patterns of cold desert habitats [12,16,19].

These factors influence the vegetation distribution on clearly distinguished north- and south-facing slopes. In general, the cold desert regions of the Indian Himalaya are mainly tree-less or, on occasion, possess a very few arboreous taxa, such as *Pinus wallichiana*, *Betula utilis*, *Hippophae rhamnoides*, *Juniperus polycarpos*, *Rhododendron companulatum* and *Crataegus songarica*. Due to a rapid rise in the human population and the consequent increasing demands for greater utilisation of resources, natural forests are under anthropogenic pressure and shrinking at an alarming rate. Thus, these resources are critical in fulfilling the wood-based requirements of indigenous communities.

In the Lahaul valley, the agro-ecosystem, comprising a willow (*Salix fragilis* and *S. alba*)-based agroforestry system and plantations, is the main source of food, fuelwood, fodder and raw materials for other domestic purposes and environmental protection [20–23] because of their wide adaptability to normal to harsh climatic conditions and ability to sustain the cold desert socio-ecological system. Scattered patches of *Betula utilis* and *Pinus wallichiana* occur on the north-facing slopes, whereas *Juniperus polycarpos* patches grow on the dry south-facing slopes and around settlements, and in willow-based agroforestry systems, willow and poplar plantations are found. These make up the basic cold desert vegetation elements and are critical for the sustainability of the Lahaul valley. Local communities have identified themselves as a part of an ecosystem and have acquired empirical knowledge on the basis of their experience while living in a harsh and resource-constrained region. Based on traditional knowledge, socio-cultural practices and religious beliefs, local communities have maintained available natural resources in a diverse and productive state that supports sustainable forest management, climate change mitigation, adaptation and biodiversity conservation. These resources are socio-culturally, religiously and ecologically valued and have also been considered a keystone resource in the xeric climatic conditions of the region, which plays a significant role in the functioning of the cold desert ecosystem [23] and has significant implications for the conservation and management of natural resources [13,24]. To meet their need for fodder, fuelwood and minor timber, farmers have extensively cultivated two species of willow (*S. fragilis* and *S. alba*) in their unique agroforestry and forestry systems. The farmers have raised trees on the margins of terraced agricultural fields and plantations in the area, where relict natural forests do not fulfil wood and fodder-based requirements. These plantations, at the same time, are also highly significant from an ecological point of view and in terms of land and biodiversity management [24], as they are intended to improve the vegetation cover of the site, to restore the ecosystem to a self-sustainable state and to reduce pressure on relict natural forests [14]. However, the vegetation of the Lahaul valley is under tremendous pressure due to increasing anthropogenic activities and also environmental perturbations. The habitat fragmentation and low regeneration potential of the existing woody species have aggravated the problems associated with the conservation of biological diversity in the region.

The anthropogenic pressure on the available forest resources has resulted in land use change [25]. The structure and composition of the forest resources, including other management units (i.e., agroforestry and forestry systems), have hardly been studied in the cold desert of the Lahaul valley. Though the vegetation of the cold desert is unique and provides precious resources for the survival of people living in the valley, environmental sustainability, livestock and wild animals, a systematic study of the vegetation has not been carried out. The scattered vegetation pattern in the Lahaul valley makes it interesting to investigate the distribution pattern, species composition, density and diversity. This study helps provide a clear picture of the status, vegetation composition, structure and conservation priorities, thereby contributing to a broad socio-economic and ecological understanding of the region for biodiversity conservation and environmental sustainability. We conducted a vegetation analysis along an altitudinal gradient to characterise the structure and composition of vegetation, thereby contributing to sustainable forest management, biodiversity and ecosystem service conservation, and the sustainability of three management units (i.e., agroforestry, forestry and natural forests).

2. Study Area and Climate

2.1. Geographical Locations

The present study was conducted in the Lahaul valley of the Lahaul-Spiti district in the state of Himachal Pradesh, India. The district is situated at a latitude between 31°44′34″ N and 32°59′57″ N and a longitude between 76°46′29″ E and 78°41′34″ E. Generally, the district has extreme cold desert climatic conditions with a short summer and a prolonged winter. Most of the district is covered by mountain outcrops. The Lahaul valley is a landlocked land area, accessible from Rohtang Tunnel and via the Rohtang Pass (3978 m) only during summer months from the neighbouring Kullu district. Numerous glacier-fed streams and rivers dissect the topography of the area and maintain the natural drainage system. The altitude varies from 2400 m to 6400 m in the alpine zones, having a complex terrain. The valley exhibits a mosaic of climate zones owing to its geographical position and varied topography. The extreme climatic conditions of the study area have resulted in the speciation of several genera, thus adding to the high endemicity of the flora. The Lahaul valley is subdivided into three valleys, the Chandra, Bhaga and Pattan valleys (Figure 1). The Chandra and Bhaga valleys are the catchment areas of the Chandra and Bhaga rivers, respectively. The confluence of both rivers is at Tandi, where they form the Chandra-Bhaga river in Himachal Pradesh, which is called Chenab in Jammu-Kashmir. The area stretching from Tandi up to a few kilometres beyond Kuthar is called Pattan Valley. This valley contains a large number of small villages. The villagers and their livestock largely depend on available bio-resources for their sustenance. The valley has natural (i.e., forest and alpine pastures) and human-dominated agroforestry systems. In general, the steep slopes of the region have forests or grasslands, while areas with gentle slopes have been extensively cultivated.

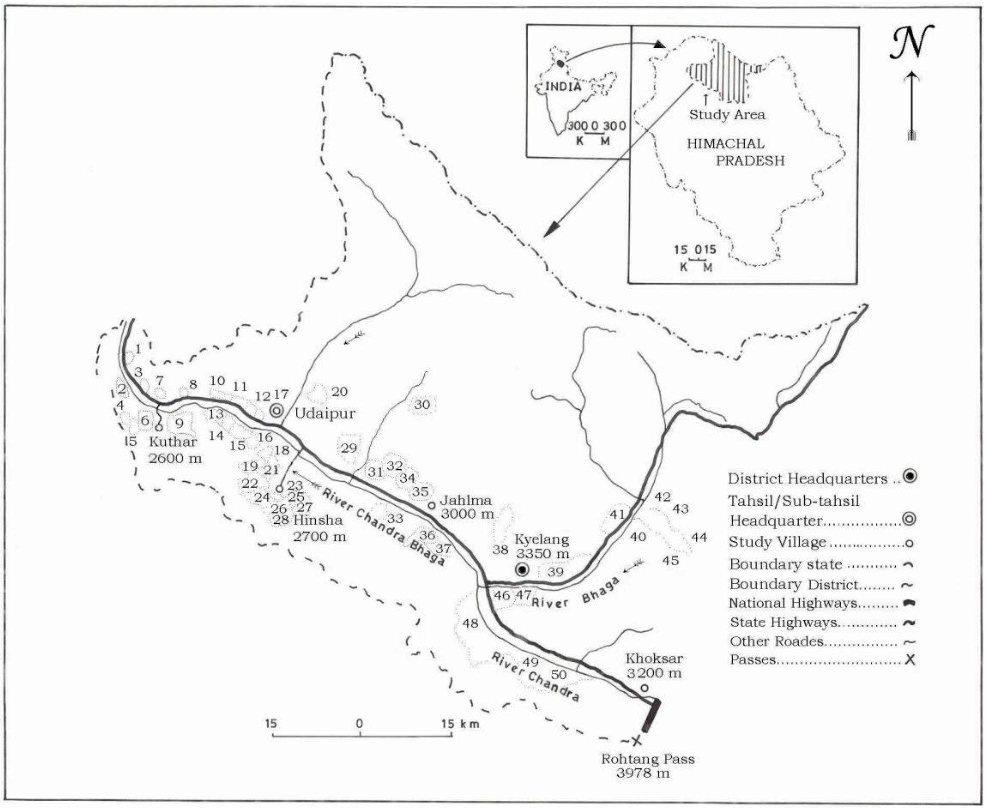

Figure 1. Map of the Lahaul valley illustrating the locations of the studied sites, Khoksar (3200 m), Jahlma (3000 m), Hinsa (2700 m) and Kuthar (2600 m), and forests with different grades of protection (reserved forest (RF), protected forest (PF) and unprotected forest (UPF); the numbers in the map represent forests, the names and protection grades of which are listed below).

1. Krakun RF
2. Chhaned RF
3. Surnali RF
4. Bharaur PF
5. Bhujund PF
6. Kain RF
7. Lohni P F
8. Dhandal RF
9. Romas RF
10. Dareda RF
11. Khurea RF
12. Suthal RF
13. Salrot RF
14. Ratoli RF
15. Salpat RF
16. Salpat UPF
17. Riodhan RF
18. Lobar RF
19. Lobar UPF
20. Phatgahar PF
21. Bardang PF
22. Bardang UPF
23. Trilokinath PF
24. Khangar UPF
25. Bhiyari PF
26. Bhingar UPF
27. Gilding PF
28. Gilding UPF
29. Sindwari PF
30. Lot PF
31. Duling RF
32. Lingche RF
33. Nalda PF
34. Chewar RF
35. Othang RF
36. Rital RF
37. Shangrang RF
38. Kyelang RF
39. Sitingri RF
40. Shang Kolong RF
41. Jispa RF
42. Sunshi RF
43. Milang RF
44. Vochi RF
45. Yoche RF
46. Guru Ghantal RF
47. Kardang RF
48. Gushal RF
49. Mulling RF
50. Dalingcha RF

Forests 1–37 are situated in the Pattan valley, 38–47 are in the Bhaga valley and 48–50 are in the Chandra valley.

The Lahaul valley is characterised by poor and thin forest cover, which is 7.9% of the total geographical area of the Lahaul-Spiti district. Forests in the form of scarce, scanty and discontinued patches can be found mainly in the Bhaga and Pattan valleys [16], whereas forests on the south-facing slopes of the Chandra valley have become almost barren. All sample sites were in the vicinity of the settlements, such as Khoksar (3200 m), Jahlma (3000 m), Hinsa (2700 m) and Kuthar (2600 m) in the Lahaul valley. On the north-facing slopes of the Lahaul valley, an agroforestry system is practiced at an altitude between 2400 m and 3000 m, plantation forestry is implemented at an altitude between 2610 m and 3010 m, and natural forests occur at an altitude between 2700 m and 4300 m. On the south-facing slopes, agroforestry and plantation forestry systems are practiced at a higher altitude (2650 m to 3200 m and 2660 m to 3200 m, respectively), and natural forests grow at an altitude between 2400 m and 4600 m. *J. indica* can even be found up to an altitude of 5000 m.

