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Forest Composition and Resource Utilization Patterns in Relation to Anthropogenic Pressure in Moist Temperate Forests of the Garhwal Himalaya

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ABSTRACT

This study investigates the intricate dynamics of vegetation composition and ecosystem services in temperate forests, focusing on the influence of elevation, forest types, and anthropogenic pressures on vegetation composition across different strata in moist temperate forests of Chamoli District, Garhwal Himalaya, Uttarakhand, India. Spanning an altitudinal range of 1500-3000 m asl. Species richness varied from 5 to 33 across forest types, with Shannon and Simpson diversity indices ranging from 1.38-2.81 and 0.69-0.93 for trees, 1.54-3.98 and 0.71-0.90 for shrubs, and 2.23-3.43 and 0.88-0.96 for herbs, respectively. Mixed broad-leaved forest (FT5) had the highest tree density (1450 ind ha^{-1}), while mainly *Quercus semecarpifolia* forest (FT10) recorded the largest basal area (116.36 m^2 ha^{-1}). Local communities depend on these forests for fuelwood, fodder, non-timber forest products (NTFPs), and medicinal plants. However, widespread anthropogenic disturbances, including lopping and stump extraction, were observed, with an average disturbance index of 10.60%. Mixed broad-leaved forest (FT4) experienced the highest disturbance (18.18%), while *Quercus floribunda* forest (FT9) had the lowest (6.45%). Lopping intensity was highest (29.73%) in Mixed *Quercus leucotrichophora* forest (FT1) and lowest (7.28%) in Mainly *Abies pindrow* forest (FT7). The findings highlight significant biodiversity in the region, but also substantial anthropogenic pressure, especially near settlements. The study emphasizes the urgent need for targeted conservation measures and sustainable management strategies to balance community reliance on forest resources with the preservation of forest health and ecosystem services.

Keywords Diversity, Resource utilization pattern, Anthropogenic disturbance, Garhwal Himalaya.

INTRODUCTION

Forests are essential to the global ecosystem, providing a wide range of benefits and services. Forests serve as crucial carbon sinks, absorbing a significant portion of human-induced greenhouse gas emissions, thereby playing a central role in mitigating climate change (Xia *et al.* 2023). Approximately 350 million people worldwide reside in or near dense forests, relying on them for sustenance and income (Darboe 2023). Forests in the Indian Himalayan region are cru-

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cial in maintaining ecosystem functions and providing valuable services. These forests are characterized by unique flora and have been traditionally significant in preserving the ecology and environment of the sub-continent (Samant 2021). The altitudinal zonation in these forests influences species composition, forest structure, and ecosystem functions, which are vital for supporting biodiversity and sustaining ecosystem services that benefit local communities (Ashton *et al*. 2022).

Furthermore, the economic value of cultural ecosystem services provided by Indian temperate forests is substantial, contributing to economic growth and employment generation (Balasubramanian 2022). These forests are vital for carbon storage, with high tree biomass and soil carbon storage playing a key role in carbon sequestration (Wei *et al*. 2013). The temperate forests in the Himalayan region provide valuable livelihood opportunities for local communities and contribute to the sustenance and well-being of local populations (Rather 2015, Chakraborty *et al.* 2017). In addition to livelihood support, Indian temperate forests play a crucial role in agriculture improvement and food security. These forests help maintain river water flow, control erosion, carbon sequestration, soil organic carbon storage, and replenish groundwater, which is essential for supporting agriculture in the Indian Himalayan region (Batar *et al.* 2021). The forests also influence regional climate patterns, affecting precipitation and temperature regimes, which in turn impact agriculture and livelihoods in the region (Gairola *et al.* 2012).

Anthropogenic disturbances in Indian temperate forests, particularly in the Himalayan region, have significantly impacted forest ecosystems and biodiversity. These disturbances include activities such as frequent and continuous grazing, extraction of non-timber forest products, illegal cutting, looping, tapering, burning, and grazing, which have contributed to noticeable disruptions in forest ecosystems (Hussain *et al.* 2019). Anthropogenic disturbances have been dominant in driving compositional changes in northern temperate forests over recent centuries (Danneyrolles *et al.* 2019).

