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Stand Structure, Species Richness, and Diversity of Community Forests with Reference to the Soil Characteristics in Western Himalaya, India

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Abstract: The present study examines the vegetation structure, density, basal area, species richness, diversity, and soil parameters of community forests in the Almora district of Uttarakhand, located in the Western Himalayas. Each community forest was divided into three sub-sites to achieve concrete, real-time vegetation data. Vegetation data for different parameters were collected using 30 quadrats in each sub-site of each community forest. Soil samples were taken from a depth of 0-30 cm at each site using a soil corer. Tree density, basal area, diversity, and richness of these forests varied significantly, ranging from 373.3 to 1200.0 ind. ha^{-1}, 25.0 to 31.9 m^2 ha^{-1}, 0.1 to 2.5, and 0.2 to 1.4, respectively. Shrub density, basal area, diversity, and richness of these forests varied significantly, ranging from 1026.7 to 3789.7 ind. ha^{-1}, 0.1 to 0.4 m^2 ha^{-1}, 0.4 to 1.3, and 0.33 to 1.0, respectively. Herb density, diversity, and richness of these forests varied significantly, varying from 9.2 to 14.6 ind. m^2, 0.3 to 2.5, and 0.15 to 3.3, respectively. The Important Value Index (IVI) of dominant tree species in community forests ranged from 119.5 (*Quercus leucotrichophora)* to 289.64 (*Pinus roxburghii*). Forests are facing significant depletion of natural resources due to unsustainable resource extraction, inadequate management, and increasing impacts of climate change. The study suggests implementing an integrated approach to conservation and management for the biodiversity conservation and sustainable development of the western Himalayan forests in the country.

Keywords*:* Species composition, Species diversity, Soil characteristics, Community Forest, Western Himalaya

Forest species composition and diversity are essential indicators of the stability and sustainability of forest communities. The assessment of these parameters plays a crucial role in planning the conservation and management of forest ecosystems (Ahmad et al., 2020). To understand the negative and positive impacts of each factor on vegetation, effective conservation and management measures must be implemented to mitigate these effects. Additionally, new policies must be adopted to enhance the sustainability of Himalayan forests. Himalayan forests provide diverse ecological services to hill communities in various ways, yet these services gradually lose their sustainability over time (Naidu and Kumar 2016, Dhyani and Dhyani 2016, Manral et al., 2018, Negi et al., 2018, Joshi et al., 2023) stated that the high community dependence on forest resources has increased the vulnerability of forests with respect to human interference. Assessing species composition, diversity, and structure has been a significant focus of ecological studies (Bhat et al., 2020). The forest area of Uttarakhand accounted for 71.05% (38,000 sq km) of the state's total geographical area (FSI 2023). Of this, 20% of the forest area has been managed by village communities. Approximately 12,089 community forests exist in Uttarakhand, with 2,199 located in the Almora district (Nagahama et al., 2016). All these community forests in the Himalayan state of Uttarakhand have played a vital role in the development of village communities by providing domestic livelihood needs and income, as well as supporting the farm activities of small landholders. Apart from these, community forests are also considered and have been utilized to mitigate the recent problems caused by human disturbances and climate change. However, the growing diversity of impacts on these community forests means that the existing conditions have not been able to meet the increasing livelihood needs of villagers in the coming years; therefore, they need adequate support to recover and manage them sustainably. Himalayan forests not only conserve local biodiversity and stabilize the climate but also play a vital role in preserving global biodiversity and the carbon cycle. The primary objective of this study is to examine the vegetation structure, density, basal area, species richness, diversity, and soil parameters of community forests in the Almora district of the Western Himalayas.

MATERIAL AND METHODS

Description of the study area*:* This study was conducted in the community forests of the western Himalayas in the state of Uttarakhand, India. These community forests are dominated by oak forest (Gairar-barati-bhainar Community Forest, GCF site-1), pine forest (Soangaon Community Forest, SCF site-2), and oak-pine forest (Bhatkot Community Forest, BCF site-3). These forests are in the Almora district, at altitudes ranging from 981 to 2149 meters, and are situated at 29.8150°N and 79.2902°E. The following map indicates the location of the community forest sites (Table 1, Fig. 1).

Meteorological information: The annual average rainfall of the study area was 1180.3 mm. The maximum and minimum rainfalls were 342.4 mm in September and 0.32 mm in March 2022, respectively. The highest temperature was 33.23 °C in June 2022, while the lowest was -3.45°C in February 2022. The annual relative humidity was 63.56%. The relative humidity was highest in September (85.75%) and August (85.19%), whereas the lowest was 30.25% in April. This meteorological data, i.e., rainfall, temperature, and relative humidity, reflects the yearly climatic changes in the study area (https://power.larc.nasa.gov, 2022) (Fig. 2).

Vegetation analysis: Species composition, density, basal area, diversity, richness and importance value index (IVI), as well as provenance value (PV) of community forests, were determined using the quadrat method (Misra 1968, Saxena and Singh 1982). Each community forest was divided into three sub-sites to enable accurate assessment during data collection. Each sub-site contained 30 random quadrats for assessing trees, shrubs, and herbs. Quadrat sizes of 10 × 10 m for trees, 5 × 5 m for shrubs, and 1 × 1 m for herbs were used. The girth of the trees was measured at a height of 1.37 m. Species diversity, evenness, and richness of community forests were assessed using the Shannon diversity index (Shannon and Wiener, 1963), Pielou's evenness index (Pielou 1966), and Margalef's richness index (Margalef 1958), respectively. 'Forest Flora of Kumaon' (Osmaston 1927) was used to identify forest species. To confirm the accepted binomial name of plants, the Royal Botanical Gardens Kew, Plants of the World online site was utilized (https://powo.science.kew.org, 2023)

Soil analysis: Soil samples were collected at a depth of 0-30 cm using a soil corer during the summer of 2022. A total of 81 samples were collected randomly from each forest site. A composite mixture was prepared for soil testing. The soil samples were analysed for soil moisture content (Jackson 1973, Misra 1968), water holding capacity (Piper 1950), soil texture (Misra 1968), bulk density ((Misra 1968), soil pH, soil porosity (Kumar 2000), soluble salts (EC) content, organic matter content Misra, 1968), available nitrogen alkaline $KMnO_4$ method (Subbiah and Asija 1956), available phosphorus (Jackson 1973) and available potassium (Jackson 1973).