2.2. Climate and Vegetation Zone

Climatically, the Lahaul valley is cold and arid, with low rainfall, high snowfall and severe winters. Broadly, the valley has two distinguished seasons, a short-lived summer and a prolonged, severe winter. The soils are skeletal due to the hilly terrain and high snowfall. The Lahaul valley has an extremely harsh climate, with annual rain and snowfall ranging from 241.5 to 272.4 mm and 466.2 to 693.2 mm, respectively. The temperature reaches a maximum of 27.8 °C in July and a minimum of −13.1 °C during the month of January [13]. Climatically, Khoksar and Hinsa are relatively humid and wet areas as compared to Jahlma and experience rain for a few days during the rainy season, whereas Jahlma and adjacent areas remain dry even during the rainy months. Winter starts in the middle of October and continues until the end of April of the subsequent year. January is the coldest month, and July is the warmest month for the entire valley. Two vegetation zones occur in the Lahaul valley, the temperate zone at an altitude between 2400 m and 3300 m and the alpine zone above 3300 m [16]. Shrubs are among the dominant vegetation in the valley. Juniper species mainly grow on the dry south-facing slopes, except for *J. communis*, which occurs on the moist north-facing slopes. Sparsely distributed *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana* and *Cedrus deodara* are also found on north-facing slopes in scattered patches.

2.3. Agriculture and Vegetation

The short summer season (May to September) is the prime period to perform agricultural activities in the valley. Previously, agricultural practices were mainly traditional, with a rich crop diversity (*Fagopyrum* spp., *Hordeum himalayense*, *Saussurea costus*, *Inula recemosa*), but recently, farmers have started growing introduced cash crops such as potatoes, peas, hops and other vegetable crops. Cash crops have been a major source of income under assured irrigation through *kuhls* (water channels) in the valley. The per capita land holding in Khoksar and Jahlma was nearly 0.12 ha/capita, and in Hinsa and Kuthar villages, it was only 0.08 ha/capita [25]. The largest area of cultivated land in the valley is concentrated between 2400 and 3600 m asl in the villages [23]. In general, cash crops such as peas, potatoes and hops are exported, and food items for daily use, fuelwood and timber are imported from the adjacent district of Kullu. *Salix* spp. and *Populus* spp. are primarily grown in the agroforestry and forestry systems to meet fuelwood and fodder requirements, while *Hippophae rhamnoides* is distributed in dense patches along the slopes and riverine areas of the valley.

The Chandra sub-valley is almost bereft of forests, except for a few scattered trees of *Betula utilis*, *Pinus wallichiana*, *Juniperus communis*, *J. indica*, *Salix flagellaris*, *S. lindleyana* and *S. pycnostachya* on the north-facing slopes. In the Bhaga sub-valley, *Juniperus polycarpos* is the most dominant tree species found on the south-facing slopes [14,16]. In the Pattan sub-valley, scattered patches of *Pinus wallichiana*, *Abies pindrow* and *Cedrus deodara* are found at the lower reaches, while a few scattered trees of *Betula utilis* are found at the upper reaches on north-facing slopes. Scrublands (grassland with tussocks of wild rose) constitute the prime land cover upon which wildlife and domesticated animals survive in the valley [23]. Grassland with patches of *Rosa webbiana*, *Berberis pseudumbelata* and *Ribes grossularia* constitute a major part of the scrubland, which grows beyond the forests in high-altitude areas. Afterwards, the land area is barren with stony outcrops and snow-bound areas. This part of the land remains devoid of any shrubs. It was noticed that the forest and scrubland were degraded, mainly due to the overextraction of forest products (i.e., fuelwood, fodder, timber and leaf collection) [13,14]. It has been predicted that the extraction of forest resources will increase in the near future as developmental activities and population growth increase. As a result, there will be pressure on the existing scanty forest resources, thereby contributing to environmental problems (i.e., forest resource depletion, land deterioration and biodiversity loss) [23].

The soil in the study area is sandy loam and moraine in nature. In the same places, its nature may be clayey loam, sandy loam, gravelly sandy or silty. Irrigation has been ensured for economic activities such as agriculture and plantation through traditional off-take water channels (*Kuhls*). Most of the soils are transported by the river, avalanches and wind. Alluvial soils along the banks of the river have been brought down and deposited by river action. Brown-earth-type soils, which are brown-yellowish in colour, are found in the lower altitudes of the valley. The distribution of saline and alkaline soils is scattered and widespread in the valley. In some parts of the valley, saline and alkaline efflorescence can be attributed to the dry nature of the tract, and in others, this transference is due to the quality of water and the deposition of salts from hills through seasonal streams.

3. Methods

3.1. Survey and Sampling

The survey of vegetation (trees and shrubs) and sampling was carried out in agroforestry, forestry and relict patches of natural forests on both the north- and south-facing slopes in the vicinity of the four villages Khoksar (3200 m), Jahlma (3000 m), Hinsa (2700 m) and Kuthar (2600 m) during the growing season, when evergreen species and other associated woody species were easier to identify. The site selection was based on the physical character and dominance of vegetation. To avoid any confusion between the northern and southern aspects of the villages, they are referred to by their respective village names in the entire text. In these villages, it is common practice to cultivate and maintain tree species such as *S. fragilis*, *S. alba*, *S. daphanoides*, *Populus nigra*, *Hippophae rhamnoides*, *Prunus communis* and *Pyrus communis* along the margins of fields with agricultural crops. This is referred to here as agroforestry. In addition, willows and poplars are cultivated on the periphery of the villages in a pure plantation for multipurpose uses, such as fodder, fuelwood and a source of raw materials for various domestic uses. This practice is referred to here as forestry. These cultivated patches of willow, particularly on the hill slopes, protect the villages from snow slides during winter. The plants (e.g., trees and shrubs) grow naturally in the relict patches of natural forests, which is referred to as natural forests in the present study. On the premise of comparing ecologically contrasting conditions, the four locations, which have different altitudinal conditions and slope aspects, were selected to understand the effects of the altitudinal gradient and slope aspect on the composition and structure of the vegetation. Additionally, it could be inferred that altitudinal differences and slope aspects are sufficient to anticipate differences in vegetation structure and composition. The aim was to explore how the unique cold desert socio-ecological system is interlinked and functions in order to achieve sustainable forest management and environmental sustainability. The four sites, therefore, were expected to differ in their diversity and structural parameters due to varying altitudinal gradients and slope aspects. It was found that agroforestry and forestry systems are floristically simpler than natural forest fragments. The proportion of native vs. non-native species was explored among the three types of management units; *Salix fragilis*, *S. alba*, *Populus* spp. and *Robinia pseudoacacia*, along with horticulture species (i.e., *Pyrus communis*, *P. malus*), were non-native species. The predicted variation in the richness of woody plant species along the altitudinal gradient suggested that the species richness would decline as the altitudinal gradient inclines, which was true in the case of the present study.

A line transect method was used to assess the vegetation patterns of trees and shrubs along an altitudinal gradient and marked topographic features. The line transect method was used to make sure that the quadrats laid out were distributed evenly throughout the management units (i.e., agroforestry, forestry and natural forests) studied. Quadrats (10×10 m^2) were laid down at ten-metre intervals using a line running method [26]. At each selected site, three transects were laid down, starting at the base of the slopes and ending where no more vegetation was detected. The first transect was aligned randomly on one side of a management unit by using a compass. Thereafter, the other transects were laid at the intervals of 200 m from each other in each management unit. Thus, the distance between the transects was 200 m. In total, 180 quadrats were laid out and analysed, with 60 quadrats in each of the three management units (i.e., agroforestry, forestry and natural forests), to obtain detailed information on the structure, composition and vegetation pattern of woody plant species (e.g., trees and shrubs) from each management unit. Twenty quadrats per transect were established in each management unit of the study area. The transects were laid down along an altitudinal gradient, which covered all three land uses (e.g., agroforestry, forestry and natural forests) studied. The diameter at breast height (DBH) of tree species was measured at 1.37 m from the ground level. However, in the case of shrubs, the diameter was measured at 5 cm above the ground level. Individuals more than 5.0 cm in diameter were considered trees, and individuals between 1.7 cm and 5.0 cm in diameter were considered saplings or shrubs (as described by Knight [27].

3.2. Data Analysis

The density, defined as the total number of individuals per unit area, was calculated following the method described by Curtis and McIntosh [28]. The abundance–frequency (A/F) ratio was used to interpret the distribution patterns of species. This ratio indicates regular (<0.025), random (0.025–0.05) and contagious (>0.05) distribution patterns [29]. Species richness (trees and shrubs) was determined as the number of species per unit area, following the methods of MacArthur [30] and Whittaker [31]. The linear regression was calculated to determine the trend in species richness (trees and shrubs) along an altitudinal gradient. The regression equation $(y) = a + bx$, where 'x' and 'y' are the variables, 'b' is the slope of the regression line, and 'a' is the intercept point of the regression line with the 'y' axis. 'R^2' is a measure of association; it represents the percent of the variance in the values of 'y' that can be explained by knowing the value of 'x'. The relative density, relative frequency and relative dominance (basal area) were calculated according to Phillips [32].

The importance value index (IVI), which is defined as the sum of the relative density, relative frequency and relative dominance [33], was calculated for the various species. Fresh samples of the species found in each sample unit were collected and identified with the help of local floras [16,34–38]. The nomenclature and nativity of the species were identified according to Anonymous [39], and information on endemism based on species distribution was obtained from the literature and from local floras [16,34–38,40]. The distributional range and elevation limits of plants were also studied to determine the species turnover along the gradients.

The concentration of dominance (cd), evenness index and similarity index were also analysed. Agroforestry, forestry and forest system vegetation were considered separately and are presented separately. Species diversity (H^-) was computed using the Shannon and Weiner [41] information index as follows (Equation (1)):

$$H^- = -\Sigma\ (Ni/N)\ \log 2\ (Ni/N) \quad (1)$$

where Ni is the total density value for species i, and N is the sum of the density values of all the species at that site.

The concentration of dominance (cd) was determined using Simpson's formula [42], where Ni and N have the same meaning as in the Shannon–Weiner information index as follows (Equation (2)):

$$Cd = \sum_{i=1}^{s} (Ni/N)^2 \quad (2)$$

The evenness index (J') was determined according to Pielou [43]. Shorensen's similarity index [44] was calculated as follows (Equation (3)):

$$\text{Similarity index} = [2c/A + B] \times 100 \quad (3)$$

where A and B are the total species encountered (trees and shrubs) in stands A and B, respectively, while c is the number of species common to both A and B stands.

It has been observed that due to scarce forest resources and a prolonged winter period in the study area, the dependency of local communities on the available relict forest patches is critical for sustaining life in the cold desert environment. However, anthropogenic activities (such as fuelwood, fodder, timber, leaf and litter collection) have exerted tremendous pressure on available forest resources. Hence, the ecological understanding of the structure and composition of forest resources, including other management units (i.e., agroforestry and forestry systems), is important for the broader socio-economic and ecological development of the region.

