**Range Management and Agroforestry 46 (2) : 228-237, 2025**
ISSN 0971-2070 (Print); 2249-5231 (Online)
https://doi.org/10.59515/rma.2025.v46.i2.07

Research article

# Ethnobotanical significance, species richness and ecosystem services of vegetation along an altitudinal gradient in Tehri Garhwal region, India

**Arvind Bijalwan[1], Naveen Tariyal[1], Kalpana Bahuguna[1], Hitesh Gupta[1], Pratik Sanodiya[2*], Rajnish Pandey[3], Tara Singh Mehra[1] and Anil Kumar Rai[4]**

[1]Veer Chandra Singh Garhwali Uttarakhand University of Horticulture and Forestry, Ranichauri-249199, India
[2]Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221005, India
[3]Uttar Banga Krishi Vishwavidyalaya, Cooch Behar-736165, India
[4]College of Agriculture, Rani Laxmi Bai Central Agricultural University, Jhansi-284003, India
[*]Corresponding author email: prsanodiya10@gmail.com

Received: 27th February, 2025 Accepted: 24th November, 2025

## Abstract

The study examines variations in plant diversity across an altitudinal gradient of up to 2600 m above mean sea level (amsl) in Tehri Garhwal district of Uttarakhand, India. Using a survey questionnaire method, we analysed changes in tree diversity, habitat similarity, and the ecosystem services provided by documented vegetation. Local residents were interviewed to gather their perceptions of ecosystem services and the traditional uses of available plant species in their surroundings. This study documented a total of 235 plant species, identifying each by its altitude range and ethnobotanical significance. Among these species, 211 were found at an altitude range of below 1200 m amsl, while 199 and 95 species were recorded at 1200–1900 m amsl and 1900–2600 m amsl, respectively. The species were grouped under nine major ethnobotanical uses. More than one-third (38.3%) of species were classified as medicinally important and traditionally used by local inhabitants in hilly areas. Asteraceae and Fabaceae were the most prominent families, with 24 and 23 species, respectively. The most dominant genus was *Ficus*, represented by seven species. The Sorensen similarity index showed the highest similarity between lower and middle elevation communities, while the lowest similarity was between high and low elevations. Beyond their ethnobotanical uses, all documented tree species provided ecosystem services, such as 77 species offered provisioning services, 46 provided regulatory services, 20 contributed to cultural services, and 24 supported ecosystem processes. These findings highlight the critical role of vegetation in sustaining ecosystem services and the need for conservation strategies that integrate traditional knowledge.

**Keywords:** Ecosystem services, Ethnobotanical uses, Forest trees, Garhwal Himalaya, Traditional uses, Vegetation

## Introduction

The Indian Himalayan region holds a unique and significant position among the world's mountain ecosystems. The Himalaya's topographic and climatic complexity makes it an ideal natural laboratory for studying ecological mechanisms governing flora and fauna, as well as assessing the impact of climate change on the region's biodiversity (Bhatt *et al.*, 2020). The Himalayan region covers eleven mountainous states, including Uttarakhand, and two union territories. It is characterized by elevated snow peaks, glaciers, dense forest, and high-altitude alpine pasture lands and wetlands (Valdiya, 1998). Garhwal Himalaya is a Himalayan region located in the state of Uttarakhand, India. It covers seven districts- Tehri, Chamoli, Uttarkashi, Dehradun, Haridwar, Rudraprayag and Pauri of Uttarakhand. Forest is one of the most important and integrated parts of the land use pattern in the Garhwal Himalaya. According to the 2011 census, the Garhwal region occupies 5329 $km^2$ of the total geographical area of Uttarakhand (https://www.indiastatpublications.com/District_Factbook/Uttarakhand/Garhwal). The forest cover in Garhwal Himalaya is 14545.18 $km^2$, which constitutes about 45.44% of its total geographical area and 59.84% of the total forest cover of Uttarakhand (India State of Forest Report, 2021). This region forms a very fragile ecosystem with peculiar geography and climate supporting all the flora and fauna of this region. Rural livelihood is mainly dependent upon agriculture and livestock, and forests are not separate from agriculture in these regions.

The elevation and aspect are crucial regulating factors that govern the distribution of tree species in the forest ecosystem of western Himalaya (Rawat and Chandra,

2014; Das *et al.,* 2020). Apart from altitude and aspect temperature, solar radiation, precipitation, humidity, speed and direction of wind, cloud cover also influences species richness and presence. The distribution and preponderance of tree species in the Himalayan forests vary with the changing physiographic gradients (Kharkwal *et al.,* 2005; Sharma *et al.,* 2009). Besides being rich in plant biodiversity, the Himalayan flora has been used therapeutically for a long time. The plant parts collected from the wild have been used as traditional medicines by native communities. The locally available vegetation is identified and utilized commonly in the treatment of various ailments as a home remedy. Different tree species at different altitudes dominate Himalayan forests. Most of these are intimately linked with hill agriculture as they protect soil fertility, watershed, and local agro-biodiversity. They also play an important role in maintaining ecosystem stability (Singh *et al.,* 2016).

The flora of Tehri Garhwal can be classified into six division's *i.e.,* tropical dry deciduous forests; sal forests; chir forests; deodar, fir and spruce forests; oak forests and alpine pastures (Chaudhary *et al.,* 2019). Pure agriculture is seldom observed in the region, as the presence of trees on farmland is very common. The crops/grasses grow along with forest/horticulture trees together on the farmland. Besides being multipurpose in nature, the common trees of this region have immense ethnobotanical importance, due to which these tree species are retained by farmers on their farm land in farm forestry/agroforestry. Besides tree species, herbs, shrubs, and climbers have important ethnobotanical utilities to the farm communities of this region.

Agroforestry provides a wide range of benefits to dependent communities, collectively known as ecosystem services. These services play a critical role at the global level in carbon sequestration (Hicks *et al.,* 2014; Apps and Price, 2013) and in mitigating global warming (Arora *et al.,* 2012). At the watershed scale, forests offer various ecological services, including regulating the water cycle, conserving soil, and providing habitat for local flora and fauna. At the local level, forests directly support rural livelihoods through both direct (Bhatta *et al.,* 2015) and indirect benefits, encompassing cultural and supportive values (Cooper *et al.,* 2016). Trees in agroforestry also hold cultural and social significance, providing aesthetic, recreational, and spiritual value in various aspects. Furthermore, numerous studies have reported that forests and agroforestry systems in mountainous regions help regulate the hydrological cycle, prevent landslides, and maintain agro-biodiversity (Vineeta *et al.,* 2022). The main objectives of this study were: to document the most common vegetation and the similarity of species along an altitudinal gradient in the district Tehri Garhwal; to assess the ethno-medicinal and traditional uses of recorded vegetation; and to explore the ecosystem services provided by tree species as perceived by local communities along the altitudinal gradient based on the Millennium Ecosystem Assessment Report.