In the Indian Himalayan Region (IHR), temperate forests are vital for ecological integrity, supporting diverse species and providing essential ecosystem services such as water regulation, soil conservation, and habitats for flora and fauna (Singh *et al.* 2010). These forests, found between middle to higher altitudes, are dominated by tree species like Himalayan Cedar (*Cedrus deodara*), blue pine (*Pinus wallichiana*), chir pine (*Pinus roxburghii*), oak (*Quercus* spp.), and rhododendron (*Rhododendron* spp.) (Singh and Pusalkar 2020). These forests are also significant for their endemic biodiversity and cultural heritage. Human activities such as cutting, lopping, and grazing profoundly impact forest ecosystems in the Western Himalayan region of Uttarakhand. These activities disrupt the ecological balance, leading to forest degradation and biodiversity loss (Thakur *et al.* 2011). To mitigate the challenges of anthropogenic pressure and conserve various forest types, it is essential to understand the structure, composition, and impact of resource utilization patterns on Himalayan forests. This study aims to explore (i) How the herb, shrub, and tree composition changes across different elevations and forest types, (ii) How forest resource utilization patterns affect forest vegetation and ecosystem services. By addressing these questions, the study seeks to provide a comprehensive understanding of forest composition and dynamics, informing management and conservation strategies tailored to the unique ecosystems of the Garhwal Himalaya.

MATERIALS AND METHODS

Study area

The present study was conducted in the moist temperate forest of Chamoli District, located in the Western Himalayan region of Uttarakhand State, India. The study area is situated between 30°27’48.34” to 30°28’17.21” N latitudes and 79°16’03.83” to 79°13’08.48” E longitudes (Fig. 1). Remarkably, this forest encompasses a wide altitudinal gradient, ranging from 1500 m asl to 3000 m asl. The climatic conditions observed within the study area can be categorized into three distinct seasons: Summer (April to June), rainy (July to September), and winter (November to February). The average rainfall was recorded as 41.47 mm/month, 359.31 mm/month, and 35.42 mm/month for three seasons: Summer, rainy,

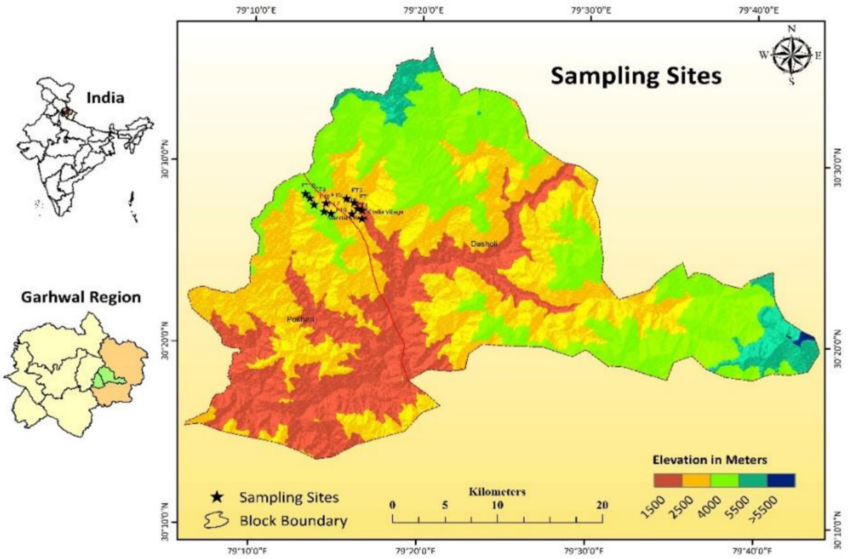

Fig. 1. Map of the study area.

and winter, respectively (Fig. 2).

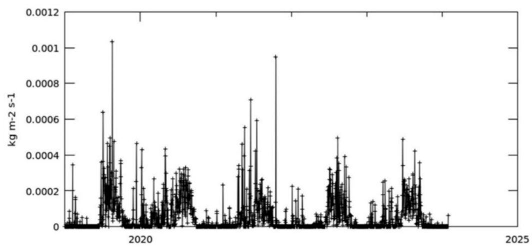

Fig. 2. Seasonal variation of daily rainfall flux in the region from 01-01-2019 to 01-02-2024 (Giovanni.gsfc.nasa.gov).

Composition of forest types

A reconnaissance survey was undertaken from March 2022 to April 2023 to evaluate the forest cover types characterized by different species compositions and altitudinal gradients (Table 1). The forest types were named based on the composition of dominant tree species, following Ram Prakash (1986). The composition of the forest types was analyzed using the nested quadrat method, as per Kent and Coker (1992). Three vegetation layers (i.e., trees, shrubs, and herbs) were analyzed for species richness, density, and diversity. Trees (≥10 cm dbh) were analyzed by 10m × 10m sized quadrats, whereas shrubs (≥1cm and ≤10 cm dbh) by 5m × 5m sized quadrats, as proposed by

Table 1. Details of the studied forest types.