4. Results

4.1. Vegetation Analysis

4.1.1. Agroforestry

In the north-facing agroforestry system in Jahlma, the highest density (699 plants ha^{-1}), basal area (886.51 $cm^2/100\ m^2$) and IVI (66.0%) were contributed by trees, followed by shrubs (32.9%) and small trees (1.1% of the total) (Table 1). In Hinsa, a reduction in the density of trees was noticed. The total density was recorded at 521 plants ha^{-1} with a total basal area of 1085.13 $cm^2/100\ m^2$; 54.6% IVI was contributed by trees, 40% was contributed by shrubs, and only 6.3% IVI was contributed by small trees. In Kuthar, the total density was 2181 plants ha^{-1} with a basal area of 1685.92 $cm^2/100\ m^2$, and the highest IVI (48.9% of the total) was contributed by shrubs, followed by trees (44.5%), and the lowest value was found for short trees (6.6%). About >80% basal area was contributed by trees, except for in Kuthar. In general, it was found that with decreasing altitude from Jahlma to Kuthar, the density, basal area and IVI of trees decreased, but the reverse trend was observed for shrubs in the agroforestry system.

Table 1. Density, basal area and IVI of plant species in the agroforestry system on north-facing slopes in the cold desert of the Lahaul valley (there is no information for the Khoksar (3200 m) locality).

Species	Jahlma (3000 m)				Hinsa (2700 m)				Kuthar (2600 m)			
Scientific Name	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**
Trees												
Abies pindrow (Royle Ex. D. Don) Royle	–	–	–	–	3	101.37	11.58	0.69	–	–	–	–
Acer accuminatum Wall. ex, D, Don.	–	–	–	–	–	–	–	–	75	77.42	12.53	0.19
Celtis australis L.	–	–	–	–	–	–	–	–	2	11.26	1.21	0.51
Corylus jaquemontii Decne.	–	–	–	–	–	–	–	–	73	218.09	22.60	0.10
Euonymous fimbriatus Wall.	–	–	–	–	–	–	–	–	61	14.03	6.79	0.32
Fraxinus floribanda Wall.	–	–	–	–	–	–	–	–	41	69.91	10.56	0.11
Juglans regia L.	–	–	–	–	14	231.88	31.33	0.15	29	691.45	46.43	0.09
Malus baccata (L.) Borkh.	8	0.94	3.23	1.11	9	21.02	6.02	0.82	8	5.28	1.58	0.51
Populus nigra L.	41	160.40	31.73	0.35	4	65.42	7.67	3.68	20	54.10	5.47	0.57
Prunus cornuta (Wall. ex Royle) Stued.	35	21.38	17.23	0.19	18	17.38	8.36	0.98	20	25.96	3.80	0.57
Robinia pseudoacacia L.	–	–	–	–	–	–	–	–	20	8.67	2.32	1.28
Salix fragilis L.	219	683.91	145.68	0.08	103	603.80	98.78	0.10	57	219.80	20.17	0.15
Total	303	866.63	197.87	–	151	1040.87	163.74	–	406	1395.97	133.46	–
Small trees												
Crataegus songarica K. Koch.	–	–	–	–	5	5.41	2.34	4.60	–	–	–	–
Fraxinus xanthoxyloides (G.Don.) DC.	–	–	–	–	17	2.77	7.61	0.59	82	13.93	8.22	0.33
Prunus armeniaca L.	–	–	–	–	1	9.00	1.84	0.92	6	24.03	2.60	0.38
Prunus prostrata Labill.	–	–	–	–	11	1.58	4.64	1.02	–	–	–	–
Pyrus communis L.	–	–	–	–	–	–	–	–	12	15.33	2.35	0.77
Pyrus malus L.	–	–	–	–	–	–	–	–	18	14.48	2.57	1.15
Salix acmophylla Bioss.	5	5.77	3.38	0.74	–	–	–	–	29	16.23	4.12	0.48
Total	5	5.77	3.38	–	34	18.76	16.43	–	147	84.00	19.86	–
Shrubs												
Berberis pseudumbellata R. Parker	–	–	–	–	28	0.55	10.30	0.66	12	0.46	1.02	3.06
Cotoneaster obtusus Wall. ex Lindl.	16	0.30	4.31	2.22	–	–	–	–	118	17.57	10.51	0.38
Cotoneaster pruinosus G. Klotz.	–	–	–	–	60	1.80	17.25	1.03	–	–	–	–
Euonymus monbeigii W.W. Sm.	–	–	–	–	–	–	–	–	25	9.04	3.06	0.74
Hippophae rhamnoides L. ssp. turkestanica Rousi	284	12.21	61.53	0.39	47	6.29	13.55	1.58	92	1.08	5.20	5.99
Juniperus communis L.var. paxatilis Pallas	–	–	–	–	21	1.31	6.49	1.94	31	8.99	3.33	0.91
Jasminum humile L.	–	–	–	–	–	–	–	–	29	14.06	4.45	0.31
Lonicera hypoleuca Decne.	–	–	–	–	30	3.03	14.97	0.21	365	33.52	32.74	0.10
Lonicera quinquelocularis Hardwp.	16	0.46	6.29	0.56	–	–	–	–	–	–	–	–
Parrotopsis jacquemontiana (Decne.) Render	–	–	–	–	–	–	–	–	84	14.76	8.81	0.27
Prunus jacquemontii Hook F.	–	–	–	–	–	–	–	–	37	22.77	4.87	0.61
Prunus sp.	–	–	–	–	–	–	–	–	33	2.45	3.48	0.54
Prunus sp.	–	–	–	–	–	–	–	–	10	0.83	0.95	2.55
Rhamnus prostrata Jacq. ex Parker	–	–	–	–	–	–	–	–	49	7.39	5.40	0.35
Ribes glaciale Wall.	–	–	–	–	–	–	–	–	35	1.76	3.08	1.02
Ribes grossularia L.	–	–	–	–	13	0.12	4.12	2.76	137	2.43	10.06	0.56

Table 1. *Cont.*

Species	Jahlma (3000 m)				Hinsa (2700 m)				Kuthar (2600 m)			
Scientific Name	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**
Ribes orientale Desf.	–	–	–	–	17	5.46	6.25	1.64	–	–	–	–
Rhamnus sp.	–	–	–	–	–	–	–	–	71	4.54	5.32	1.15
Rosa webbiana Wall. ex Royle	70	0.74	23.85	0.20	107	1.01	39.82	0.16	84	2.05	7.16	0.45
Salix daphnoides Vill.	–	–	–	–	11	4.38	4.90	1.02	–	–	–	–
Sorbus lanata (D.Don) S.Schauer	–	–	–	–	–	–	–	–	51	46.38	8.26	0.27
Sorbaria tomentosa (Lindl.) Rehder	–	–	–	–	–	–	–	–	102	4.09	7.63	0.74
Spiraea canescens D.Don	–	–	–	–	–	–	–	–	247	10.27	20.08	0.20
Syringa emodi Wall. ex Royle	5	0.40	2.78	0.74	2	1.55	2.17	0.46	–	–	–	–
Viburnum continifolium D.Don	–	–	–	–	–	–	–	–	16	1.51	1.26	4.08
Total	391	14.11	98.76	–	336	25.50	119.82	–	1628	205.95	146.67	–
Gross Total	699	886.51	300.00	–	521	1085.13	300.00	–	2181	1685.92	300.00	–

In the south-facing agroforestry system in Khoksar, mainly *Salix fragilis* and a few trees of *Populus nigra* were found. *Salix fragilis* was the main species, with 102 plants ha^{-1} density, 197.98 cm^2/100 m^2 basal area and 214.5 IVI (Table 2). However, the density of these trees in Jahlma was much higher as compared to Khoksar and Hinsa villages. The density, basal area and IVI of *Salix fragilis* in Jahlma were, respectively, 365 plants ha^{-1}, 1862.36 cm^2/100 m^2 and 123.89. In Hinsa, *Juniperus polycarpos* was the most dominant species in the agroforestry system, with a density, basal area and IVI of 378 plants ha^{-1}, 2199.28 cm^2/100 m^2 and 97.92, respectively. Small trees such as *Pyrus malus* and *Fraxinus xanthoxiloides* were present at a higher density in Hinsa as compared to small trees in Jahlma, though the number of small tree species in Jahlma was higher than that of the small tree species in Hinsa. The contribution of shrubs in terms of basal area (178.64 cm^2/100 m^2) and IVI (103.57) in Jahlma was much higher as compared to the basal area (100.49 cm^2/100 m^2) and IVI (93.74) of shrubs in Hinsa, in spite of the higher number of shrub species in Hinsa. It was recorded that naturally grown willows had a lower density as compared to cultivated ones.

Table 2. Density, basal area and IVI of plant species in the agroforestry system on south-facing slopes in the cold desert of the Lahaul valley (there is no information for the Kuthar (2600 m) locality).

Species	Khoksar (3200 m)				Jahlma (3000 m)				Hinsa (2700 m)			
Scientific Name	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**
Trees												
Juglans regia L.	–	–	–	–	4	17.38	2.35	0.41	56	281.62	15.50	0.11
Juniperus polycarpos K. Koch	–	–	–	–	17	16.90	5.06	0.30	378	2199.28	97.92	0.06
Malus baccata (L.) Borkh.	–	–	–	–	12	22.73	4.45	0.28	22	61.58	5.19	0.18
Populus nigra L.	7	36.84	32.12	0.34	37	266.87	19.85	0.14	11	29.75	3.76	0.09