Statistical analysis: MS Excel was used to create graphs and tables, while RStudio was employed for statistical analysis. Indicator species analysis was done to identify specific species significantly associated, PCA was applied to determine relationships between vegetation and soil parameters, and a Venn diagram was prepared to analyse the beta diversity of plants across the community forest. The map of the study area was prepared using QGIS software.

RESULTS AND DISCUSSION

A total of 67 plant species from 35 families were recorded in the studied community forest. Trees, shrubs, and herbs comprise 14.9%, 22.4%, and 62.7% of the total, respectively. Among these species, the distribution of various plant groups was as follows: Angiosperms (95.5%) (dicotyledons 76.1% and monocots 19.4%) > Ferns (3%) > Gymnosperms (1.5%) (Table 2). The results were similar to those of previous studies on Indian and Central Himalayan forests (Khera et al., 2001, Mandal et al., 2014, Haq et al., 2024). A Venn diagram was utilized to understand the biodiversity distribution of plants in forests at the beta level (Fig. 3). For a

Table 1. Geographical features of community forests in the Almora district of the Western Himalaya

Parameter	Name of the community forest site		
	Oak forest (GCF site-1)	Pine forest (SCF site-2)	Oak pine forest (BCF site-3)
Elevation (m)	1613-2149	1049-1282	981-1103
Aspect	West facing	South facing	North East
Latitude	29°48'36.0"N	29°53'38.4"N	29°52'05.3"N
Longitude	79°26'09.6"E	79°19'08.4"E	79°20'42.4"E

GCF site-1 (Gairar-bairati-bhainar community), SCF site-2 (Soangaon community forest), and BCF site-3 (Bhatkot community forest).

Table 2. Plant species of different groups in the community forests of the Western Himalaya

Component	No. of species	Angiosperms	Monocots	Dicots	Gymnosperm	Ferns
Tree	10	9	0	9	1	0
Shrub	15	15	0	15	0	0
Herb	42	40	13	27	0	2
Total	67	64	13	51	1	2

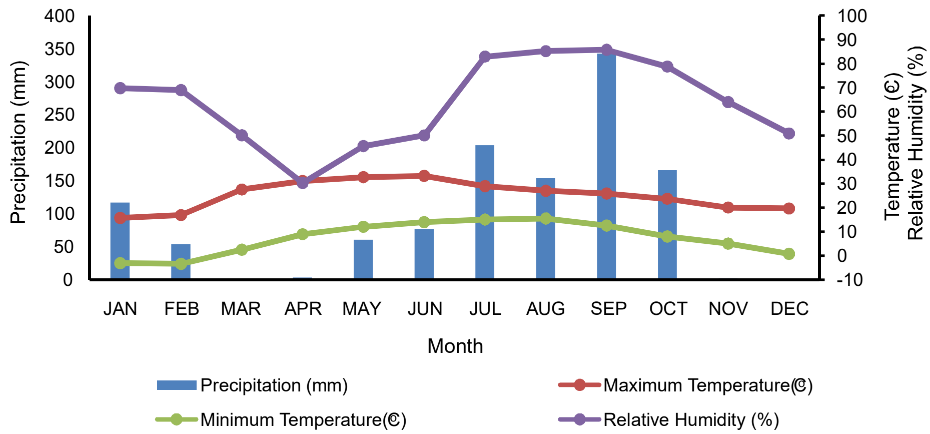

Fig. 1. Meteorological depiction of temperature, rainfall, and relative humidity of the study sites in 2022 (Source: power.larc.nasa.gov).

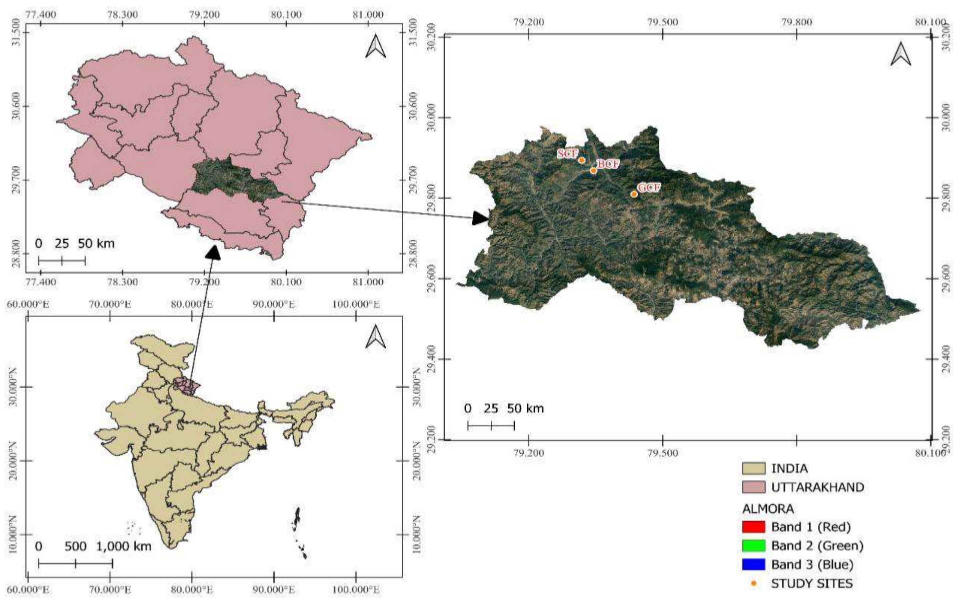

Fig. 2. GPS locations of the studied community forests

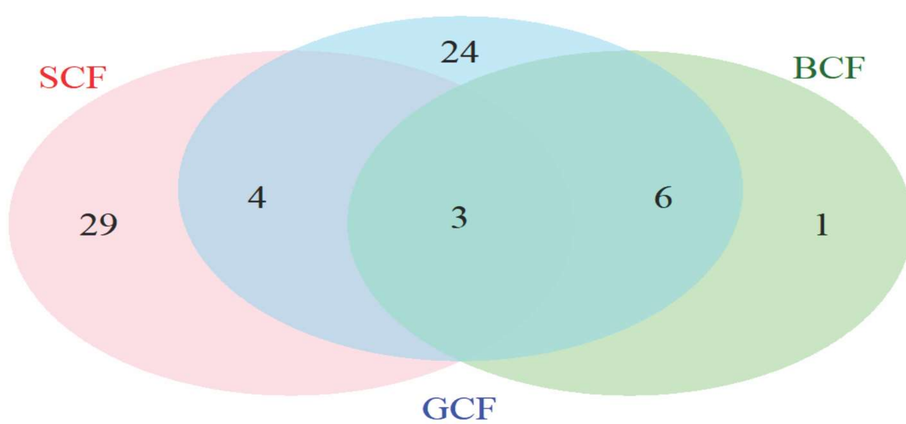

Fig. 3. Venn diagram of plant species in the community forests of the Western Himalaya

more comprehensive analysis of this forest, hierarchical clustering has been conducted to provide a graphical representation of the 67 plant species (Fig. 8).