FT	Forest type	Elevation (m asl)	Latitude N°	Longitude E°
FT1	Mixed *Quercus leucotrichophora*	1500-1650	30.462’70”	79.267’29”
FT2	Mainly *Alnus nepalensis*	1550-1650	30.457’32”	79.270’90”
FT3	Mixed broad-leaved	1650-1950	30.466’46”	79.259’70”
FT4	Mixed broad-leaved	1900-2150	30.452’44”	79.265’18”
FT5	Mixed broad-leaved	2150-2400	30.462’04”	79.239’18”
FT6	Conifer mixed broad-leaved	2400-2550	30.027’09”	79.014’40”
FT7	Mainly *Abies pindrow*	2500-2600	30.027’15”	79.014’15”
FT8	Pure *Acer caesium*	2550-2650	30.027’38”	79.013’39”
FT9	Mainly *Quercus floribunda*	2550-2650	30.027’59”	79.013’24”
FT10	Mainly *Quercus semecarpifolia*	2650-2850	30.028’13”	79.013’08”

Curtis and McIntosh (1950) and Phillips (1959). Further, quadrats of 1m ×1m size were randomly laid out within each 10m × 10m sized quadrat in each forest type to study plants in the herb layer.

Community parameters, i.e., frequency, density, TBA, and the Importance Value Index (IVI), were determined using the methodology described by Cottam & Curtis (1956). The Shannon-Wiener diversity Index ($\bar{H}$) was computed following Shannon and Weaver (1963) and the Simpson Dominance Index (Cd), as per Simpson (1949). Species evenness, as per Pielou (1966), was calculated for each forest type to know the complete structure of the forest. Plant identification was done with the help of flora of the Garhwal district in the North West Himalaya (Gaur 1999), flora of Chamoli (Naithani 1984) and existing taxonomic literature.

People's reliance on forest ecosystem goods and services

Information on the dependency of locals on the main provisioning services (ecosystem services) derived from the studied forest was collected using a combination of methods, including focus group discussions, key informant interviews with structured questionnaires and field observations in the locality.

Impact of anthropogenic disturbance on various forest types

Forest disturbance analysis involves examining the frequency of anthropogenic activities across various forest types. In each sampling plot, cut stems were counted, and their diameter at breast height (dbh) was measured. Using the data collected on cut stumps, disturbance indices were calculated based on the density and total basal area of the cut stumps, following the methodology described by Murali *et al.* (1996).

$$DI\_D = \frac{\text{Density of cut stumps per hectare}}{\text{Total density (standing stems + cut stems) per hectare}} \times 100$$

$$DI\_TBC = \frac{\text{TBC of cut stumps per hectare}}{\text{Total TBC (standing stems + cut stems) per hectare}} \times 100$$

$$\text{Lopping percentage (\%)} = \frac{\text{Number of trees with lopped sign per hectare}}{\text{Total forest density per hectare}} \times 100$$

RESULTS

Composition of forest types

Species richness and diversity

The diversity among forest types varied significantly, showcasing a species richness ranging from 22 species in Mixed broad-leaved forest (FT5) to 5 species in Mainly *Quercus floribunda* forest (FT9). Shannon's Index ranged from 1.38 (FT9) to 2.81 (FT5) for trees, 1.54 (FT6) to 3.98 (FT3) for shrubs, and 2.23 (FT7) to 3.43 (FT5) for herbs. Simpson index values reflected similar patterns, with the highest observed in FT4/FT5 (0.93) for trees, FT4 (0.90) for shrubs, and FT5 (0.96) for herbs, and the lowest in FT9/FT10 (0.69) for trees, FT3 (0.71) for shrubs, and FT7 (0.88) for herbs. The Pielou evenness was recorded between 0.72 (FT1) to 0.93 (FT4) for the tree community, 0.88 (FT5) to 1.40 (FT3) for shrubs, and 0.97 (similar for FT1, FT2 and FT7) to 1.00 (FT8) for the herbaceous community (Table 2).

Species evenness index values ranged from 0.72 to 0.93 for trees, 0.88 to 1.40 for shrubs, and 0.97 to 1.00 for herbs. Notably, the highest value was observed in FT4 (0.93) for trees, FT3 (1.40) for shrubs, and FT8 (1.00) for herbs. Species richness varied considerably across the forest types, ranging from 5-22 for trees, 5-17 for shrubs, and 10-33 for herbs.

Density and stand basal area

A total of 8590 individual trees were recorded in the studied forest types. The mean stand density varied from 560 trees ha^{-1} in the FT7/FT10 forest to 1450 trees ha^{-1} in the FT5 forest (Table 2). The total basal area ranged from 42.10 m^2 ha^{-1} in FT2 to 116.36 m^2 ha^{-1} in FT10 forest. The highest shrub density was 3,020 ind ha^{-1} with a basal area of 5.54 m^2 ha^{-1}, observed in the FT9 forest, whereas FT5 exhibited the lowest shrub density at 100 indi ha^{-1} and a basal area of 1.79 m^2 ha^{-1}. For the herbaceous community, the FT5 forest had the highest density at 321,700 ind ha^{-1} and an abundance of 559.49 ind ha^{-1}, while the FT6 and FT1 forests recorded the lowest density at 18,400 ind ha^{-1} and the lowest abundance at 172.49 ind ha^{-1}, respectively.