Table 2. *Cont.*

Species	Khoksar (3200 m)				Jahlma (3000 m)				Hinsa (2700 m)			
Scientific Name	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F
Prunus cornuta (Wall. ex royle) Stued.	–	–	–	–	20	18.10	4.88	0.49	–	–	–	–
Robinia pseudoacacia L.	–	–	–	–	5	5.20	1.49	1.16	56	17.33	7.82	0.11
Salix fragilis L.	102	197.98	214.54	0.17	365	1862.36	123.89	0.10	244	564.25	37.14	0.12
Total	109	234.82	246.66	–	460	2209.54	161.97	–	767	3153.81	167.33	–
Small trees												
Crataegus songarica K. Koch.	–	–	–	–	6	6.89	1.64	1.40	–	–	–	–
Fraxinus xanthooxiloides (G.Don.) DC.	–	–	–	–	–	–	–	–	300	148.60	32.38	0.07
Prunus armeniaca L.	–	–	–	–	6	15.52	2.43	0.62	–	–	–	–
Prunus avium L.	–	–	–	–	3	0.55	1.16	0.70	–	–	–	–
Prunus communis Huds.	–	–	–	–	18	38.44	5.53	0.44	–	–	–	–
Prunus sp.	–	–	–	–	16	1.40	1.66	13.95	–	–	–	–
Pyrus malus L.	–	–	–	–	67	61.10	14.40	0.23	67	38.74	6.57	0.54
Salix acmophylla Boiss.	–	–	–	–	34	40.24	7.65	0.47	–	–	–	–
Total	–	–	–	–	150	164.14	34.47	–	367	187.34	38.95	–
Shrubs												
Berberis jaeschkeana Schneid.	9	0.06	11.68	1.80	18	0.52	2.23	3.95	44	1.16	4.46	0.36
Cotoneaster obtusus Wall. ex Lindl.	–	–	–	–	–	–	–	–	144	1.69	13.82	0.13
Hippophae rhamnoides L. ssp. turkestanica Rousi	–	–	–	–	440	172.23	55.36	0.26	378	73.61	26.63	0.34
Juniperus communis L. var. saxatilis Pallas	–	–	–	–	–	–	–	–	22	0.22	3.41	0.18
Lonicera hypoleuca Decne.	–	–	–	–	24	1.16	4.00	0.82	167	21.80	17.81	0.08
Ribes grossularia L.	–	–	–	–	31	0.61	4.06	169	–	–	–	–
Rosa webbiana Wall. ex Royle	33	0.27	26.64	6.75	275	4.12	37.92	15	289	2.01	27.61	0.07
Sorbus aucuparia L.	13	1.58	15.02	2.70	–	–	–	–	–	–	–	–
Total	55	1.91	53.34	–	788	178.64	103.57	–	1044	100.49	93.74	–
Gross total	164	236.73	300.00	–	1398	2552.32	300.00	–	2178	3441.64	300.00	–

4.1.2. Forestry

Salix fragilis was the most dominant species at all three study sites in the forestry system. In the Jahlma and Hinsa villages, three species (*Pyrus malus*, *P. communis and Salix acmophylla*) and one species (*Fraxinus xanthoxyloides*) of small trees were dominant, respectively. However, *Prunus cornuta* and *Juglans regia* were dominant species in both Jahlma and Hinsa villages in the north-facing forestry system. *Salix acmophylla* and *Pyrus malus* were two small tree species in Jahlma village. *Rosa webbiana* and *Hippophae rhamnoides* were two shrub species that were common to the Jahlma and Hinsa sites. In the south-facing forestry system, shrubs such as *Berberis jaeschkeana* and *Rosa webbiana* were common species found at the Khoksar, Jahlma and Hinsa sites.

In north-facing slopes, the densities of plants were more or less similar in Jahlma (1119 plants ha^{-1}) and Hinsa (1107 plants ha^{-1}, respectively) (Table 3). However, the basal area in Hinsa was 2.38 times higher than in Jahlma. The contribution to the basal area by trees was very high in Hinsa as compared to Jahlma. The IVI of trees in both Jahlma and Hinsa was more or less similar. However, in Hinsa, shrubs contributed a high IVI (31.1% of the total) as compared to the IVI of the shrubs in Jahlma (24.4%). In Jahlma, small trees constituted 4.7% of the total IVI; in Hinsa, small trees were absent.

Table 3. Density, basal area and IVI of plant species in the forestry system on north-facing slopes in the cold desert of the Lahaul valley (there is no information for the Khoksar (3200 m) and Kuthar (2600 m) localities).

Species	Jahlma (3000 m)				Hinsa (2700 m)			
Scientific Name	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F
Trees								
Betula utilis D.Don	26	2.39	5.40	0.95	–	–	–	–
Juglans regia L.	11	81.23	10.33	0.38	13	218.80	12.58	0.30
Malus baccata (L.) Borkh.	47	5.49	10.38	0.43	–	–	–	–
Populus nigra L.	5	20.82	5.00	0.19	–	–	–	–
Prunus cornuta (Wall. ex Royle) Stued.	168	102.48	40.41	0.17	47	43.88	13.70	0.26
Salix fragilisI L.	305	953.66	129.68	0.14	453	2650.78	174.29	0.08
Total	562	1166.07	201.20	–	513	2913.46	200.57	–
Small trees								
Pyrus mallus L.	21	2.52	4.94	0.76	–	–	–	–
Salix acmophyla Boiss.	53	56.22	20.65	0.12	–	–	–	–
Total	74	58.74	25.58	–	–	–	–	–
Shrubs								
Berberis pseudumbellata R. Parker	–	–	–	–	33	0.65	7.03	0.75
Hippophae rhamnoides L. ssp. turkestanica Rousi	247	10.64	34.35	0.56	320	43.09	42.37	0.80
Lonicera quinquelocularis Hardwp.	105	2.99	15.34	0.95	–	–	–	–
Ribes grassularia L.	–	–	–	–	27	0.24	6.42	0.60
Ribes orientale Desf.	–	–	–	–	27	8.37	6.69	0.60
Rosa webbiana Wall. ex Royle	84	0.89	13.30	0.76	187	1.77	36.93	0.17
Syringa emodi Wall. ex Royle	47	3.48	10.22	0.43	–	–	–	–
Total	483	18.00	73.21	–	594	54.12	99.44	–
Gross Total	1119	1242.81	300.00	–	1107	2967.58	300.00	–

In Khoksar, *Salix fragilis* was the only species in the south-facing forestry system (Table 4), with a density of 471 plants ha^{-1}, 913.02 cm^2/100 m^2 basal area and 250.04 IVI. In Hinsa, *Robinia pseudoacacia* was the most dominant species, with a density, basal area and IVI of 967 plants ha^{-1}, 301.46 cm^2/100 m^2 and 124.77, respectively. The contribution of shrubs that grew through natural regeneration in the forestry system was higher at the Jahlma site as compared to the Khoksar and Hinsa sites in terms of density, basal area and IVI, which were, respectively, 5.49 plants ha^{-1}, 108.84 cm^2/100 m^2 and 89.62. Overall, it was noticed that *S. fragilis* (based on density) was dominant in Khoksar (south-facing slopes), followed by Hinsa (north-facing slopes) and Jahlma (south- and north-facing slopes), with the least in Hinsa (south-facing slopes). Finally, agroforestry and forestry management units have contributed greatly to socio-economic and ecological development by providing multiple goods and services to the local communities in the valley.

Table 4. Density, basal area and IVI of plant species in the forestry system on south-facing slopes in the cold desert of the Lahaul valley (there is no information for the Kuthar (2600 m) locality).

Species	Khoksar (3200 m)				Jahlma (3000 m)				Hinsa (2700 m)			
Scientific Name	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F	Density ha^{-1}	Basal Area (cm^2/100 m^2)	IVI	A/F
Trees												
Juniperus polycarpos K. Koch	–	–	–	–	42	41.05	13.40	0.14	–	–	–	–
Malus baccata (L.) Borkh.	–	–	–	–	4	7.88	1.83	0.68	–	–	–	–
Populus nigra L.	–	–	–	–	49	359.00	28.95	0.08	–	–	–	–
Robinia peudoacacia L.	–	–	–	–	16	15.08	3.07	2.58	967	301.46	124.77	0.22
Salix fragilis L.	471	913.02	250.04	0.26	429	2190.23	146.45	0.10	283	654.01	101.16	0.26
Total	471	913.02	250.04	–	540	2613.24	193.70	–	1250	955.47	225.93	–
Small trees												
Fraxinus xanthoxyloides (G.Don.) DC.	–	–	–	–	–	–	–	–	17	8.26	10.92	0.06
Prunus communis Huds.	–	–	–	–	2	5.17	1.19	0.92	–	–	–	–
Pyrus malus L.	–	–	–	–	19	17.28	4.62	0.78	–	–	–	–
Salix acmophylla Boiss.	–	–	–	–	51	59.43	10.87	0.63	–	–	–	–
Total	–	–	–	–	72	81.88	16.68	–	17	8.26	10.92	–
Shrubs												
Berberis jaeschkeana Schneid.	14	0.10	13.65	0.28	15	0.42	2.88	1.37	–	–	–	–
Cotoneaster obtusus Wall. ex Lindl.	43	1.22	18.84	0.84	–	–	–	–	–	–	–	–
Hippophae rhamnoides L. ssp. turkestanica Rousi	–	–	–	–	266	104.01	38.92	0.41	–	–	–	–
Lonicera hypoleuca Decne	–	–	–	–	10	0.48	2.06	1.63	200	26.16	32.82	0.18
Ribes grossularia auct.non L.	–	–	–	–	16	0.31	2.55	2.58	–	–	–	–
Rosa webbiana Wall. ex Royle	36	0.29	17.47	0.70	242	3.62	43.21	0.11	200	1.39	30.32	0.18
Total	93	1.61	49.96	–	549	108.84	89.62	–	400	27.55	63.14	–
Gross total	564	914.63	300.00	–	1161	2803.96	300.00	–	1667	991.28	300.00	–

4.1.3. Natural Forests

Forest resources are scattered and scanty in the entire Lahaul valley. The Chandra valley is almost denuded of all forests except for very few scattered trees of *Betula utilis*, *Pinus wallichiana*, *Juniperus communis*, *J. indica*, *Salix flegilaris*, *S. lindleyana* and *S. pycnostachya*. These are mostly found on the north-facing slopes. In the Bhaga valley, both slopes have some patches of open forests. *Juniperus polycarpos* is a key tree species found on the south-facing slope. In Hinsa, the few patches of relict forests included *Abies pindrow*, *Picea smithiana* and *Cedrus deodara* trees. In the Kuthar area, a pure patch of *Abies pindrow*, *Picea smithiana* and *Cedrus deodara* can be seen on both sides of the narrow valley. Besides these, some broad-leaved trees, such as *Celtis australis*, *Euonymous fimriatus*, *Fraxinus floribanda*, *Corylus jaquemontii* and *Sorbaria tomentosa*, were also found.

Among all the locations in north-facing forests, Jahlma (3430 plants ha^{-1}) showed the highest density, followed by a dense patch of a developing forest of *Betula utilis* near Khoksar (1915 plants ha^{-1}, including saplings), Hinsa (925 plants ha^{-1}) and Kuthar (9.63 plants ha^{-1}) (Table 5). In Jahlma, *Pinus wallichiana* was the most dominant tree species, with 761 plants ha^{-1} density, 1659.31 cm^2/100 m^2 basal area and 137.41 IVI. In Hinsa, *Abies pindrow* was the dominant tree species with 200 plants ha^{-1} density, 1046.01 cm^2/100 m^2 basal area and 90.27 IVI; other important species were *Picea smithiana*, *Pinus wallichiana*, *Betula utilis* and *Salix fragilis*. In Kuthar, *Picea smithiana* was the dominant tree species with 200 plants ha^{-1} density, 1703.01 cm^2/100 m^2 basal area and 81.79 IVI.