Vegetation Characteristics

Tree layer: Among tree species, the indicator value of tree species was highest for *Lyonia ovalifolia* in the oak forest, while *Syzygium cumini* and *Pinus roxburghii* were dominant indicators in the pine forest. In the Oak-Pine forest, the maximum indicator value for tree species *Pinus roxburghii is* followed by *Quercus leucotrichophora*. In tree species, the maximum IVI was 119.5 recorded for *Quercus leucotrichophora,* followed by *Myrica esculent*a in oak forest. In the pine forest, *Pinus roxburghii,* showed the highest IVI 289.6, followed by *Syzygium cumini* 10.36. In the oak-pine forest, *Quercus leucotrichophora* had the maximum IVI of 152.9 followed by *Pinus roxburghii* 138.6 (Table 4). The density of trees ranged from 373.3 - 1200 ind. ha^{-1}(Fig.4). The tree density was somewhat similar to central and Kumaun Himalaya forests (360 - 1140 ind. ha^{-1}) (Pandey et al., 2022, Joshi et al., 2023, Haq et al., 2024), while was higher than 153 to 182 ind. ha^{-1} (Kaushal and Baishya 2021, Panday et al., 2022).

The basal area of trees ranged from 25.01 - 31.9 $m^2 ha^{-1}$ (Fig.4). The estimated tree basal area falls within the range of 28.02 - 29.50 m^2 ha^{-1} reported for central and Kumaun Himalayan forests (Kaushal and Baishya, 2021 Pandey et al., 2022, Haq et al., 2024). Area was higher than 12.6 -18.8 m^2 ha^{-1} reported for western and central Himalayan forests (Gurarni et al., 2010, Pandey et al., 2022) and was lower than (33.4-43.6 m^2 ha^{-1}) reported for central Himalayan forests (Joshi et al., 2023).

The diversity, evenness and richness of trees ranged from 0.1 - 0.8, 0.2 – 0.8 and 0.2 – 1.4, respectively (Fig. 4). The diversity of tree species was close to 0-0.5 for western and Kumaun Himalayan forests (Kharkwal et al., 2009, Gurarni et al., 2010, Pandey et al., 2022) but the present finding was lower than 1.2-3.13 was compared to Kumaun and western Himalayan forests (Khan and Arya, 2017, Joshi et al., 2023, Haq et al., 2024) (Table 5). This variation was attributed to differences in tree species composition and abundance within the forests, influenced by external factors such as anthropogenic activities, summer fires, and the regular felling of tree species for fuel and fodder.

Shrub layer: For shrubs, the indicator value was highest for *Indigofera tinctoria* in the oak forest, while *Carissa spinarum*, *Woodfordia fructicosa,* and *Ziziphus nummularia* were dominant indicators in the pine forest and *Berberis aristata,* followed by *Himalrandia tetrasperma* in oak-pine forest. In the oak forest, the maximum IVI of 184.2 was for *Berberis aristata* among shrubs, followed by *Himalrandia tetrasperma,* while in the pine forest, the highest IVI of 128.7 was estimated for *Carissa spinarum,* followed by *Woodfordia fructicosa* .. In the oak-pine forest, the maximum IVI 197.7 for shrubs was observed for *Berberis aristata,* followed by *Rubus ellipticus* 61.7 (Table 4). The density of shrub species ranged between 1026.7 -3789.6 ind. ha^{-1} (Fig. 4) which falls within the range (760-8520 ind. ha^{-1}) reported for Kumaun Himalayan forests (Gurarni et al., 2010, Khan and Arya 2017, Joshi et al., 2023). The value is higher than 40 - 540 ind. ha^{-1} as observed for central Himalayan forests (Kharkwal et al., 2009, Khan and Arya, 2017), and shrub density was on the lower side than (26107-28546 ind. ha^{-1}) r for Himalayan forests of Uttarakhand (Arya and Ram, 2016). The basal area of shrub species ranged between 0.1 - 0.4 $m^2 ha^{-1}$ (Fig. 4) and was lower than (4.7 m^2 ha^{-1}) reported for Himalayan forests (Gurarni et al., 2010).

Shrubs diversity, evenness and richness ranged from 0.4 - 1.3, .5 - 0.8 and 0.3 - 1.0, respectively (Fig. 4). The diversity of shrubs falls within the range of 0.9-1.7 reported for Himalayan forests (Kharkwal et al., 2009, Khan and Arya 2017) (Table 5). However, were lower than 1.5-4.6 reported for Himalayan forests (Arya and Ram, 2016, Khan and Arya 2017, Joshi et al., 2023). The variation was observed due to changes in soil and climate change at the site. Additionally, the opening up of the forest site, and frequent forest fires influence the density and diversity of shrub species.

Herb layer: In the herb layer, the maximum indicator was recorded for *Galium aparine*, *Paeonia emodi,* and *Thalictrum foliolosum* in oak forest and *Chaerophyllum tainturieri*, *Chrysopogon aciculatus*, *Euphorbia hirta*, *Evolvulus alsinoides*, *Flemingia procumbens*, *Imperata cylindrica*, *Lepidagathis incurve,* and *Oxalis corniculate* for pine forest. For oak-pine forest, the maximum indicator value was for *Ageratina Adenophora,* followed by *Themeda anathera* (Table 3). The maximum PV in oak forest was 63.8 observed for *Ageratina Adenophora,* followed by *Themeda anathera*. In the pine forest, the highest PV of 39.43 was for *Chrysopogon aciculatus* followed by *Themeda anathera* . In the oak-pine forest, *Ageratina Adenophora* shows the highest PV of 179.0, followed by *Themeda anathera* for oak-pine forest (Table 5).