## *Materials and Methods*

***Study area*:** Tehri Garhwal district is located in the Garhwal Himalayan region of Uttarakhand, India (Fig. 1). The present study was conducted in three blocks-Narendra Nagar, Chamba, and Thauldhar of the district Tehri Garhwal during 2023, covering an altitudinal range of up to 2600 m above mean sea level (amsl). The altitude was categorized into three ranges: below 1200 m, 1200–1900 m and 1900–2600 m (including upper edges of the study villages).

***Phytosociological analysis and ethnobotanical use*:** To document the phytosociology and ethnobotanical uses of flora in the region, five villages were selected from each altitude range. In total, twenty-five respondents from each

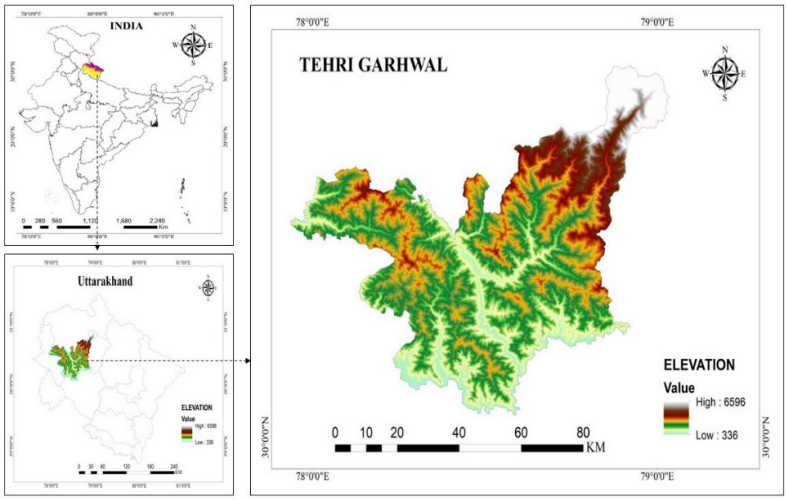


**Fig 1.** Map of the study area (Tehri Garhwal)

village were interviewed, primarily consisting of elderly individuals and those with traditional or ethnobotanical knowledge. To ensure authenticity, the collected information was cross-verified with available literature (Gaur, 1999). A total of 375 villagers from 15 villages (25 respondents from each village) were interviewed. Data on common plant species in Tehri Garhwal district, Uttarakhand, along with their ethnobotanical uses, were collected, compiled, and documented based on personal observations, questionnaires, interviews, and a review of existing literature.

***Sorensen similarity index*:** The Sorensen similarity index was calculated to assess the distribution of altitude and scale the similarity of species between selected altitudinal ranges within the study area. This index serves as a metric for the degree of overlap between two sets of populations. It was computed by comparing the proportion of shared species between the two populations to the total number of species present in both populations. The index ranges from zero, indicating no overlap, to one, signifying perfect overlap. This index (SI) measures the level of similarity in species within different habitats, employing the equation below based on Sørensen (1948).

$$SI = \frac{2D}{A+B+C}$$

Where A represents the count of species in elevation below 1200 m; B is the number of species in elevation 1200–1900 m; C denotes the number of species in elevation 1900–2600 m; D represents the count of species common in all elevations

***Assessment of ecosystem services*:** A significant advancement in the classification of ecosystem services was marked by the Millennium Ecosystem Assessment (MEA, 2005), which emphasized the intricate connection between human well-being and ecosystems. Ecosystem services provided by recorded tree species at three different altitudes in Tehri Garhwal district were documented through personal interviews with farmers from selected villages and local users. The interviews focused on understanding how these tree species are utilized. Based on their utilization value, the recorded tree species were broadly classified into four ecosystem service categories: provisioning, regulatory, supporting, and cultural services.

## Results and Discussion

***Diversity and species richness*:** Species richness data categorized into different elevation levels (lower, middle, and higher) and an overall total were recorded (Table 1). The richness is measured for different plant groups, *i.e.*, plants (total), trees, shrubs, herbs, and climbers, by using three parameters- species richness, family richness and genus richness. The highest species richness is recorded in the lower elevation zone for most plant categories and decreases progressively with increasing elevation. The overall plant species richness was (235) higher than at individual elevation levels. Altogether, there were 80 tree species represented by 28 families; 13 shrub species represented by 8 families; 129 herb species represented by 38 families and 13 climbers' species represented by 5 families (Table 1). The lower altitude class was documented with 211 plant species represented by 172 genera and 68 families. In comparison, the middle altitude class was represented by 199 species belonging to 156 genera and 67 families and in the higher altitude class, 95 species represented by 77 genera and 31 families were listed. The major plant form found in all the altitude classes was herb, followed by tree, shrub and climber. The data suggest that species richness decreases with increasing elevation, with low-elevation zones having the highest diversity across all plant categories. This pattern highlights the importance of lower elevation habitats for maintaining plant biodiversity.

Slobodkin and Sanders (1969) suggested that the species richness of a community depends on the severity, variability, and predictability of its environment. Consequently, diversity tends to rise as the environment becomes more hospitable and consistent (Putman, 1984). In the present study, the species richness for trees was highest at the middle elevation and showed a gradual decline towards the lower elevation, while lowest in the upper elevation. This might be due to the favourable environment of the study area at a middle altitude for increasing tree diversity as compared to the higher altitudes. Our study aligns with previous findings that emphasize the relationship between elevation and plant species richness in other parts of the Himalaya (Rawat et al., 2021; Rana *et al.*, 2019; Sharma *et al.*, 2019). Bhat *et al*. (2020) conducted a study in the Kedarnath Wildlife Sanctuary and reported that species richness, Shannon–Wiener diversity index, beta diversity and total biomass carbon declined sharply with increasing altitude. A significant negative relationship was observed between altitude and species richness ($r = -0.348$, $p < 0.01$, $n = 60$), indicating a gradual decline in species richness with increasing altitude in the Chamoli and Pithoragarh districts of Uttarakhand (Arya *et al*., 2017). Similarly, Shaheen *et al*. (2012) reported a negative correlation between species diversity and richness with the altitudinal gradient in the Bagh district of Pakistan. Moreover, Sharma *et al*. (2017) recorded a decline in tree diversity with increasing altitude across ridge-top ecosystems in Narendranagar–Hindolakhal, Mussoorie–Dhanolti, Chaurangikhal–Harunta and Dayara–Gidara.