Table 5. Density, basal area and IVI of plant species in natural forests on north-facing slopes in the cold desert of the Lahaul valley.

Species	**Khoksar (3200 m)**				**Jahlma (3000 m)**				**Hinsa (2700 m)**				**Kuthar (2600 m)**			
Scientific Name	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**
Trees																
Abies pindrow (Royle Ex. D. Don) Royle	–	–	–	–	–	–	–	–	200	1046.01	90.27	0.07	175	1857.71	82.20	0.04
Betula utilis D. Don	1915	1437.09	223.91	0.49	9	2.76	1.35	0.46	23	122.30	11.48	0.31	11	24.82	2.64	1.77
Cedrus deodara (Roxb. ex D.Don) G. Don	–	–	–	–	–	–	–	–	–	–	–	–	161	544.63	38.99	0.18
Picea smithiana (Wall.) Boiss.	–	–	–	–	–	–	–	–	122	557.71	59.91	0.04	200	1703.01	81.79	0.04
Pinus wallichiana A.B. Jackson	–	–	–	–	761	1659.31	137.41	0.08	109	498.17	54.36	0.04	68	654.31	34.10	0.05
Salix fragilis L.	–	–	–	–	–	–	–	–	6	3.61	1.88	0.90				
Total	1915	1437.09	223.91	–	770	1662.07	138.76	–	460	2227.80	217.90	–	615	4784.48	239.72	–
Small trees																
Crataegus songarica K. Koch.	–	–	–	–	–	–	–	–	5	1.07	0.96	6.96	–	–	–	–
Salix acmophylla Boiss.	–	–	–	–	865	46.67	46.75	0.11	–	–	–	–	–	–	–	–
Total	–	–	–	–	865	46.67	46.75	–	5	1.07	0.96	–	–	–	–	–
Shrubs																
Berberis jaeschkeana Schneid.	44	0.76	3.91	0.75	–	–	–	–	–	–	–	–	–	–	–	–
Berberis pseudumbellata R. Parker	–	–	–	–	39	0.79	4.02	0.23	23	0.47	4.66	0.87	65	0.74	12.55	0.26
Cotoneaster obtusus Wall. ex Lindl.	–	–	–	–	326	4.60	22.98	0.09	53	0.98	9.63	0.58	15	0.79	2.93	1.00
Cotoneaster pruinsesus G. Kotz.	–	–	–	–	–	–	–	–	–	–	–	–	4	0.05	0.93	2.75
Hippophae rhamnoides L.ssp. turkestanica Rousi	–	–	–	–	–	–	–	–	3	0.03	0.64	3.48	–	–	–	–
Indigofera hilerentha Wall. ex Brand.	–	–	–	–	–	–	–	–	–	–	–	–	4	0.69	1.11	1.05
Juniperus communis L.var. saxatilis Pallas	6	0.07	0.88	1.56	500	11.09	29.36	0.12	218	14.81	35.58	0.29	29	0.32	4.14	2.83
Lonicera govaniana Wall. ex DC.	–	–	–	–	91	3.10	5.67	0.54	–	–	–	–	–	–	–	–
Lonicera myrtillus Hk.f. & Th.	–	–	–	–	122	3.17	9.39	0.18	–	–	–	–	35	1.26	6.44	0.60
Lonicera quinquelocularis Hardwp.	85	1.19	8.50	0.28	–	–	–	–	–	–	–	–	–	–	–	–
Rhododendron companulatum D.Don.	152	14.62	15.98	0.16	–	–	–	–	–	–	–	–	–	–	–	–
Ribes grossularia L.	–	–	–	–	–	–	–	–	5	0.07	0.92	6.96	11	0.17	2.58	0.79
Ribes orientale Desf.	–	–	–	–	–	–	–	–	1	1.21	0.50	1.16	–	–	–	–
Rosa webbiana Wall. ex Royle	158	1.55	16.74	0.13	91	1.53	6.52	0.30	32	0.41	5.95	0.88	31	0.30	5.03	1.18
Salix denticulata Anderss.	–	–	–	–	–	–	–		59	8.52	10.62	0.65	–	–	–	–
Salix karelinii Turcz.	296	26.27	30.09	0.09	–	–	–	–	–	–	–	–	–	–	–	–
Sorbaria tomentosa (Lindl.) Rehder	–	–	–	–	–	–	–	–	–	–	–	–	11	0.18	1.59	6.67
Spiraea canescens D.Don	–	–	–	–	–	–	–	–	–	–	–	–	75	0.87	11.23	0.82
Rubus irritants Focke	–	–	–	–	–	–	–	–	7	0.16	1.11	9.28	–	–	–	–
Viburnum continifolium D.Don	–	–	–	–	626	23.38	36.56	0.10	59	3.31	11.54	0.41	68	1.73	11.75	0.42
Total	741	44.46	76.10	–	1795	47.66	114.50	–	460	29.97	81.15	–	348	7.10	60.28	–
Gross Total	2656	1481.55	300.00	–	3430	1756.40	300.00	–	925	2258.84	300.00	–	963	4791.58	300.00	–

Among small trees, *Salix acmophylla* was the dominant species on the north-facing slopes of Jahlma, and *Crataegus songarica* was dominant in Hinsa. Small trees were not found at the Khoksar and Kuthar sites; however, shrubs were recorded at all locations. *Salix karelenii* and *Rhododendron companulatum* were the most dominant shrubs in Khoksar, *Viburnam continifolium* and *Juniperus communis* were the most dominant shrubs in Jahlma and Hinsa, and *Spireae conescense*, *Viburnam continifolium* and *Berberis pseudumbellata* were dominant shrubs in Kuthar. *Juniperus communis* and *Rosa webbiana* were the two shrubs that were recorded at all four locations. Forest vegetation showed a contagious distribution pattern at the Khoksar and Jahlma sites. In Hinsa and Kuthar, *Pinus wallichiana* and *Picea smithiana* showed random distribution patterns. Similarly, in Kuthar, along with *Pinus wallichiana* and *Picea smithiana*, *Abies pindrow* also showed a random distribution pattern. None of the species was recorded with a regular distribution pattern.

In south-facing forests at the Jahlma and Hinsa sites, *Juniperus polycarpos* was the dominant species on south-facing slopes (Table 6). In Kuthar, *Cedrus deodara* was the dominant species in terms of density (99 plants ha^{-1}), basal area (2459.62 cm^2/100 m^2) and IVI (128.74). In Jahlma, the density, basal area and IVI of *Juniperus polycarpos* were 307 plants ha^{-1}, 2445.32 cm^2/100 m^2 and 222.44, respectively, whereas the density, basal area and IVI of *Juniperus polycarpos* in Hinsa were, respectively, 469 plants ha^{-1}, 2000.41 cm^2/100 m^2 and 160.33. In Khoksar, all five recorded shrub species showed sparse distributions; among them, *Juniperus indica* was the most dominant species, with the highest density, basal area and IVI of 2595 plants ha^{-1}, 258.37 cm^2/100 m^2 and 216.33, respectively. *Juniperus* species contributed more to species richness, density, basal area and IVI than those on the north-facing slopes. *Juniperus polycarpos* contributed greatly to the total density, basal area and IVI in the natural forests at the Jahlma site and, to a lesser extent, at the Hinsa site. However, a trend towards a decreasing density of *Juniperus polycarpos* was observed. *Rosa webbiana* was a widely distributed shrub on dry south-facing slopes in Jahlma and Hinsa. In Kuthar, *Parrotopsis jaquemontiana* was the most dominant shrub, with a density, basal area and IVI of 99 plants ha^{-1}, 20.21 cm^2/100 m^2 and 18.26, respectively. *Juniperus polycarpos* was absent on the south-facing slopes of the Khoksar and Kuthar sites, as well as on the north-facing slopes of all studied sites. In general, south-facing slopes in Jahlma, Hinsa and Kuthar showed a contagious distribution pattern of the species, except for *Juniperus polycarpos* (A/F ratio; 0.04) in Jahlma and *Cedrus deodara* (A/F ratio: 0.4) in the Kuthar area, which showed a random distribution pattern. None of the species on south-facing slopes showed a regular distribution pattern. Furthermore, due to high anthropogenic activity, reduced growth and a contagious distribution pattern were noticed.

Table 6. Density, basal area and IVI of plant species in natural forests of south-facing slopes in the cold desert of the Lahaul valley.

Species	Khoksar (3200 m)				Jahlma (3000 m)				Hinsa (2700 m) (Kukumseri)				Kuthar (2600) (Lauhani)			
Scientific name	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**
Trees																
Cedrus deodara Roxb. ex D. Don	–	–	–	–	–	–	–	–	–	–	–	–	99	2459.62	128.74	0.04
Celtis australis L.	–	–	–	–	–	–	–	–	–	–	–	–	9	9.01	3.13	0.81
Euonymous fimbriatus Wall.	–	–	–	–	–	–	–	–	–	–	–	–	23	10.20	6.67	0.53
Fraxinus floribanda Wall.	–	–	–	–	–	–	–	–	–	–	–	–	2	1.28	0.88	1.82
Juglans regia L.	–	–	–	–	–	–	–	–	3	88.40	4.82	1.16	–	–	–	–
Juniperus polycarpos K. Koch	–	–	–	–	307	2445.32	222.44	0.04	469	2000.41	160.33	0.06	–	–	–	–
Malus baccata (L.) Borkh.	–	–	–	–	–	–	–	–	14	21.61	3.96	0.52	–	–	–	–
Pinus wallichiana A.B. Jackson	–	–	–	–	–	–	–	–	10	52.44	4.42	0.87	–	–	–	–
Populus nigra L.	–	–	–	–	3	8.64	1.79	2.79	2	21.44	1.71	0.58	40	50.45	11.40	0.51
Robinia pseudoacacia L.	–	–	–	–	–	–	–	–	–	–	–	–	97	34.93	19.83	0.66
Salix fragilis L.	–	–	–	–	20	44.53	9.33	0.85	7	7.32	1.52	2.32	9	16.13	2.84	1.82
Total	–	–	–	–	330	2498.49	233.56	–	505	2191.62	176.76	–	279	2581.62	173.49	–
Small trees																
Crataegus songarica K. Koch.	–	–	–	–	–	–	–	–	–	–	–	–	21	2.87	5.00	1.08
Fraxinus xanthoxyloides (D. Don.)DC.	–	–	–	–	–	–	–	–	207	51.71	36.23	0.10	–	–	–	–
Total	–	–	–	–	–	–	–	–	207	51.71	36.23	–	21	2.87	5.00	–
Shrubs																
Berberis jaeschkeana Schneid.	751	5.44	44.66	0.46	–	–	–	–	–	–	–	–	–	–	–	–
Berberis pseudumbellata R. Parker	–	–	–	–	16	0.23	5.09	2.16	14	0.13	2.39	1.16	8	0.09	2.10	1.59
Cotoneaster microphylla Wall. ex Lindl.	173	1.10	15.52	0.48	–	–	–	–	–	–	–	–	–	–	–	–
Cotoneaster obtusus Wall. ex Lindl.	–	–	–	–	29	0.88	10.18	0.83	45	0.81	8.10	0.31	–	–	–	–
Cotoneaster pruinosus G. Kotz.	–	–	–	–	–	–	–	–	–	–	–	–	11	1.81	2.59	2.28
Euonymus monbeigii W.W.Sm.	–	–	–	–	–	–	–	–	–	–	–	–	8	1.11	2.14	1.59
Hippophae rhamnoides L.ssp. turkestanica Rousi	–	–	–	–	–	–	–	–	10	1.81	1.56	3.48	–	–	–	–
Indigofera hilerentha Wall. ex Brand	–	–	–	–	–	–	–	–	–	–	–	–	53	13.85	13.94	0.30