The herb density ranged between 9.2 - 14.6 ind. m^{-2}(Fig.4). The estimated herb density was somewhat similar to Kumaun Himalayan forests(9.4-15.8 ind. m^{-2}) (Kharkwal et al., 2009, Arya and Ram 2016). But was lower than 81-234.8 ind. ha^{-1} for central and Kumaun Himalayan forests (Gurarni et al., 2010, Joshi et al., 2012, Arya and Ram, 2016, Joshi et al., 2023). The value is higher than the value 4.7 - 5.14 reported for Himalayan Forest (Gurarni et al., 2010, Rawal et al., 2012).

The herb diversity, evenness and richness ranged

Table 3. Indicator value of plant species in the community forests of Western Himalaya

Forest plant species	Oak forest GCF, Site-1	Pine forest SCF, Site-2	Oak-pine forest BCF, Site-3
Adiantum capillus-veneris L.	0.00	0.58	0.00
Ageratina Adenophora Spreng.	0.69	0.11	0.69
Ajuga parviflora Benth.	0.00	0.58	0.00
Anaphalis adnata DC.	0.82	0.00	0.00
Anaphalis contorta D Don Hook f.	0.92	0.22	0.00
Apluda mutica L.	0.61	0.54	0.00
Arundinella nepalensis Trin.	0.82	0.00	0.00
Asparagus racemosus Willd.	0.89	0.00	0.26
Barleria cristata L.	0.00	1.00	0.00
Berberis asiatica Griff.	0.68	0.00	0.74
Boenninghausenia albiflora Hook...Rchb..ex	0.58	0.00	0.00
Carissa spinarum L.	0.00	1.00	0.00
Caryopteris odorata D Don BL Rob.	0.58	0.00	0.00
Chaerophyllum tainturieri Hook Arn.	0.00	1.00	0.00
Chrysopogon spp.	0.00	1.00	0.00
Chrysopogon fulvus Spreng Chiov.	0.58	0.00	0.00
Cirsium wallichii DC.	0.00	0.58	0.00
Cotinus coggygria Scop.	0.58	0.00	0.00
Daphne papyracea Wall ex Steud.	0.58	0.00	0.00
Dioscorea bulbifera L.	0.00	0.58	0.00
Erigeron canadensis L.	0.00	0.58	0.00
Eulaliopsis binata Retz	0.77	0.18	0.00
Euphorbia hirta L.	0.00	1.00	0.00
Evolvulus alsinoides L.	0.00	1.00	0.00
Flemingia procumbens Roxb.	0.00	1.00	0.00
Flemingia strobilifera L W T Aiton	0.00	0.82	0.00
Galinsoga parviflora Cav.	0.58	0.00	0.00
Galium aparine L.	1.00	0.00	0.00
Glochidion velutinum Wight	0.58	0.00	0.00
Grevillea robusta A Cunn ex R Br.	0.00	0.00	0.58
Grona heterophylla Willd H Ohashi K Ohashi	0.00	0.82	0.00
Heteropogon contortus LP Beauv ex Roem Schult.	0.00	0.82	0.00
Himalrandia tetrasperma Wall ex Roxb T Yamaz.	0.70	0.00	0.42
Imperata cylindrica L Raeusch.	0.00	1.00	0.00
Indigofera tinctoria L.	0.82	0.00	0.00
Indigofera cassioides Rottler ex DC.	0.42	0.70	0.00
Jacobaea nudicaulis Buch Ham ex D Don B Nord.	0.00	0.82	0.00
Jasminum nervosum Lour	0.00	0.82	0.00
Lantana camara L.	0.58	0.00	0.00
Lepidagathis incurve Buch Ham ex D Don	0.00	1.00	0.00
Leucas lanata Benth.	0.00	0.58	0.00
Lyonia ovalifolia Wall Drude	1.00	0.00	0.00
Micromeria biflora buch Ham ex D Don Benth	0.00	0.58	0.00

Cont...

Table 3. Indicator value of plant species in the community forests of Western Himalaya

Forest plant species	Oak forest GCF, Site-1	Pine forest SCF, Site-2	Oak-pine forest BCF, Site-3
Myrica esculenta Buch Ham ex D Don	0.88	0.00	0.27
Myrsine africana L.	0.58	0.00	0.00
Onychium lucidum D Don Spreng.	0.82	0.00	0.00
Oplismenus hirtellus L P Beauv.	0.58	0.00	0.00
Oplismenus undulatifolius Ard P Beauv.	0.00	0.58	0.00
Origanum vulgare L.	0.82	0.00	0.00
Oxalis corniculate L.	0.00	1.00	0.00
Paeonia emodi Royle	1.00	0.00	0.00
Pinus roxburghii Sarg.	0.36	0.62	0.70
Pleurolobus gangeticus L J St Hil ex H Ohashi K Ohashi	0.00	0.82	0.00
Prunus cerasoides D Don	0.58	0.00	0.00
Pyrus pashia Buch Ham ex D Don	0.82	0.00	0.00
Quercus leucotrichophora A Camus	0.81	0.00	0.59
Rhododendron arboreum nilagiricum Zenker Tagg	0.82	0.00	0.00
Rubus ellipticus Sm.	0.62	0.00	0.37
Scutellaria scandens D Don	0.58	0.00	0.00
Senna tora L Roxb.	0.00	0.82	0.00
Syzygium cumini L Skeels	0.00	0.82	0.00
Teucrium quadrifarium Buch Ham ex D Don	0.00	0.58	0.00
Thalictrum foliolosum DC.	1.00	0.00	0.00
Themeda anathera Nees ex Steud Hack.	0.58	0.43	0.40
Viburnum mullaha Buch Ham ex D Don	0.58	0.00	0.00
Woodfordia fruticose L Kurz	0.00	1.00	0.00
Ziziphus nummularia Burm f Wight Walk Arn.	0.00	1.00	0.00

See Table1 for details

between 0.3 - 2.5, 0.2 – 0.7, and 0.15 – 3.3 respectively (Fig. 4). The observed herb diversity was close to (2.2-2.7) reported for Himalayan forests (Arya and Ram, 2016, Khan and Arya, 2017, Joshi et al., 2023), but was lower than central Himalayan forests (3.0 – 4.0) (Kharkwal et al., 2009; Joshi et al., 2023) (Table 5). The variations in herb density and diversity in the present study forest site resulted from seasonal climate variations, existing topographical features, anthropogenic pressures and disturbances caused by humans and animals, accumulation of herbs and grasses, frequent summer forest fires, and alteration in the microclimate of the forest sites, which affected the density, and diversity of the herbs.