***Ethnobotanical uses of plants*:** The species were grouped under nine major ethnobotanical uses (Table 2).

**Table 1.** Species, family and genera richness at different elevation levels

| Richness | Lower | Middle | Higher | Overall |
|---|---|---|---|---|
| Total plants | | | | |
| SR | 211 | 199 | 95 | 235 |
| FR | 68 | 67 | 31 | 71 |
| GR | 172 | 156 | 77 | 188 |
| Trees | | | | |
| SR | 62 | 70 | 36 | 80 |
| FR | 18 | 24 | 16 | 28 |
| GR | 48 | 52 | 31 | 61 |
| Shrub | | | | |
| SR | 12 | 10 | 5 | 13 |
| FR | 6 | 5 | 3 | 08 |
| GR | 9 | 7 | 3 | 10 |
| Herb | | | | |
| SR | 124 | 108 | 50 | 129 |
| FR | 37 | 32 | 9 | 38 |
| GR | 104 | 87 | 40 | 106 |
| Climber | | | | |
| SR | 13 | 11 | 4 | 13 |
| FR | 7 | 6 | 3 | 05 |
| GR | 11 | 10 | 3 | 11 |

SR: Species richness; FR: Family richness; GR: Genera richness

A total of 235 species were documented for various uses under three elevations (lower, middle and higher). Out of the 235 documented species, 38.3% were classified as medicinally important and traditionally used by local inhabitants in hilly areas to treat various ailments, including headaches, fever, dysentery, urinary disorders and skin diseases. Additionally, 35.7% of the species were classified as food/fruit sources, followed by 11.1% as recreational/aesthetic, 8.9% as fodder, 5.5% as tools and implements, 4.7% as timber, 4.3% as fuelwood and 3.8% as religious/cultural. The minimum percentage, 1.3%, of species fell under the fibre and flosses category. Kumar *et al*. (2011) reported similar findings, noting that among the 57 documented species, 33 were herbs, 14 were trees and 10 were shrubs. Their study indicated a high level of consensus among local inhabitants regarding the use of individual plant species, with the highest use value index recorded for medicinal purposes. Likewise, Pandey *et al*. (2024) documented results consistent with the present study, reporting that most identified species were herbs (36%), followed by trees (31%), shrubs (20%) and climbers (7%). They also observed that the majority of species were used for medicinal purposes (56%), followed by food and edible uses (25%), fuelwood (7%) and fodder (6%).

Asteraceae and Fabaceae were the most prominent families, with 24 and 23 species, respectively, while Ficus was the dominant genus, represented by seven species. At lower altitudes, Asteraceae was the principal family, comprising 21 species, whereas Ficus remained the most prominent genus with seven species. At middle altitudes, Asteraceae and Fabaceae were the most prominent families, represented by 19 and 18 species, respectively, while Ficus and Brassica were the dominant genera, with six and five species, respectively. At higher altitudes, Fabaceae and Asteraceae remained the dominant families, with seven and six species, respectively, while Brassica was the major genus, represented by four species. Overall, plant species richness declined significantly with increasing altitude. These findings align with the results of Sharma *et al*. (2014). This difference might be due to the variations in terms of growth forms, farmers' practices and utilization patterns. Asteraceae and Fabaceae were the most dominant families in the study area; these families have also been reported as being dominant in the Himalayan region (Dar and Khuroo, 2013; Ahmad *et al*., 2021). The dominance of families may be due to these plant families having larger ecological amplitudes and wide distributions, increasing the possibility of encountering the members of these families. A similar observation was also recorded by Mumshad *et al*. (2021). The dominance of herbaceous growth forms in the present study is in accordance with several other studies conducted in the Indian Himalayan Region (Samant *et al*., 2007; Malik *et al*., 2015; Sharma *et al*., 2019; Haq *et al*., 2023; Rawat *et al*., 2021). Dominance of herbaceous growth may be due to the fact that herbs are considered common growth forms in most mountainous regions owing to their ability to acclimate to an extensive range of ecological settings (Wani *et al*., 2023).

***Sorenson's similarity index*:** Overall, Sorenson's similarity index (Between lower, middle and higher elevations) indicated low species similarity (0.28) across the Tehri Garhwal district in the Garhwal Himalayan region of Uttarakhand. Additionally, only 73 species were common across the entire altitudinal gradient, including 46 herb species, 19 tree species, four climbers (*Cucurbita maxima, Cucurbita moschata, Cuscuta reflexa*, and *Tinospora cordifolia*), and three shrub species (*Eupatorium adenophorum*, *Rosa brunonii*, and *Rosa spp*.).

The similarity of the species decreased gradually with increasing altitude as 177 species were common between low and mid altitude class, while only 93 species were common between mid and high altitude class and 73 species were common between low and high altitude class. Additionally, the composition of vegetation across the altitude was compared using a similarity coefficient based on species richness (Fig 2). The varying degree of similarity among different altitudes is understandable, as the number of plant species varies from altitude to