Table 6. *Cont.*

Species	Khoksar (3200 m)				Jahlma (3000 m)				Hinsa (2700 m) (Kukumseri)				Kuthar (2600) (Lauhani)			
Scientific name	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**	**Density ha^{-1}**	**Basal Area (cm^2/100 m^2)**	**IVI**	**A/F**
Jasminum humile L.	–	–	–	–	–	–	–	–	–	–	–	–	34	13.72	12.63	0.14
Juniperus indica Bertol.	2595	258.37	216.33	0.31	–	–	–	–	–	–	–	–	–	–	–	–
Juniperus communis L.var. saxatilis Pallas	108	4.89	10.70	0.93	17	0.48	6.53	0.90	–	–	–	–	19	0.53	4.08	1.72
Lonicera hypoleuca Decne.	–	–	–	–	–	–	–	–	110	8.33	18.22	0.19	87	11.13	25.40	0.12
Parrotopsis jaquemontiana (Decne.) Render	–	–	–	–	–	–	–	–	–	–	–	–	99	20.21	18.46	1.01
Rhamnus prostrata Jacq. ex Parker	–	–	–	–	–	–	–	–	–	–	–	–	20	2.93	4.87	1.02
Ribes grossularia L.	–	–	–	–	1	0.01	0.62	3.72	–	–	–	–	–	–	–	–
Ribes orientale Desf.	–	–	–	–	–	–	–	–	10	0.09	2.10	0.87	–	–	–	–
Rosa webbiana Wall. ex Royle	81	0.43	12.79	0.23	119	1.26	44.02	0.16	288	2.84	51.97	0.05	5	0.08	1.26	4.55
Salix spp.	–	–	–	–	–	–	–	–	16	3.20	2.67	1.31	11	3.09	3.19	1.01
Sorbus lanata (D.Don) S.Schauer	–	–	–	–	–	–	–	–	–	–	–	–	55	10.88	11.90	0.71
Spiraea canescens D.Don	–	–	–	–	–	–	–	–	–	–	–	–	69	2.18	18.94	0.18
Total	3708	270.23	300.00	–	182	2.86	66.44	–	493	17.21	87.01	–	479	81.61	121.50	–
Gross Total	3708	270.23	300.00	–	512	2501.35	300.00	–	1205	2260.54	300.00	–	779	2666.10	300.00	–

4.1.4. Comparison of Species Richness, Density and Basal Area on North- and South-Facing Slopes

A comparison of north- and south-facing slopes in terms of species richness, density and basal area in different management units (agroforestry, forestry and natural forests) showed that in natural forests, the species richness, plant density and basal area were generally higher on the north-facing slopes than on the south-facing slopes, except for at the Kuthar site, where the richness of shrubs was higher than on the north-facing slopes (Table 7). In human-managed systems such as agroforestry and forestry, no uniform patterns were found for species richness, density or basal area. In Khoksar, the richness of shrubs was high on both the north- and south-facing slopes as compared to other sites.

Table 7. Comparison of species richness, density and basal area in agroforestry, forestry and natural forests on north- and south-facing slopes in the cold desert of the Lahaul valley.

Attributes	**Sites**	**Species Richness**		**Density (Plants ha^{-1})**		**Basal Area (cm^2/100 m^2)**	
		N [a]	S [b]	N	S	N	S
Agroforestry	Khoksar	–	5	–	164	–	236.73
	Jahlma	5	19	699	1398	886.50	255.32
	Hinsa	20	14	521	2178	1085.13	3441.64
	Kuthar	36	–	2181	–	1685.92	–
Forestry	Khoksar	–	4	–	564	–	914.63
	Jahlma	12	13	1119	1161	1242.81	2803.96
	Hinsa	8	5	1107	1667	2967.58	991.28
	Kuthar	–	–	–	–	–	–
Natural Forests	Khoksar	7	5	2656	3708	1481.55	270.23
	Jahlma	10	8	3030	512	1756.40	2501.35
	Hinsa	16	14	925	1205	2258.84	2260.54
	Kuthar	16	21	963	779	4791.58	2666.10

[a] N—north-facing slope; [b] S—south-facing slope.

4.2. Synthetic Characters

4.2.1. Species Richness

A total of 64 species (27 trees and 37 shrubs) of vascular plants were recorded altogether in the selected study sites. On the north-facing slopes, the species richness was highest in Kuthar, followed by Hinsa and Jahlma in the agroforestry system (Table 7). In the forestry system, the highest species richness was in Jahlma, and the lowest was in Hinsa. *S. fragilis* was the most dominant tree species in Khoksar, Hinsa and Jahlma, while *Prunus cornuta* and *Juglans regia* were dominant species at both the Jahlma and Hinsa sites on north-facing slopes (Table 7). In the south-facing forestry system, species richness was highest in Jahlma, followed by Hinsa, and the lowest was in Khoksar.

In natural forests, species richness was highest at the Hinsa and Kuthar sites, followed by Jahlma and Khoksar in north-facing natural forests (Table 7). With decreasing altitude, the species richness on the north-facing slopes increased (R^2 = 0.6881) (Figure 2). In north-facing forests, among the tree species, *Betula utilis* was a common species at all four study locations. At the Hinsa and Kuthar sites, five tree species were found, dominated by coniferous species. In north-facing forests, there were 6 shrub species in Khoksar, 7 in Jahlma, 10 in Hinsa and 11 in Kuthar. However, *Rosa webbiana* was the only common shrub that was found at all four study sites in south-facing forests.

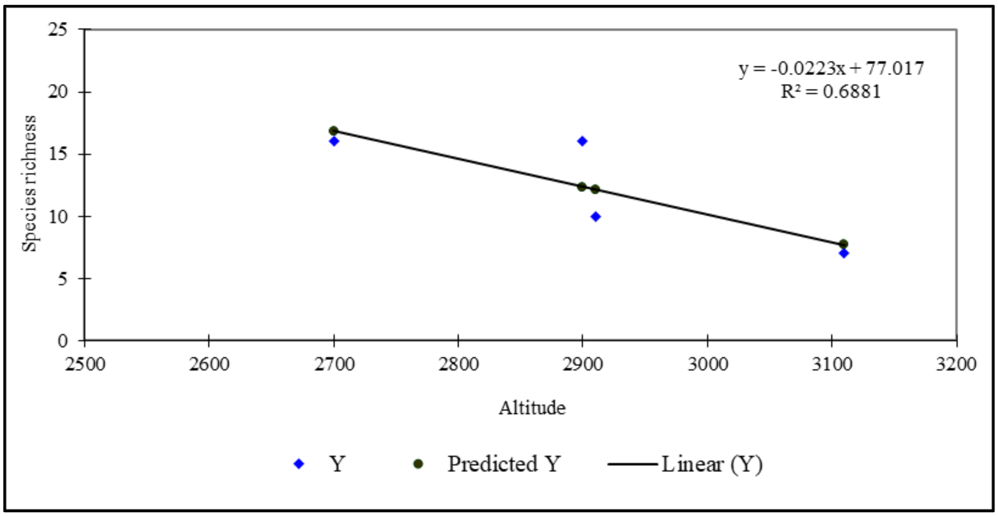

Figure 2. Altitudinal species richness of natural forests on north-facing slopes.

In Kuthar, the forest system was more developed on south-facing slopes as compared to Hinsa, Jahlma and Khoksar. As a result, the maximum species richness was found in Kuthar, followed by Hinsa and Jahlma, and the lowest was in Khoksar (Table 7). Like on the north-facing slopes, on the south-facing slopes, the decrease in altitude corresponded to an increase in the number of species (R^2 = 0.9776) (Figure 3). South-facing slopes in Khoksar were more or less barren, except for a few shrubs and grasses. There were three tree species in Jahlma, six in Hinsa and seven in Kuthar. At the Kuthar site, the maximum number (7) of tree species was recorded, and among them, *Cedrus deodara*, *Robinia pseudoacacia* and *Euonymous fimbriatus* were dominant species.

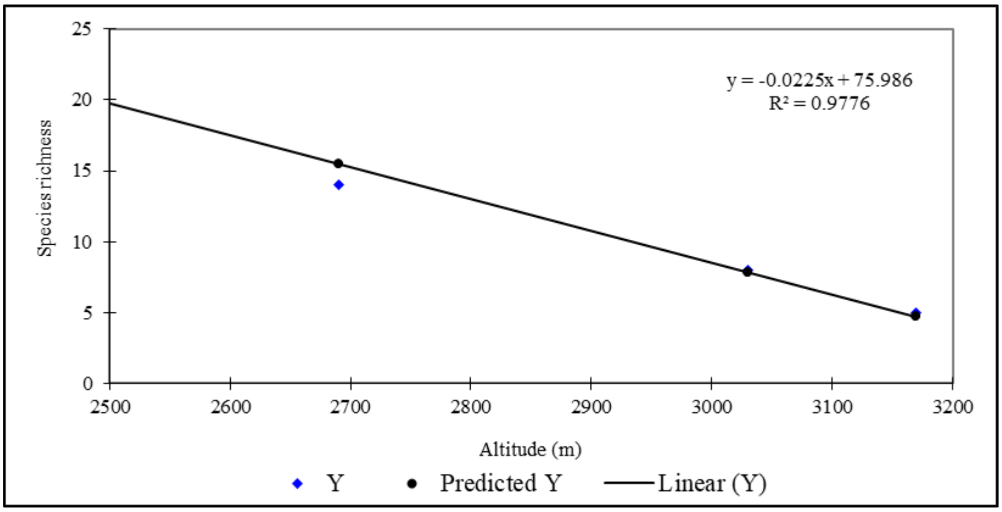

Figure 3. Altitudinal species richness of natural forests on the south-facing slopes.