Soil physicochemical characteristics: The soil texture, consisting of sand, silt, and clay, ranged from 17.5 - 29.9, 35.8 -59.1, and 23.3- 42.1%, respectively. The soil moisture, bulk density, porosity, and water holding capacity ranged between 2.8 - 10.85%, 0.9 – 1.2 g cm^{-3}, 53.3 - 64.5%, and 31.2 - 58.3%, respectively. The estimated soil moisture level was lower than the 19.7- 26.5% reported for the Western Himalayan and Shiwalik forests (Lodhiyal et al., 2016, Joshi et al., 2023). The bulk density falls within the range of value 0.56-1.24g cm^{-3} reported for the central Himalayan, Shiwalik subtropical coniferous and mixed forests (Lodhiyal et al., 2016, Bargali et al., 2018, Khan et al., 2025). This was higher than of 0.42-0.65 g cm^{-3} reported for the central Himalayan Forest (Bargali et al., 2018). The water-holding capacity falls within the range between 41.5-51.50% of the Western and central Himalayan Forest (Bargali et al., 2018, Manral et al., 2020, Joshi et al., 2023). The chemical properties of the soil, including soil pH, electrical conductivity (EC), organic matter, and total nitrogen, ranged from 5.6 - 6.1, 0.8 - 1.1 dS m^{-1}, 1.2 - 1.3%, and 0.06 - 0.07%, respectively. The phosphorus and potassium levels were 28.3 – 34.7 and 285.3 – 442.3 kg ha^{-1}, respectively across the forest sites (Fig. 5). The soil moisture level was 10.85%, which was lower than the 25.3% reported for the Western Himalayan forest (Joshi et al., 2023). The soil pH was lower than 6.91 in the coniferous forest and 7.24 in the mixed forest of the Himalayan region (Khan et al., 2025). The electrical conductivity is somewhat similar to of

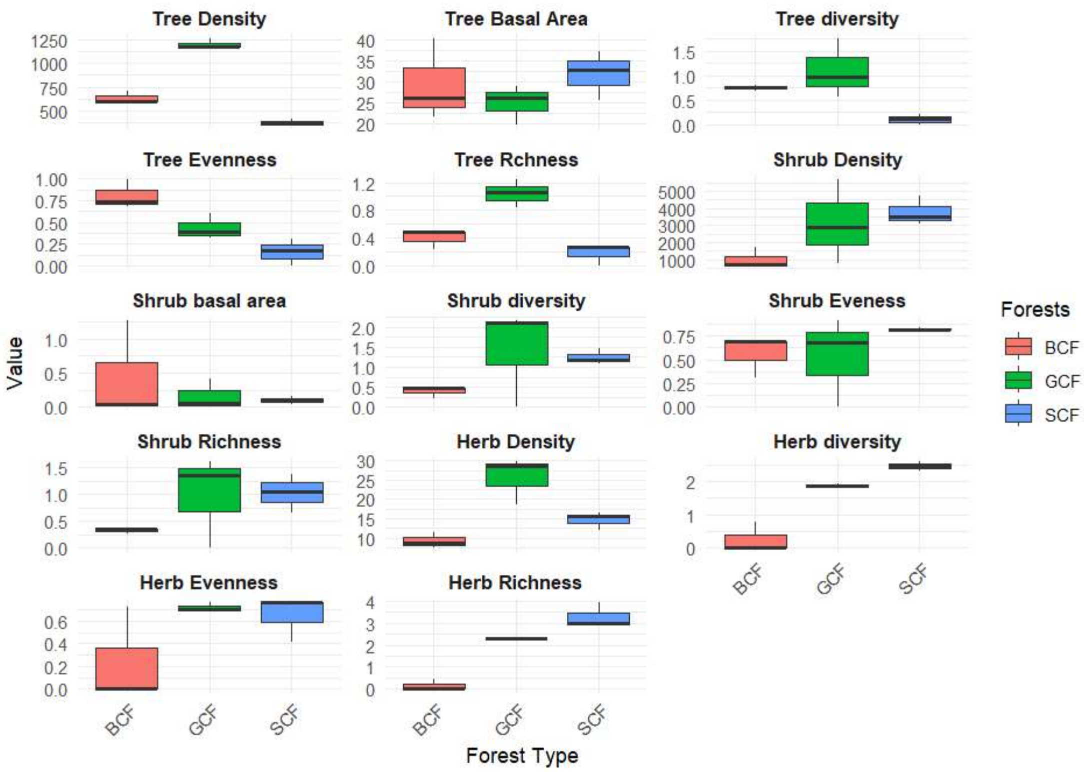

Fig. 4. Vegetation characteristics of the community forests of the Western Himalaya.Tree and shrub density are in (ind. ha^{-1}), herb density is in (ind. m^{-2}), and Tree basal area and shrub basal area are in (m^{2}ha^{-1})