**Table 2.** Ethnobotanical uses of common plants at different elevations of the study area

| Use category (species%) | Species used |
|---|---|
| Fodder (8.9%) | *Ilex dipyrena* (T, m, h), *Carpinus viminea* (T, l, m, h), *Celtis australis* (T, l, m, h), *Swida macrophylla* (T, m, h), *Cyperus niveus* (H, l), *Bauhinia retusa* (T, l, m), *Bauhinia variegata* (T, l, m), *Erythrina suberosa* (T, l), *Vicia tenera* (C, l, m), *Quercus floribunda* (T, m, h), *Quercus leucotrichophora* (T, l, m, h), *Quercus serrata* (T, m), *Machilus odoratissima* (T, m, h), *Grewia optiva* (T, l, m), *Melia azedarach* (T, l, m), *Toona ciliata* (T, l, m, h), *Ficus glomerata* (T, l, m), *Ficus nemoralis* (T, l, m), *Ficus semicordata* (T, l, m), *Morus alba* (T, l, m), *Morus serrata* (T, l, m, h) |
| Fuelwood (4.3%) | *Rhus parviflora* (T, l, m, h), *Ilex dipyrena* (T, m, h), *Alnus nepalensis* (T, l, m, h), *Betula alnoides* (T, l, m, h), *Cornus capitata* (T, m, h), *Lyonia ovalifolia* (T, m, h), *Mallotus philippensis* (T, l, m), *Quercus leucotrichophora* (T, l, m, h), *Phoebe lanceolata* (T, l, m), *Grewia optiva* (T, l, m) |
| Fibre/ floss (1.3%) | *Bombax ceiba* (T, l), *Grewia optiva* (T, l, m), *Symplocos chinensis* (T, m, h) |
| Timber (4.7%) | *Terminalia alata* (T, l, m), *Shorea robusta* (T, l), *Dalbergia sissoo* (T, l, m), *Quercus floribunda* (T, m, h), *Toona serrata* (T, l, m), *Eucalyptus globulus* (T, l, m), *Cedrus deodara* (T, m, h), *Pinus roxburghii* (T, l, m, ,h), *Pinus wallichiana* (T, m, h), *Populus ciliata* (T, l, m, h), *Holoptelea integrifolia* (T, l) |
| Medicinal (38.3%) | *Dicliptera bupleuroides* (H, l), *Achyranthes aspera* (H, l, m), *Achyranthes bidentate* (H, m), *Aerva sanguinolenta* (H, l), *Pistacia integerrima* (T, l, m), *Bupleurum hamiltonii* (H, l, m), *Centella asiatica* (H, l, m, h), *Catharanthus roseus* (H, l, m), *Asparagus racemosus* (H, l, m, h), *Ageratum conyzoides* (H, l), *Anaphalis adnata* (H, m, h), *Anaphalis busua* (H, m, h), *Artemisia capillaries* (H, l, m), *Blainvillea acmella* (H, l, m), *Calendula officinalis* (H, l, m), *Coreopsis lanceolata* (H, l, m), *Cosmos bipinnatus* (H, l, m), *Eclipta prostrata* (H, l, m), *Eupatorium adenophorum* (S, l, m, h), *Tagetes patula* (H, l, m), *Taraxacum officinale* (H, m, h), *Tridax procumbens* (H, l), *Alnus nepalensis* (T, l, m, h), *Rorippa indica* (H, l, m, h), *Buxus wallichiana* (T, m, h), *Drymaria cordata* (H, l, m), *Stellaria media* (H, l, m), *Ipomoea nil* (C, l, m), *Convolvulus arvensis* (C, l), *Cuscuta reflexa* (C, l, m, h), *Terminalia bellirica* (T, l, m), *Terminalia chebula* (T, l, m), *Commelina benghalensis* (H, l, m), *Sedum multicaule* (H, l, m), *Lyonia ovalifolia* (T, m, h), *Rhododendron arboretum* (T, m, h), *Euphorbia hirta* (H, l), *Euphorbia prostrate* (H, l), *Ricinus communis* (S, l), *Acacia catechu* (T, l, m), *Cassia fistula* (T, l, m), *Trifolium repens* (H, l, m, h), *Melilotus indica* (H, l), *Geranium wallichianum* (H, l, m, h), *Leucas lanata* (H, l, m), *Micromeria biflora* (H, l, m), *Nepeta ciliaris* (H, l, m), *Ocimum basilicum* (H, l, m, h), *Origanum vulgare* (H, l, m, h), *Cinnamomum camphora* (T, l, m), *Litsea glutinosa* (T, l, m), *Woodfordia fruticosa* (S, l, m), *Malva parviflora* (H, l, m), *Malvastrum coromandelianum* (H, l), *Sida rhombifolia* (H, l), *Azadirachta indica* (T, l), *Heynea trijuga* (T, l, m), *Tinospora cordifolia* (C, l, m, h), *Boerhavia diffusa* (H, l, m), *Olea glandulifera* (T, l), *Oxalis corniculata* (H, l, m), *Phytolacca acinosa* (H, l, m), *Phyllanthus emblica* (T, l, m), *Plantago major* (H, l, m), *Bistorta amplexicaulis* (S, h), *Portulaca oleracea* (H, l, m), *Delphinium denudatum* (H, l, m, h), *Ranunculus sceleratus* (H, l, m), *Thalictrum foliolosum* (H, l, m), *Duchesnea indica* (H, l, m), *Fragaria nubicola* (H, l, m, h), *Potentila gerardiana* (H, m, h), *Rosa brunonii* (S, l, m, h), *Rosa spp.* (S, l, m, h), *Galium acutum* (H, l, m), *Rubia manjith* (C, l, m), *Boenninghausenia albiflora* (H, l, m), *Acer caesium* (T, m, h), *Bergenia ligulata* (H, l, m, h), *Nicotiana plumbaginifolia* (H, l), *Physalis peruviana* (H, l, m), *Solanum anguivi*, (S, l), *Solanum nigrum* (H, l, m, h), *Solanum surattense* (H, l, m), *Ulmus wallichiana* (T, l, m), *Valeriana jatamansii* (H, l, m, h), *Vitex negundo* (S, l, m), *Viola biflora* (H, l, m), *Curcuma longa* (H, l, m, h), *Zingiber officinale* (H, l, m) |
| Food/ fruit (35.7%) | *Amaranthus caudatus* (H, l, m), *Amaranthus cruentus* (H, l, m), *Amaranthus hypochondriacus* (H, l, m, h), *Amaranthus viridis* (H, l, m, h), *Beta vulgaris* (H, l, m), *Spinacia oleracea* (H, l, m, h), *Allium cepa* (H, l, m, h), *Allium sativum* (H, l, m, h), *Coriandrum sativum* (H, l, m, h), *Daucus carota* (H, l, m, h), *Colocasia ascelenthas* (H, l, m, h), *Colocasia esculenta* (H, l, m, h), *Helianthus annus*, (H, l, m, h), *Senecio nudicaulis* (H, l), *Brassica campestris* (H, l, m), *Brassica juncea* (H, l, m, h), *Brassica oleracea* var. Botrytis (H, l, m, h), *Brassica oleracea* var. Capitates (H, l, m, h), *Brassica rapa* var. Rapa (H, l, m, h), *Raphanus sativus* (H, l, m, h), *Cleome viscose* (H, l, m), *Celtis australis* (T, l, m, h), *Cornus capitata* (T, m, h), *Cucurbita maxima* (C, l, m, h), *Cucurbita moschata* (C, l, m, h), *Lagenaria siceraria* (C, l, m), *Luffa cylindrical* (C, l, m), *Momordica dioica* (C, l, m), *Tricosanthes anguina* (C, l, m), *Bauhinia retusa* (T, l, m), *Bauhinia variegate* (T, l, m), *Cajanus cajan* (H, l, m, h), *Cicer arietinum* (H, l), *Glycine max* (H, l, m, h), *Indigofera heterantha* (S, l, m), *Lablab purpureus* (H, l), *Lens culinaris* (H, l, m, h), *Macrotyloma uniflorum* (H, l, m), *Phaseolus vulgaris* (H, l, m, h), *Pisum sativum* (H, l, m, h), *Trigonella foenumgraecum* (H, l, m, h), *Vigna mungo* (H, l, m), *Vigna umbellate* (H, l, m), *Vigna unguiculata* (H, l), *Cinnamomum tamala* (T, l, m), *Cinnamomum zeylanicum* (T, l, m), *Abelmoschus esculentus* (H, l, m), *Triumfetta rhomboidea* (S, l, m), *Ficus auriculata* (T, l, m), *Ficus glomerata* (T, l, m), *Ficus palmata* (T, l, m, h), *Myrica esculenta* (T, m, h), *Oxalis dehradunensis* (H, l), *Seasmum indicum* (H, l, m), *Echinochloa frumentacea* (H, l, m, h), *Eleusine coracana* (H, l, m, h), *Hordeum vulgare* (H, l, m, h), *Oryza sativa* (H, l, m), *Triticum aestivum* (H, l, m, h), *Zea mays* (H, l, m, h), *Polygonum plebeium* (H, l), *Rubus ellipticus* (S, l, m, h), *Rubus niveus* (S, l, m, h), *Rubia cordifolia* (C, l, m), *Aesculus indica* (T, l, m, h), *Capsicum annuum* (H, l, m, h), *Capsicum frutescens* (H, l, m, h), *Lycopersicon esculentum* (H, l, m, h), *Solanum melongena* (H, l, m), *Solanum tuberosum* (H, l, m, h), *Curcuma longa* (H, l, m, h), *Zingiber officinale* (H, l, m), *Malus domestica* (T, m, h), *Mangifera indica* (T, l) |