4.2.2. Diversity, Evenness Index and Concentration of Dominance

In the agroforestry system, the diversity index (H^-) and evenness index (J′) showed similar patterns to species richness at all four locations and on both the north- and south-facing slopes (Figure 4A–F). The highest species richness on the north-facing slope was in Kuthar in the agroforestry system; this stand also showed the highest values for the diversity index (3.12) and evenness index (0.87) among all the sites (Figure 4A). The values of the diversity index and evenness index were also low for this stand (1.11 and 0.69, respectively), whereas other sites ranged between Jahlma and Hinsa (Figure 4B). In the forestry system, the highest diversity index was recorded in Jahlma, followed by

Hinsa, whereas a similar trend was observed for the evenness index on north-facing slopes (Figure 4C). The diversity index ranged between Khoksar and Jahlma on south-facing slopes, whereas the evenness index ranged between Khoksar and Hinsa sites (Figure 4D).

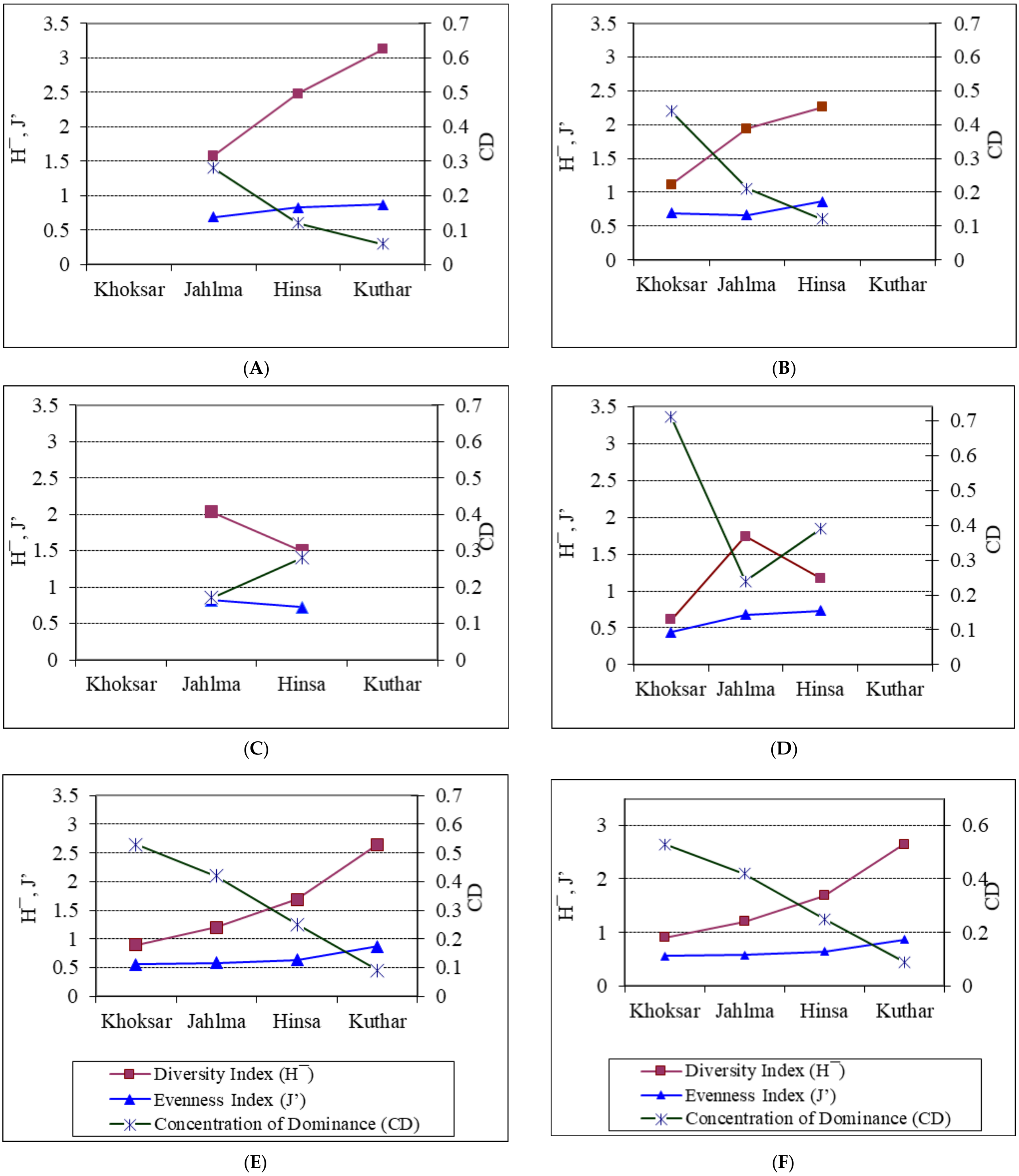

Figure 4. (**A**) Synthetic characters of agroforestry on north-facing slopes in the Lahaul valley. (**B**) Synthetic characters of agroforestry on south-facing slopes in the Lahaul valley. (**C**) Synthetic characters of forestry on north-facing slopes in the Lahaul valley. (**D**) Synthetic characters of forestry on south-facing slopes in the Lahaul valley. (**E**) Synthetic characters of natural forests on north-facing slopes in the Lahaul valley. (**F**) Synthetic characters of natural forests on south-facing slopes in the Lahaul valley.

In the natural forests of north-facing slopes, the highest diversity and evenness indexes were, respectively, 2.29 and 0.83, with the highest species richness in Kuthar (Figure 4E), whereas south-facing slopes in Kuthar had the highest species richness, with the highest diversity index (2.65) and evenness index (0.87) among all the sites (Figure 4F).

The concentration of dominance showed a nearly reverse trend to the diversity index and evenness index in all types of management systems on both slope aspects (Figure 4A,F). The concentration of dominance ranged between 0.12 in Hinsa and 0.44 in Khoksar in the agroforestry system, while in forestry, it ranged between 0.17 in Jahlma and 0.71 in Khoksar (Figure 4C,D). In the natural forests, it ranged from 0.09 in Kuthar to 0.76 in Khoksar (Figure 4E,F).

4.2.3. Similarity Index

The similarity indexes for agroforestry in Hinsa and Kuthar with respect to Jahlma were 46.67 and 34.78, respectively (Table 8). On the south-facing slopes in the agroforestry system, the similarity indexes of Jahlma and Hinsa were 33.33 and 42.11 with respect to Khoksar. In the forestry system of north-facing slopes, the similarity index in Hinsa was 50 with respect to Jahlma, whereas south-facing slopes had similarity indexes between 35.29 in Jahlma and 44.44 in Hinsa with reference to Khoksar (Table 8). The natural forests on north-facing slopes had similarity indexes of 35.29 for Jahlma, 26.09 for Hinsa and 26.09 for Kuthar with respect to Khoksar (Table 8). The natural forests of south-facing slopes had a lower similarity index than north-facing slopes.

Table 8. Similarity index of plant species on north- and south-facing slopes in the cold desert of the Lahaul valley.

	Khoksar (3200 m)	Jahlma (3000 m)	Hinsa (2700 m)	Kuthar (2600 m)
North-facing slopes				
Agroforestry	0.00	0.00	0.00	0.00
		100.00	46.67	34.78
			100.00	57.14
Forestry	0.00	0.00	0.00	0.00
		100.00	50.00	0.00
			100.00	0.00
Natural Forests	100.00	35.29	26.09	26.09
		100.00	53.85	53.85
			100.00	62.50
South-facing slopes				
Agroforestry	100.00	33.33	42.11	0.00
		100.00	72.73	0.00
			100.00	0.00
Forestry	100.00	35.29	44.44	0.00
		100.00	44.44	0.00
			100.00	0.00
Natural Forests	100.00	30.77	10.53	15.38
		100.00	54.55	34.48
			100.00	34.29

5. Discussion

5.1. Vegetation Study

5.1.1. Agroforestry and Forestry

Willow is cultivated in agroforestry and forestry systems along the settlements by local communities to meet fuelwood, fodder and timber requirements in the valley [23].

The growth conditions improve the density, basal area and IVI of the species as the altitude declines and vice versa in the study area. However, the use of farmyard manure (FYM) and fertiliser in the agricultural system has resulted in improvements in the density and basal area of plant species at middle altitudes (i.e., Jahlma and Hinsa) [22], whereas, at lower altitudes, it is better due to a longer growth period. Moist north-facing slopes favour a larger number of plant species in agroforestry and forestry systems and natural forests as compared to south-facing dry slopes. Augusseau et al. [45] found that fallow land was an important site to farmers for the plantation of trees in southern Burkina Faso Parkland, and this land use increased and maintained the tree density. The land holding of the farmers determines the number of trees in agroforestry and forestry systems in the present study [46,47]. The influence of social and ecological factors is considered when determining the use of certain species in agroforestry and forestry systems. For instance, willow in agroforestry and forestry systems plays a vital role in socio-economic development by providing multiple goods and services and ecologically maintaining the Lahaul valley (e.g., stabilising hill slopes, protecting villages from avalanches, promoting climate change mitigation and adaptation, and reducing pressure from relict natural patches of forests).

On the north-facing slopes, highly developed willow-based agroforestry and forestry systems were found in Jahlma, a middle-altitude site. In this area, natural forest species were very scanty and sparse. Farmers have maintained high densities of willow trees in agroforestry and forestry (plantations) management units to meet fodder, fuelwood and timber requirements [25]. Trees are the single most important sources of fodder for livestock, which, in turn, provide drought power for cultivation, provide food products such as milk and meat, and maintain soil productivity through compost and manure in the north-western Himalaya of India [48] and in Nepal Himalaya [46,47]. At the Kuthar site, the density of shrubs was reported to be higher in the agroforestry system due to natural regeneration and a better growth period.

On the south-facing slopes, developed agroforestry and forestry systems were recorded in Jahlma. *Salix fragilis* trees in agroforestry and forestry systems were maintained at a high density by local communities. A few trees of *Salix fragilis* and *Populus nigra* were also planted on the lower parts of the slope near settlements by the villagers for fodder, fuelwood and timber as per the provision given by the Department of Forest, Govt. of Himachal Pradesh, particularly for the Lahaul-Spiti area (Working Plan of Lahaul Forest Division, 1993–1994 to 2006–2007). In the Hinsa area, *Juniperus polycarpos* was also maintained at a higher density in the agroforestry system. The high densities of willows and *Juniperus polycarpos* in Jahlma and Hinsa meet the fodder and fuelwood requirements of local communities. Trees maintained on the edges of farms in Nepal [46,47] and India [48] and those planted by farmers in south-western Burkina Faso Parkland [45] meet the fuelwood and fodder requirements.