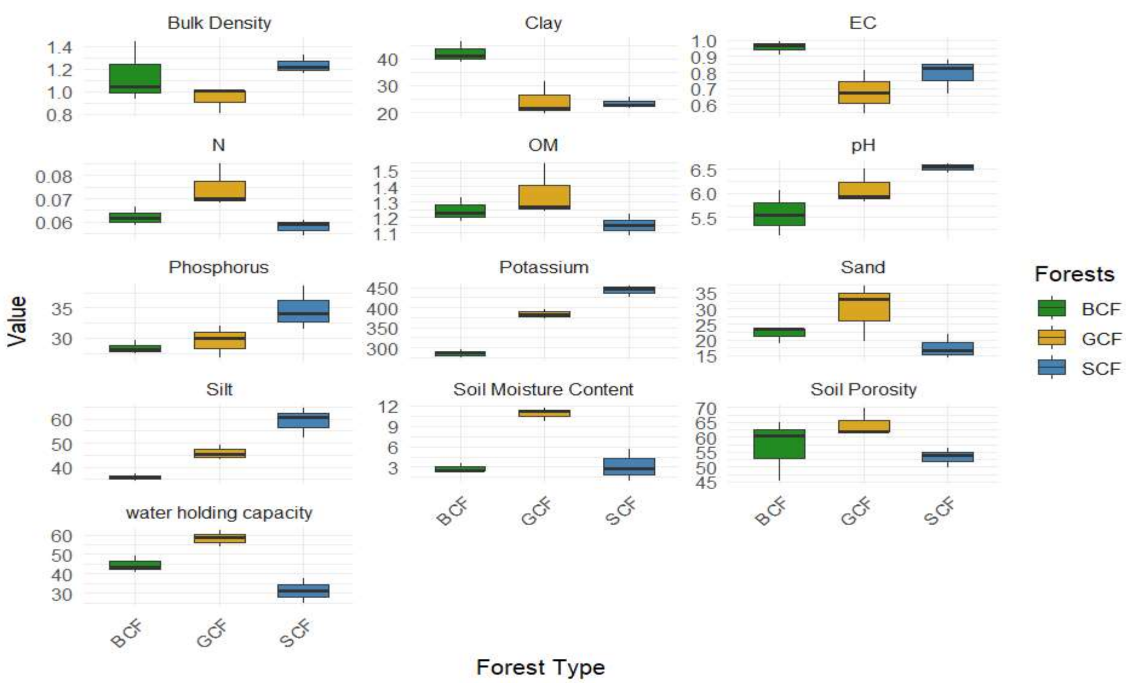

Fig. 5. Physico-chemical properties of soils of the community forests in Western Himalaya (Sand, silt, clay, soil moisture, soil porosity, water holding capacity, Organic matter, and Nitrogen (N) in (%), bulk density in (g cm^{-2}), EC in (dS m^{-1}), Phosphorus (P) and Potassium (K) are in (Kg ha^{-1})

Table 5. Provenance value of herb species in community forest of Western Himalaya

Herb species	Oak forest GCF, Site-1	Pine forest SCF, Site-2	Oak-pine forest BCF, Site-3
Adiantum capillus-veneris L.	-	3.56	-
Ageratina adenophora (Spreng.)	178.99	2.85	63.78
Ajuga parviflora Benth.	-	1.28	-
Anaphalis adnata DC.	-	-	7.92
Anaphalis contorta (D.Don) Hook.f.	-	1.07	13.92
Apluda mutica L.	-	2.76	4.96
Arundinella nepalensis Trin.	-	-	7.56
Asparagus racemosus (Willd.)	5.43	-	7.04
Barleria cristata L.	-	11.80	-
Boenninghausenia albiflora (Hook.) Rchb. ex	-	-	2.45
Chaerophyllum tainturieri Hook. & Arn.	-	9.43	-
Chrysopogon spp	-	39.43	-
Chrysopogon fulvus (Spreng.) Chiov.	-	-	5.40
Cirsium wallichii DC.	-	2.55	-
Dioscorea bulbifera L.	-	1.07	-
Erigeron canadensis L.	-	2.14	-
Eulaliopsis binata (Retz.)	-	1.70	14.34
Euphorbia hirta L.	-	12.21	-
Evolvulus alsinoides (L.) L.	-	11.57	-
Flemingia procumbens Roxb.	-	1.28	-
Flemingia prostrata Roxb.Junior ex Roxb.	-	4.48	-
Galinsoga parviflora Cav.	-	-	7.71
Galium aparine L.	-	-	6.39
Grona heterophylla (Willd.) H.Ohashi & K.Ohashi	-	3.95	-
Heteropogon contortus (L.) P.Beauv. ex Roem. & Schult.	-	2.64	-
Imperata cylindrica (L.) Raeusch.	-	17.75	-
Curcuma longa L.	-	-	5.54
Jacobaea nudicaulis (Buch. -Ham. ex D.Don) B.Nord.	-	4.27	-
Lepidagathis incurva Buch. -Ham. ex D.Don	-	11.17	-
Leucas lanata Benth.	-	1.49	-
Micromeria biflora (buch.-Ham. ex D.Don) Benth	-	1.27	-
Onychium lucidum (D.Don) Spreng.	-	-	2.53
Oplismenus hirtellus (L.) P.Beauv.	-	-	3.12
Oplismenus undulatifolius (Ard.) P.Beauv.	--	0.96	-
Origanum vulgare L.	-	-	7.84
Oxalis corniculata L.	-	9.19	-
Paeonia emodi Royle	-	-	5.07
Pleurolobus gangeticus (L.) J. St.-Hil. ex H. Ohashi & K. Ohashi	-	5.51	-
Scutellaria scandens D.Don	-	-	7.22
Teucrium quadrifarium Buch.-Ham. ex D.Don	-	3.82	-
Thalictrum foliolosum DC.	-	-	5.94
Themeda anathera (Nees ex Steud.) Hack.	15.58	28.78	21.26

See Table1 for details

0.9 dS m^{-1} reported for mixed forests (Khan et al., 2025). The soil organic matter in the present forest site was significantly lower than the value 2.91 - 3.87% reported for mixed forests and coniferous forests (Khan et al., 2025). The soil nitrogen concentration was somewhat close to the values of 0.05 - 0.06% reported for Western Himalayan forests (Manral et al., 2020). However, it is significantly lower than the value of 0.10 - 0.38 0.21% for Western and central Himalayan forests (Manral et al., 2020, Joshi et al., 2023).

Based on the soil properties studied in the community forests, these forests contain very small quantities of organic matter due to various internal and external reasons, such as collection of litter, burning of litter organic matter in summer season, surface run-off during the rainy season, collection of fodder and grasses. Apart from these, erratic weather and climatic conditions prevail in the forest areas. The study forest sites were in a warm climatic zone, resulting in the rapid decomposition of litter present in the forest, which was washed out due to runoff. This is why the addition of organic nutrients could not penetrate the forest soils. Thus, it is essential to conserve and manage the organic litter present in the forest so that the soil structure and fertility of these forest sites can be maintained for the health of the soil and the growth of forest stands.