| | |
|---|---|
| Religious/ cultural (3.8%) | *Betula alnoides* (T, l, m, h), *Reinwardtia indica* (H, l, m), *Ficus benghalensis* (T, l), *Ficus religiosa* (T, l, m), *Abies pindrow* (T, m, h), *Prunus cerasoides* (T, l, m, h), *Zanthoxylum armatum* (T, l, m, h), *Sapindus mukorossi* (T, l), *Datura metel* (S, l) |
| Tools and implements (5.5%) | *Lannea coromandelica* (T, l, m), *Carpinus viminea* (T, l, m, h), *Terminalia alata* (T, l, m), *Cornus capitata* (T, m, h), *Mallotus philippensis* (T, l, m), *Ougeinia oojeinensis* (T, l, m), *Quercus leucotrichophora* (T, l, m, h), *Fraxinus micrantha* (T, h), *Pyrus pashia* (T, l, m, h), *Salix alba* (T, l, m), *Acer oblongum* (T, l, m, h), *Boehmeria platyphylla* (T, l, m, h), *Boehmeria rugulosa* (T, l, m) |
| Recreational/ aesthetic (11.1%) | *Callistephus chinensis* (H, l), *Dahlia variabilis* (H, l, m), *Dendranthema grandiflora* (H, l, m), *Gaillardia pulchella* (H, l, m), *Gazania rigens* (H, l), *Gerbera gossypina* (H, l, m), *Tagetes erecta* (H, l, m, h), *Tagetes minuta* (H, l, m, h), *Zinnia elegans* (H, l, m), *Jacaranda mimosifolia* (T, l, m), *Dianthus barbatus* (H, l, m), *Dianthus caryophyllus* (H, m, h), *Rosularia adenotricha* (H, l, m), *Cupressus torulosa* (T, m, h), *Sapium insigne* (T, l, m), *Hydrangea spp.* (H, l, m, h), *Gladiolus gandavensis* (H, l, m), *Salvia lanata* (H, l, m), *Althaea rosea* (H, l), *Hibiscus rosa sinensis* (S, l, m), *Callistemon viminalis* (T, l, m, h), *Antirrhinum majus* (H, l), *Grevillea robusta* (T, l, m), *Acer pictum* (T, m, h), *Tropaeolum majus* (H, l, m), *Viola tricolor* (H, l, m) |

Letters in parentheses following species names indicate life form (H=Herb, S=Shrub, T=Tree and C=Climber) and elevational distribution (l = lower, m = middle, h = higher)

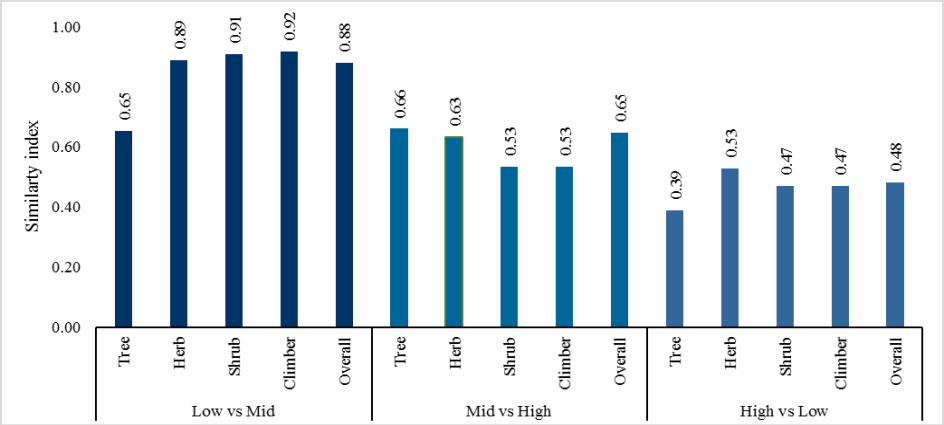


**Fig 2.** Sorenson's similarity index of vegetation across the elevation gradients

altitude. The highest similarity in plant composition was recorded between low and mid-altitudes, with climbers showing the highest similarity (0.92), followed by shrubs (0.91) and herbs (0.89). Trees exhibited moderate similarity (0.65), while the overall similarity index was 0.88, indicating a significant resemblance in vegetation composition between the low- and mid-altitude zones. Between the mid and high altitude zones, similarity indices were 0.66 for trees, 0.63 for herbs, and 0.53 for shrubs and climbers, with an overall similarity index of 0.65. The lowest similarity indices were recorded between the high and low altitude zones, indicating the greatest variation in vegetation composition. Similarity indices were 0.39 for trees, 0.53 for herbs, and 0.47 for both shrubs and climbers, with an overall similarity index of 0.48 (Fig 2).