5.1.2. Natural Forests

The vegetation pattern in the mountains is determined by a variety of ambient factors, such as the altitudinal gradient, slope aspect, pedological conditions, soil moisture regime, wind velocity and solar radiation, which are some of the key determinants [49,50]. Varying topography and weather conditions exert tremendous stress on eco-physiological processes, resulting in the diversity of these fragile and vulnerable ecosystems. Therefore, the natural vegetation exhibits considerable diversity in plant form and function [51]. The distribution patterns of the plants in different phyto-geographical locations are also determined by available solar radiation, as well as the aspect and angle of the slope [52]. Cold deserts are well-recognised phyto-geographical regions of the Indian Himalaya due to their herbaceous vegetation composition, which has immense economic value, ecological potential and sparsely distributed tree species [16]. In the study region, *Betula utilis*, *Pinus wallichiana*, *Abies pindrow*, *Picea smithiana* and *Cedrus deodara* are some of the tree species found on north-facing slopes, while south-facing slopes contain *Rosa webbiana* and *Juniperus polycarpos.* The regeneration of *Juniperus polycarpos* was observed to be poor [14]. The relatively better climatic conditions for tree growth at lower elevations account for the higher density and basal area at the lower elevation as compared to high-altitude sites such as Khoksar.

In natural forests on the southern slopes, *Juniperus polycarpos* showed a high density in Jahlma and Hinsa. *Juniperus polycarpos* is the most successful tree species on the dry and xeric south-facing slopes in the valley [16]. Kuthar is a relatively moist area as compared to Jahlma and Hinsa due to higher rainfall during the summer season. *Cedrus deodara*, along with other species, showed a higher tree density on these slopes. The higher density of shrubs was also due to higher moisture contents and better growth conditions in Kuthar as compared to the other three locations. The management and preference of plant species by the local communities determined the density [53,54]

5.2. Synthetic Characters

5.2.1. Species Richness in Agroforestry, Forestry and Natural Forests

Species richness is influenced by the better growth conditions of the environment [15]. On the north-facing slopes, species richness was higher due to relatively moist soil conditions than on the exposed south-facing dry slopes. Species richness increased on both slope aspects due to better growth conditions at lower altitudes. The highest species richness was due to the higher number of trees and bushes present in the system due to natural regeneration and maintenance by farmers along the edges of terraced agricultural fields at the Kuthar site.

On the north-facing slopes, species richness was higher due to relatively moist soil conditions as compared to the dry south-facing slopes [55]. Forest diversity is mostly influenced by topography, soil characteristics, climate, altitude, soil moisture, geographical location and the intensity of the biotic factors of the area, such as anthropogenic pressure [56,57]. Species composition changed with respect to the altitude for all forest types. Species richness in Hinsa and Kuthar forests was similar; these values were higher than those of other sites in north-facing forests. Saxena and Singh [58] recorded a high species richness (4 to 22) and diversity (0.74 to 3.10) for the shrub layer in Kumaun Himalaya, which is more or less comparable to the present study. Species richness ranged from 9 to 22, with an average of 16 tree species per site in the Southern Appalachian Mountains [59]. The distribution of forest structure by natural and anthropogenic disturbances alters species richness and other ecosystem properties [9,15,54).

In the present study, species richness increased with decreasing altitude on both slope aspects due to relatively better growth conditions at lower altitudes [15]. Sundriyal and Bisht [60], in their study in the central Himalaya at four altitudinal gradients above the timberline, found the highest species richness (eight) at an altitude of 3000 m, followed by 3200 m (six species), 3250 m (five species) and 3400 m altitudes (five species). In their study, *Abies pindrow*, *Betula alnoides*, *Quercus semecarpifolia* and *Rhododendron campanulatum* were common species on all four altitudinal gradients. Gargya et al. [61], in their study in the central Himalaya in the alpine and sub-alpine regions, found similar results for the distribution of tree seedlings. At 3300 m altitude at the Yamnotri-Uttarkashi site, seedlings of *Pyrus*. sp., *Quercus semecarpifolia* and *Abies pindrow* were recorded. However, in forests, a few well-adapted xeric species, such as *Juniperus polycarpos* and *Rosa webbiana*, can survive under the extremely xeric soil conditions of south-facing slopes during summer [14]. In Kuthar, species richness was higher on both the north- and south-facing slopes because of its warmer and higher-rainfall conditions compared to the other three sites. Only species such as *Betula utilis* and *Pinus wallichiana*, along with a few shrubby species of willow, were found growing here, and it was observed that species richness in Khoksar, being at a high altitude, was less than at the other three lower-altitude sites [15]. Trees were represented in small numbers up to 3000 m altitude, whereas shrubs were distributed up to 3500 m, and the maximum was in the range between 2500 and 3500 m [62]. In the present study, the observed patterns of species diversity cannot be solely due to differences in sampling intensity. The patterns observed here might be due to the presence of microclimates or environmental heterogeneity, which resulted in a different number of individuals at different altitudes [63]. In the study region, snow-fed streams run almost everywhere, which may enhance heterogeneity in two ways: i.e., (i) very different moisture regimes may occur within small distances, and (ii) streams create local variations and different soil conditions [64].

5.2.2. Concentration of Dominance (CD) in Agroforestry, Forestry and Natural Forests

The concentration of dominance ranged between 0.13 in Kuthar and 0.76 in Khoksar. On the south-facing slopes, it ranged in a similar pattern from 0.09 to 0.53 in Kuthar and Khoksar, respectively. The values of the concentration of dominance (cd) at all the sites were more or less similar, as reported by Whittaker [65] and Risser and Rice [66] for temperate vegetation (0.01 to 0.99). Saxena and Singh [58] reported values of 0.131 to 1.00 for woody species in temperate Kumaun Himalaya.

5.2.3. Diversity Index in Agroforestry, Forestry and Natural Forests

Species diversity showed an increasing trend with decreasing altitude. The highest species diversity was found in Kuthar on both the north- and south-facing slopes, with the lowest in Khoksar. These values are comparable to values generally reported for temperate forests [67]. Parker and Swank [68] found that harvesting and disturbances in the forest changed the relative species composition in eastern deciduous forests and influenced species diversity [69]. Among the natural forests, sub-alpine coniferous forests had the least diversity. Among the other types, evergreen broad-leaved coppice and *Pinus densiflora* stands had a high diversity because of the large number of species with weak concentration dominance. Risser and Rice [66] found that species diversity was between 2.00 and 3.00 for temperate forests. Sharma et al. [70] reported a species diversity of 1.7986 to 2.9673 in the Trikuta Hills of Jammu-Kashmir. Thus, single-species-dominated communities may be important for ecosystem health, but disturbances trigger plant biodiversity and influence resource availability [9,24,54].

Varying topography and weather conditions exert tremendous stress on eco-physiological processes, resulting in the diversity of fragile and vulnerable ecosystems. Therefore, natural vegetation exhibits considerable diversity in plant form and function [51]. Bhandari et al. [71] found that species diversity was highest (2.53) on the middle slopes. The low diversity in the south-facing forests in the Lahaul valley was due to exhaustive anthropogenic pressure and xeric soil conditions. Both slope aspects in the Lahaul valley showed a marked difference in species distribution and composition. Forest diversity is mostly influenced by topography, soil characteristics, climate, altitude, soil moisture, geographical location and the intensity of the biotic factors of the area [56,57].

5.2.4. Evenness Index in Agroforestry, Forestry and Natural Forests

The evenness index was found to be highest in Kuthar on both north- and south-facing slopes (0.83 and 0.87) and lowest in Khoksar on both slope aspects (0.30 to 0.56). Both middle-altitude sites fall within this range for the evenness index. Elliott and Hewitt [59] found evenness indexes ranging from 0.357 to 0.822 in Southern Appalachian Mountains. The values in the present study were more or less similar to this study. The evenness index in the tropical semi-evergreen forests of the Kalrayan Hills ranged from 0.201 to 0.745 [72]. Tree evenness increased with disturbance. Low evenness was found in single-species-dominated minimally disturbed forests and indicates that these species are highly abundant in the forest as compared to other species. High evenness indicates that more than one species has a similar abundance in the forests [9,54].

5.2.5. Similarity Index in Agroforestry, Forestry and Natural Forests

The vegetation of the Lahaul valley showed a sparse distribution pattern due to xeric climatic conditions. There were considerable differences in the species composition of vegetation in the cold desert of the Lahaul valley. There was little or no similarity in vegetation in agroforestry and forestry systems from Khoksar to Jahlma. Khoksar is above the tree distribution zone of willow. Even then, willow and poplar trees were cultivated in agroforestry and forestry systems. Similarly, plant species found in the forest system in Khoksar showed a higher similarity in Jahlma than the similarity in Hinsa and Kuthar due to a change in the environmental conditions as compared to Khoksar and Jahlma on both the north- and south-facing slopes. Higher similarity (near about 50%) was observed for natural forest species of Hinsa and Kuthar on both slope aspects due to more or less similar environmental conditions as compared to Khoksar and Jahlma. Similarity between undisturbed and disturbed stands indicates changes in species richness owing to disturbances that alter the microenvironment [9,15].

6. Conclusions and Recommendations

This study reveals that the cold desert region has limited patches of vegetation that fulfil the socio-economic demand of the local populace in the area. The population density of the species is comparatively low and sparse in these areas due to xeric climatic conditions and anthropogenic pressure on the relict patches of natural forests. In the present study, the vegetation is sparsely distributed and significantly varied in species composition and structure along altitudinal gradients and slope aspects. Thus, the vegetation of the region is degrading due to high anthropogenic pressure on limited available forest resources and exhaustive land use changes. These patches of vegetation are subjected to deforestation and further fragmentation due to the overextraction of fuelwood, fodder, timer, leaf and medicinal plants, etc. The available relict forest patches need immediate conservation planning due to the increased dependency of local communities and global climate change. Hence, sustainable forest resource management is crucial for deriving ecosystem services and ecosystem function improvement in the cold desert environment. Furthermore, it will also support slope stabilisation, snow slides and soil erosion in the area. The strategy should be based on a broad socio-economic and ecological understanding of the region for climate change mitigation, adaptation, biodiversity conservation and environmental sustainability. The establishment of enclosures, coupled with mimicking courses of nature, can be realistic and viable options for successful plant regeneration and accelerated succession on degraded dry lands. Classifying the vegetation into management unit types is critical for management purposes, and reorganising the variability within and among community types is equally important. Thus, information on the composition and population density of the vegetation may be useful for conservation and management planning in the Lahaul valley in particular and the cold desert region in the Himalaya in general.

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