Ordination analysis: Principal Component Analysis (PCA) was conducted using 29 parameters to assess the relationships between vegetation, soil, and topography associated with community forests. Of these, 14 were vegetation parameters and 15 were environmental parameters. Vegetation parameters include tree density, shrub density, herb density, tree basal area, shrub basal area, tree diversity, shrub diversity, herb diversity, tree richness, shrub richness, herb richness, tree evenness, shrub evenness, and herb evenness. The environmental

Table 4. Important Value Index of tree and shrub species in the community forest of Western Himalaya

Tree species name	Oak forest GCF, Site-1	Pine forest SCF, Site-2	Oak-pine forest BCF, Site-3
Glochidion velutinum Wight	-	-	3.27
Grevillea robusta A. Cunn. ex R. Br.	3.41	-	-
Lyonia ovalifolia (Wall.) Drude	-	-	17.01
*Myrica esculent*a Buch. -Ham. ex D. Do	5.14	-	83.63
Pinus roxburghii Sarg.	138.58	289.64	36.5
Prunus cerasoides D. Don	-	-	3.48
Pyrus pashia Buch. -Ham. ex D. Don	-	-	9.88
Quercus leucotrichophora A. Camus	152.87	-	119.53
Syzygium cumini (L.) Skeels	-	10.36	-
Rhododendron arboreum nilagiricum (Zenker) Tagg	-	-	26.69
Shrub species name			
Berberis aristata DC.	197.67	-	184.18
Carissa spinarum L.	-	128.66	
Caryopteris odorata (D.Don) B.L.Rob.	-	-	12.52
Cotinus coggygria Scop.	-	-	2.65
Daphne papyracea Wall. ex Steud.	-	-	1.74
Himalrandia tetrasperma (Wall. ex Roxb.) T.Yamaz.	40.62	-	40.04
Indigofera cassioides Rottler ex DC.	-	17.71	21.65
Jasminum nervosum Lour.	-	12.98	-
Lantana camara L.	-	-	3.56
Myrsine africana L.	-	-	1.80
Rubus ellipticus Sm.	61.71	-	14.26
Senna tora (L.) Roxb.	-	32.60	-
Viburnum mullaha Buch. -Ham. ex D.Don	-	-	17.59
Woodfordia fruticosa (L.) Kurz	-	66.35	
Ziziphus nummularia (Burm. f.) Wight & Walk. -Arn.	-	41.70	-

See Table1 for details

parameters included one topographical parameter (i.e., elevation) and thirteen soil parameters (i.e., sand, silt, clay, bulk density, soil moisture, soil porosity, water holding capacity, soil pH, soil electrical conductivity, organic matter, nitrogen, phosphorus, and potassium). The bi-plot reveals that tree richness, density, basal area, diversity, and

Table 6. Summary of PCA plot

Dimension	Eigenvalue	Variance	Cumulative variance (%)
Dim. 1	15.396	54.99	54.99
Dim. 2	12.604	45.01	100.00
Dim. 3	~0	~0	100.00

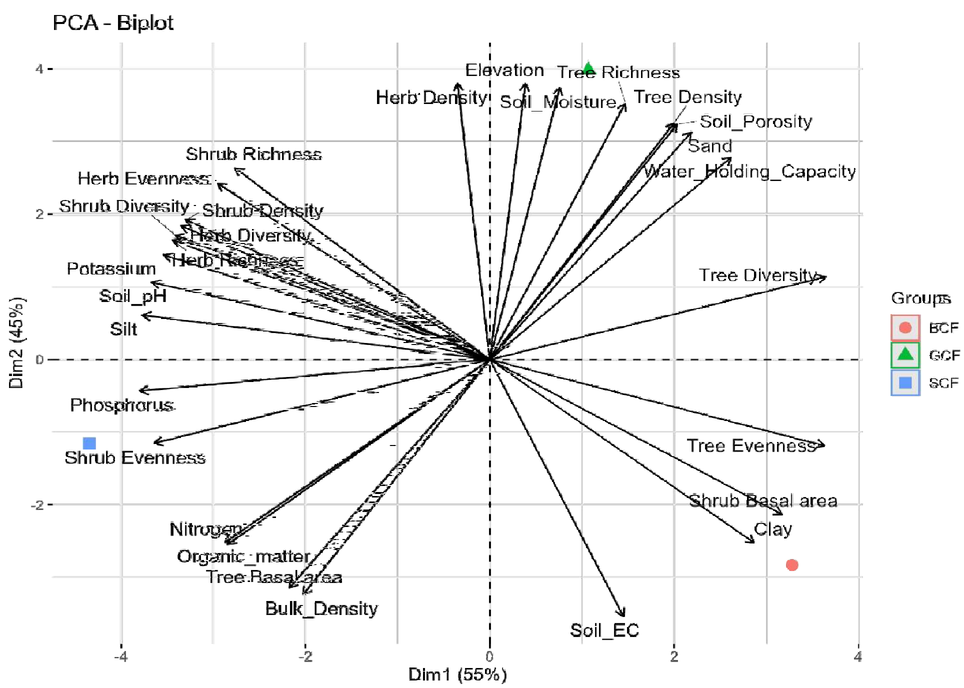

Fig. 6. PCA biplot of vegetation, soil, and topographic characteristics of the community forests in Western Himalaya

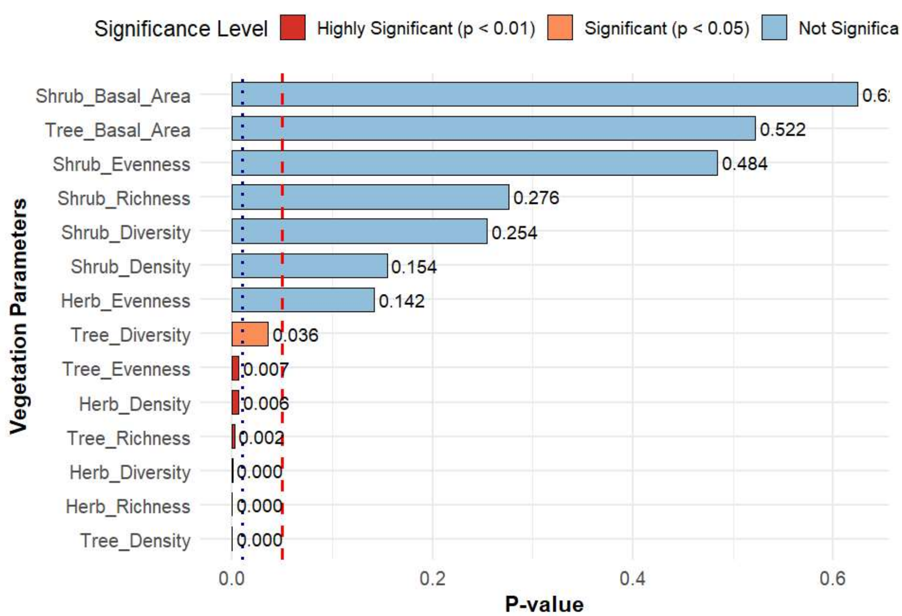

Fig. 7. Tukey HSD test for vegetation characteristics of the community forests in Western Himalaya