It is also observed that 178 species were common in lower and mid altitude, which might be due to a large habitat range and suitability for growth. It is a well-established fact that the species similarity index is influenced by various local factors, including climate, slope, temperature, solar radiation, and soil (Lomolino, 2001). The highest similarity occurs between lower and middle elevations, while the lowest similarity is observed between higher and lower elevations. Trees exhibit the greatest variation across elevations, whereas climbers and shrubs show higher similarity at lower elevation ranges. This pattern suggests that elevation has a strong influence on vegetation composition, with significant shifts occurring as elevation increases, likely due to differences in climate, soil, and ecological conditions. Many researchers in the Himalayan region have studied the connection of elevation and similarity indices (Ahmad *et al.*, 2021; Wani *et al.*, 2023; Rana *et al.*, 2020). These studies have revealed that species habitat overlaps at various elevations due to the environmental conditions required for growing in a region. The plant species similarity decreased with increasing altitude due to environmental filtering and the dominance of plant species tolerant of extreme environmental conditions at higher altitudes (Rana *et al.*, 2020). The middle and lower elevation categories expressed more species similarity. A similar result was also reported by Birhane *et al.* (2020), revealing that similarity and dissimilarity in species

habitat between different elevations could be due to habitat requirements of species, site characteristics, farmers' preferences for tree species, management approach and socioeconomic pattern. Das *et al.* (2017) also found similar observations and stated that there was very less similarity in plant composition between low elevation and higher elevation. Similarity in the species might be observed due to similar microclimatic situations even with the varying elevation.

***Ecosystem services*:** The documented tree species were also classified based on their ecosystem services, i.e., provisional, regulatory, supportive, and cultural service (Fig 3). In the Tehri Garhwal district of Uttarakhand, 77 species were classified as providing provisional services, 46 as regulatory, 20 as cultural, and 24 as supporting services. The respondents and local users opined that the trees play a vital role in their livelihood. Communities residing near forests depend most of the time on local flora for the fulfilment of daily needs and non-timber forest products (NTFPs), folk medicine, and cultural uses.

The results of this study clearly demonstrate that trees on farm bunds and in adjoining forests provide a greater variety and higher value of ecosystem services and goods (Provisioning services) compared to sole agricultural croplands for rural communities in the Western Himalayan region. Farmers typically retain trees, shrubs, and herbs on agricultural fields, often scattered across infields, to meet their daily needs and livelihood goals. These include income generation, risk minimization, food security and the efficient use of farmland, available labour, and capital as key resources (Chittapur and Patil, 2017). In the study area, the trend of the services was consistent with the results of Vineeta *et al*. (2022). The dominance of provisioning services may be attributed to the local population deriving more direct benefits from plants compared to supporting and cultural services. This is due to the fact that the tangible nature of provisioning services can diminish the value of regulatory services, as people often view provisions like food and medicine as more beneficial than other services (Caballero-Serrano *et al.*, 2016). Similar findings were recorded in previous studies, highlighting that local communities highly value agroforestry trees for their provisioning services. These include nutrient-rich green fodder, especially during lean periods for livestock, high-calorific-value fuelwood and nutrient-rich litter used as a natural fertilizer to maintain soil fertility. Additionally, farmers utilize stem wood for agricultural implements and collect minor forest products for various uses (Vineeta *et al*., 2022). Agroforestry vegetation plays a crucial role in regulatory and supporting services by protecting and conserving soil, regulating and filtering water, facilitating rainwater infiltration and reducing the velocity of running streams. These findings align with the findings of Joshi and Negi (2011). One of the most significant intangible ecosystem services provided by agroecosystems is carbon sequestration (Ranjan, 2021). Rao and Saha (2014) emphasized that agroecosystems are vital to the global carbon cycle, storing approximately 12% of Earth's terrestrial carbon. The total terrestrial carbon stored in plants and soil is estimated to be around 2,000 ± 500 petagrams, accounting for 25% of the world's carbon stocks. Trees also provide important indirect

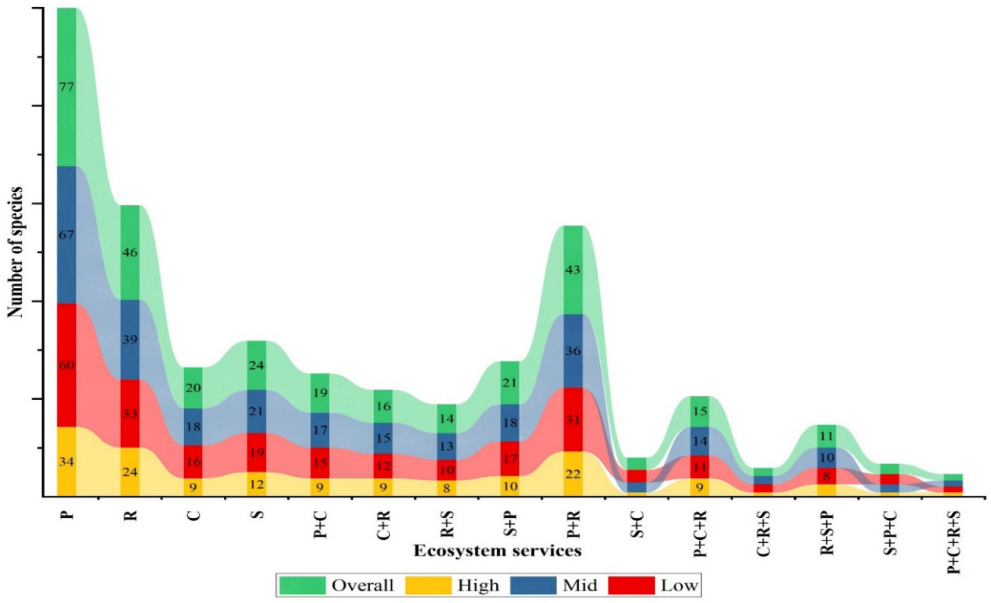


**Fig 3.** Ribbon diagram showing the ecosystem services of overall documented plant species [P: Provisional; C: Cultural; R: Regulatory; S: Supportive]

services. Their canopies can lower soil temperatures by 5.85°C and air temperatures by approximately 1.33°C, offering shade for both livestock and farmers during agricultural activities. Additionally, trees contribute to habitat creation, soil quality improvement and soil moisture conservation (Dhanya *et al*., 2014). The present study documented the traditional uses of various plant species by local practitioners, which can contribute to future technological advancements, economic prosperity and new opportunities for local communities. Indigenous knowledge of ecosystem services emerges from a deep interconnection between environmental understanding and cultural practices. This knowledge is transmitted orally, guided by cultural principles and regulations that stress secrecy and sacredness, which in turn shape how it is preserved and practiced (Tripathi *et al*., 2019).