Table 7. Comparative study of different vegetation parameters of trees, shrubs, and herbs of forests in the regions of the country

Forest type	Density (ind. ha^{-1})		Density ($ind.m^{-2}$)	Basal area (m^2ha^{-1})		Diversity			Reference
	Tree	Shrub	Herb	Tree	Shrub	Tree	Shrub	Herb	
Oak forest	1200	3120	11.9	25.0	0.2	0.8	1.0	1.9	Present study
Oak forest	400-933	995-1404	4.8-5.0	29.50-40.16	-	-	-	-	(Rawal et al., 2012)
Oak forest	390	540	-	28.02		1.2	1.5	-	(Khan and Arya 2017)
Oak forest	652	1700	234.8	51.58	-	2.0	3.0	3.3	(Joshi et al., 2023)
Oak forest	670-1140	40-100	15.8-42.9	-	-	0.2-0.4	1.8-2.8	3.0-4.2	(Kharkwal et al., 2009)
Oak forest	360	50.43	-	-	-	-	-	-	(Kaushal and Baishya 2021)
Ban oak forest	381-930	22.0-35.05	-	-	-	0.9-1.7	-	-	(Pandey et al., 2022)
Oak forest	640±140.9	-	-	-	-	3.31±0.13	-	-	(Haq et al., 2024)
Pine forest	373.3	3789.7	14.6	31.9	0.1	0.1	1.3	2.5	Present study
Pine forest	307.8-376.5	26107-28546	8.1-9.4	28.4-33.2	-	2.1-2.2	4.5-4.6	2.5-2.7	(Arya and Ram 2016)
Pine forest	485	1460	4.7	12.6	-	0.5	2.1	2.2	(Gurarni et al., 2010)
Pine forest	300-560	760-8,520	-	28.7 -34.4	-	0.4-1.5	0.9-1.7	-	(Khan and Arya 2017)
Pine forest	672	6160	119.9	43.6	-	1.1	2.3	4.1	(Joshi et al., 2023)
Pine forest	470-850	200-1360	13.9-44.0	-	-	0-0.3	0.5-1.5	2.4-4.5	(Kharkwal et al., 2009)
Pine forest	153	-	-	37.40	-	-	-	-	(Kaushal and Baishya 2021)
Pine forest	182	-	-	18.8	-	0.3	-	-	(Pandey et al., 2022)
Pine forest	707.5± 148.2	-	-	-	-	2.99±0.26	-	-	(Haq et al., 2024)
Oak-pine mixed forest	633.3	1026.7	9.2	29.4	0.4	0.8	0.4	0.3±	Present study
Pine-oak forest	1000	1660	5.14	14.55	4.69	1.26	2.42	2.45	(Gurarni et al., 2010)
Pine-oak forest	-	-	67.2	-	-	-	-	-	(Joshi et al., 2012)
Oak-pine mixed forest	160	-	-	39.17	-	-	-	-	(Joshi et al., 2013)
Oak pine mixed forest	640-930	-	-	21.0-32.7	-	--	-	-	(Verma and Garkoti 2019)
Mixed-oak Forest	884	3504	152.5	33.4		2.3	3.3	2.5	(Joshi et al., 2023)

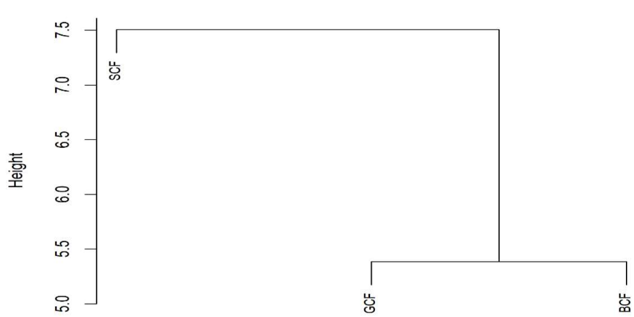

Fig. 8. Cluster analysis of plant species of the community forests in Western Himalaya

evenness are positively correlated with certain soil components, including moisture, porosity, water-holding capacity, and organic matter. Shrub and herb parameters show a positive correlation with nitrogen, phosphorus, and elevation. Additionally, clay and EC are negatively correlated with tree parameters. (Fig. 6 and Table 4). The P-value indicated that these forests differed significantly in terms of tree density, tree diversity, tree richness, herb density, and herb diversity. However, these forests did not vary considerably in terms of tree basal area, shrub density, shrub basal area, shrub diversity, and herb diversity (Fig. 7).

CONCLUSION

The community forests are home to a diverse variety of flora and fauna, and also considered one of the livelihood options for village communities, particularly in the Himalayan region of Uttarakhand, India. However, with the growing human population and its interference, these forest areas are highly affected by fragmentation, summer forest fires, and the uncontrolled extraction of forest resources, which has also led to a decline in biodiversity in the forest. Apart from these disturbing factors, the community forest faces poor productivity, a declining growing stock, and a lower CO2 mitigation potential., The findings of vegetation and soil characteristics of community forests varied from one forest to another, indicating that the forests were not in good condition. This assumes that several factors, including unscientific resource extraction, fires, anthropogenic pressure, and climate-related variations, have influenced the forests. This inadequate management inputs have consequently led to a poor and degraded condition of community forests in the studied sites. The soil properties, such as moisture, porosity, water-holding capacity, and organic matter, favour the tree layer. In contrast, the shrub and herb layers were found to be correlated with nitrogen, phosphorus, and elevation. The high clay content and soil electrical conductivity (EC) limit the abundance of plants in the forest.

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