## Conclusion

The altitudinal gradient significantly influenced the species richness. The species richness decreased with increasing elevation, and lower elevation zones had the highest diversity across all plant categories. Middle altitude comprises more species richness as compared to upper elevation, while the maximum similarity index was recorded between lower and mid altitudes. The highest similarity is observed between lower and middle elevations, while the lowest occurs between higher and lower elevations. Trees exhibit the greatest variation across elevations, whereas climbers and shrubs show higher similarity at lower elevation ranges. Additionally, these systems provide a wide range of ecosystem services. All species have some ecosystem importance, and most of the tree species come under the provisioning service, followed by regulatory and cultural services. These properties make these trees more valuable besides their economic, ecological and social importance. This scientific channelization will also contribute to the economic valuation of wild floral diversity, which in turn will boost socioeconomic development and ecosystem services maintenance. Thus, the findings of this study highlight the crucial role of traditional agroforestry systems in sustaining plant diversity and ecosystem stability

## References


Ahmad, M., P. Sharma, S. Rathee, H.P. Singh, D.R. Batish, G.R. Lone, S. Kaur, V. Jaryan and R.K. Kohli. 2021. Niche width analyses facilitate identification of high-risk endemic species at high altitudes in western Himalayas. *Ecological Indicators* 126: 107653.

Apps, M.J. and D.T. Price. 2013. *Forest Ecosystems, Forest Management and the Global Carbon Cycle*. Springer Science and Business Media. Vol. 40.

Arora, S., R. Trivedi and G.G. Rao. 2012. Bioremediation of coastal and inland salt affected soils using halophilic soil microbes. *Salinity News* 18: 3.

Arya, V., B. Kumar and J.S. Rawat. 2017. Tree species diversity, community composition and distribution across six forest stands of Uttarakhand, Central Himalaya, India. *Indian Journal of Ecology* 44: 722e728.

Bhat, J.A., M. Kumar, A. K. Negi, N.P. Todaria, Z.A. Malik, N.A. Pala, A. Kumar and G. Shukla. 2020. Species diversity of woody vegetation along altitudinal gradient of the Western Himalayas. *Global Ecology and Conservation* 24: e01302.

Bhatt, D., K. Chandra Sekar and K. Kumar. 2020. *Tree Diversity of Indian Himalayan Region*, G.B. Pant National Institute of Himalayan Environment, Almora, Uttarakhand, India.

Bhatta, L.D., B.E.H. van Oort, N.E. Stork and H. Baral. 2015. Ecosystem services and livelihoods in a changing climate: understanding local adaptations in the upper Koshi, Nepal. *International Journal of Biodiversity Science, Ecosystem Services and Management* 11: 145-155.

Birhane, E., S. Ahmed, M. Hailemariam, M. Negash, M.M. Rannestad and L. Norgrove. 2020. Carbon stock and woody species diversity in homegarden agroforestry along an elevation gradient in southern Ethiopia. *Agroforestry Systems* 94: 1099-1110.

Caballero-Serrano, V., M. Onaindia, J.G. Alday, D. Caballero, J.C. Carrasco and B. McLaren. 2016. Plant diversity and ecosystem services in amazonian homegardens of Ecuador. *Agriculture, Ecosystems and Environment* 225:116-125.

Chaudhary, S., A. Kumar and M. Negi. 2019. A geospatial appraisal of Garhwal Himalayan bio-geodiversity and its ecotourism potentials. *International Journal of Research and Analytical Reviews* 6: 911-926.

Chittapur, B.M. and D.K. Patil. 2017. Ecosystem services rendered by tree based land use systems. *The Indian Journal of Agricultural Sciences* 87: 1419-1429.

Cooper, N., E. Brady, H. Steen and R. Bryce. 2016. Aesthetic and spiritual values of ecosystems: Recognising the ontological and axiological plurality of cultural ecosystem 'services'. *Ecosystem Services* 21: 218-229.

DAR, G. and A. Khuroo. 2013. Floristic diversity in the Kashmir Himalaya: progress, problems and prospects. *Sains Malaysiana* 42: 1377-1386.

Das, A.K., L.B. Singha and M.L. Khan. 2017. Community structure and species diversity of *Pinus merkusii* Jungh. & de Vriese forest along an altitudinal gradient in eastern Himalaya, Arunachal Pradesh, India. *Tropical Ecology* 58: 397-408.

Das, D.S., D.S. Rawat and D. Maity. 2020. Species richness patterns of different life-forms along altitudinal gradients in the great Himalayan National Park, Western Himalaya, India. *Taiwania* 65: 154-162.

Dhanya, B., B.N. Sathish, S. Viswanath and S. Purushothaman. 2014. Ecosystem services of native trees: experiences from two traditional agroforestry systems in Karnataka, southern India. *International*

*Journal of Biodiversity Science, Ecosystem Services and Management* 10: 101-111.

Gaur, R.D. 1999. *Flora of the District Garhwal, North West Himalaya*. Transmedia. https://www.indiastatpublications.com/District_Factbook/Uttarakhand/Garhwal

Haq, S.M., A.A. Khoja, F.A. Lone, M. Waheed, R.W. Bussmann, E.A. Mahmoud and H.O. Elansary. 2023. Floristic composition, life history traits and phytogeographic distribution of forest vegetation in the western Himalaya. *Frontiers in Forests and Global Change* 6: 1169085.

Hicks, C., S. Woroniecki, M. Fancourt, M. Bieri, H. Garcia Robles, K. Trumper and R. Mant. 2014. The relationship between biodiversity, carbon storage and the provision of other ecosystem services: critical review for the forestry component of the international climate fund. United Nations Environment Programme, Cambridge.

India State of Forest Report (ISFR). 2021. Forest Survey of India, Dehradun. https://fsi.nic.in

Joshi, G. and G.C. Negi. 2011. Quantification and valuation of forest ecosystem services in the western Himalayan region of India. *International Journal of Biodiversity Science, Ecosystem Services and Management* 7: 2-11.

Kharkwal, G., P. Mehrotra, Y.S. Rawat and Y.P.S. Pangtey. 2005. Phytodiversity and growth forms in relation to altitudinal gradient in central Himalaya (Kumaon) region of India. *Current Science* 89: 873-878.

Kumar, M., M.A. Sheikh and R.W. Bussmann. 2011. Ethnomedicinal and ecological status of plants in Garhwal Himalaya, India. *Journal of Ethnobiology and Ethnomedicine* 7: 32.

Lomolino, M.V. 2001. Elevation gradients of species density: historical and prospective views. *Global Ecology and Biogeography* 10: 3-13.

Malik, A.H., I. Rashid, A.H. Ganie, A.A. Khuroo and G.H. Dar. 2015. Benefitting from geoinformatics: estimating floristic diversity of Warwan valley in north-western Himalaya, India. *Journal of Mountain Science* 12: 854-863.

MEA (Millennium Ecosystem Assessment). 2005. *Ecosystems and Human Well-being.* Vol. 5. Island Press, Washington, DC. pp. 1-563.

Mumshad, M., I. Ahmad, S.M. Khan, Abdullah, K. Rehman, M. Islam, S. Sakhi, S.U. Khan, S.G. Afridi, S. Shams and S. Azam. 2021. Phyto-ecological studies and distribution pattern of plant species and communities of Dhirkot, Azad Jammu and Kashmir, Pakistan. *Plos One* 16: e0257493.

Pandey, M., S.P. Joshi and S.A. Sharma. 2024. Total importance value of medicinal plants in Jaunpur Range, Garhwal Himalaya, Uttarakhand. *Annals of Plant and Soil Research* 26(2): 311-316.

Putman, R.J. 1984. Practical exercises for community ecology at Advanced Level. *Journal of Biological Education* 18: 229-238.

Rana, D., K.S. Kapoor, S.S. Samant and A. Bhatt. 2020. Plant species conservation priority index for preparing management strategies: a case study from western Himalayas of India. *Small- Scale Forestry* 19(4): 461-481.

Rana, S.K., K. Gross and T.D. Price. 2019. Drivers of elevational richness peaks, evaluated for trees in the east Himalaya. *Ecology* 100: e02548.

Ranjan, R. 2021. Payments for ecosystems services-based agroforestry and groundwater nitrate remediation: the case of *Populus deltoides* in Uttar Pradesh, India. *Journal of Cleaner Production* 287: 125059.

Rao, A.S. and R. Saha. 2014. Agroforestry for soil quality maintenance, climate change mitigation and ecosystem services. *Indian Farming* 63(11): 26-29.

Rawat, D.S., A.S. Bagri, M. Parveen, M. Nautiyal, P. Tiwari and J.K. Tiwari. 2021. Pattern of species richness and floristic spectrum along the elevation gradient: a case study from western Himalaya, India. *Acta Ecologica Sinica* 41: 545-551.

Rawat, V.S. and J. Chandra. 2014. Vegetational diversity analysis across different habitats in Garhwal Himalaya. *Journal of Botany* 2014: 538242.

Samant, S. Pant, M. Singh, M. Lal, A. Singh, A. Sharma and S. Bhandari. 2007. Medicinal plants in Himachal Pradesh, north western Himalaya, India. *The International Journal of Biodiversity Science and Management* 3: 234-251.

Shaheen, H., S.M. Khan and D.M. Harper. 2012. Species diversity, community structure and distribution patterns in western Himalayan alpine pasture of Kashmir, Pakistan. *Mountain Research and Development* 31: 153-159.

Sharma, C.M., A.K. Mishra, O.P. Tiwari, R. Krishan and Y.S. Rana. 2017. Effect of altitudinal gradients on forest structure and composition on ridge tops in Garhwal Himalaya. *Energy, Ecology and Environment* 2: 404-417.

Sharma, C.M., N.P. Baduni, S. Gairola, S.K. Ghildiyal and S. Suyal. 2009. Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *Forest Ecology and Management* 260: 2170-2179.

Sharma, N., M.D. Behera, A.P. Das and R.M. Panda. 2019. Plant richness pattern in an elevation gradient in the eastern Himalaya. *Biodiversity and Conservation* 28: 2085-2104.

Sharma, P., J.C. Rana, U. Devi, S.S. Randhawa and R. Kumar. 2014. Floristic diversity and distribution pattern of plant communities along altitudinal gradient in Sangla Valley, Northwest Himalaya. *The Scientific World Journal* 2014: 1-11.

Singh, S., Z.A. Malik and C.M. Sharma. 2016. Tree species richness, diversity, and regeneration status in different oak (*Quercus spp.*) dominated forests

of Garhwal Himalaya, India. *Journal of Asia-Pacific Biodiversity* 9: 293-300.

Slobodkin, L.B. and H.L. Sanders. 1969. On the contribution of environmental predictability to species diversity. *Brookhaven Symposium in Biology* 22: 82-95.

Sorenson, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content, and its application to analysis of vegetation on Danish commons. *Kong Dan Vidensk Selsk Biol Skr* 5: 1-5.

Tripathi, R., K.C. Moharana, A. Nayak, B. Dhal, M. Shahid, B. Mondal, S. Mohapatra, P. Bhattacharyya, N. Fitton, P. Smith and A. K. Shukla. 2019. Ecosystem services in different agro-climatic zones in eastern India: impact of land use and land cover change. *Environmental Monitoring and Assessment* 191: 1-16.

Valdiya, K.S. 1998. Dynamic Himalaya. London: Sangam Books, by arrangement with Universities Press (India) Ltd, for the Jawahariaa Nehru Centre for Advanced Scientific Research. *Geological Magazine* 138: 219-232.

Vineeta, B.C. Sarkar, M. Tamang, G. Shukla, M.K. Debnath, A.J. Nath and S. Chakravarty. 2022. Floristic diversity, and conservation status of large cardamom based traditional agroforestry system along an altitudinal gradient in the Darjeeling Himalaya, India. *Agroforestry Systems* 96: 1199-1210.

Wani, Z.A., V.S. Negi, J.A. Bhat, K.V. Satish, A. Kumar, S. Khan, R. Dhyani, S. Siddiqui, R. N. Al-Qthanin and S. Pant. 2023. Elevation, aspect and habitat heterogeneity determine plant diversity and compositional patterns in the Kashmir Himalaya. *Frontiers in Forests and Global Change* 6: 1019277.