Table 2. Phytosociological and diversity parameters of the studied forest types.

FT	Layer	SR	Den (ind ha^{-1})	TBC (m^2 ha^{-1})	Cd	SDI	($\bar{H}$)	Ep	Het
FT1	Herb	20	96100	-	0.05	0.94	2.92	0.97	4.19
	Shrub	8	2110	4.11	0.16	0.83	1.90	0.91	2.43
	Tree	14	950	49.70	0.23	0.76	1.91	0.72	2.05
FT2	Herb	29	206300	-	0.04	0.95	3.27	0.97	4.99
	Shrub	11	2250	4.04	0.11	0.88	2.28	0.95	2.98
	Tree	8	580	42.10	0.22	0.77	1.76	0.84	2.10
FT3	Herb	21	271100	-	0.05	0.94	2.99	0.98	4.40
	Shrub	17	2080	3.75	0.28	0.71	3.98	1.40	1.86
	Tree	21	1330	68.48	0.15	0.84	2.49	0.81	2.57
FT4	Herb	25	289100	-	0.04	0.95	3.16	0.98	4.81
	Shrub	15	2010	3.10	0.94	0.90	2.50	0.92	3.24
	Tree	20	810	43.64	0.06	0.93	2.80	0.93	3.78
FT5	Herb	33	321700	-	0.03	0.96	3.43	0.98	5.45
	Shrub	6	100	1.79	0.23	0.76	1.58	0.88	2.06
	Tree	22	1450	79.81	0.07	0.93	2.81	0.91	3.71
FT6	Herb	16	18400	-	0.06	0.93	2.73	0.98	3.85
	Shrub	5	980	2.30	0.22	0.77	1.54	0.95	2.08
	Tree	12	690	102.30	0.11	0.88	2.30	0.92	2.92
FT7	Herb	10	142800	-	0.11	0.88	2.23	0.97	2.99
	Shrub	7	1220	3.50	0.18	0.81	1.77	0.91	2.30
	Tree	6	560	100.22	0.29	0.70	1.48	0.83	1.83
FT8	Herb	15	122800	-	0.07	0.92	2.73	1.00	3.64
	Shrub	6	1350	2.55	0.22	0.77	1.62	0.90	2.10
	Tree	11	1080	112.46	0.22	0.77	1.88	0.78	2.12
FT9	Herb	21	221900	-	0.05	0.94	3.01	0.99	4.46
	Shrub	9	3020	5.54	0.12	0.87	2.14	0.97	2.84
	Tree	5	580	106.37	0.30	0.69	1.38	0.85	1.82
FT10	Herb	18	234100	-	0.05	0.94	2.87	0.99	4.15
	Shrub	8	2710	5.48	0.13	0.86	2.05	0.98	2.74
	Tree	6	560	116.36	0.30	0.69	1.44	0.80	1.81

Abbreviations: SR= Species richness; Den= Density; TBC= Total basal cover; Cd= Concentration of dominance; SDI= Simpson's index; ($\bar{H}$) = Shannon-Wiener index; Ep= Pielou evenness; Het= Species heterogeneity; FT= Forest type.

Population density

The population density of the enumerated 14 tree species varied considerably across the seven forest types. In FT1, *Quercus leucotrichophora* was the most abundant species per hectare (430 ind ha^{-1}) in terms of density and IVI. Dominant species in other forest types were as follows: *Alnus nepalensis* (260 ind ha^{-1}) in FT2, *Daphniphyllum himalense* (430 ind ha^{-1}) in FT3, *Rhododendron arboreum* (110 ind ha^{-1}) in FT4, Machilus duthiei (290 ind ha^{-1}) in FT5, *Abies pindrow* (120 ind ha^{-1}) in FT6, *Abies pindrow* (250 ind ha^{-1}) in FT7, *Acer caesium* (530 ind ha^{-1}) in FT8, *Q. floribunda* (280 ind ha^{-1}) in FT9, and *Q. semecarpifolia* (260 ind ha^{-1}) in FT10.

Himalayacalamus falconeri was the most abundant shrub species in terms of both density and IVI in FT6 (600 ind ha^{-1}), FT8 (820 ind ha^{-1}), FT7 (700 ind ha^{-1}), FT5 (640 ind ha^{-1}), and FT4 (540 ind ha^{-1}). In FT10, *Synotis kunthiana* (1040 ind ha^{-1}) was the most abundant species. *Drepanostachyum falcatum* was abundant in FT9 (980 ind ha^{-1}), FT1 (900 ind ha^{-1}), and FT2 (720 ind ha^{-1}). In FT3, *Sarcococca saligna* (460 ind ha^{-1}) was the dominant species.

In the herbaceous community, *Fragaria nubicola* was the dominant species in FT10 (258,000 ind ha^{-1}), FT7 (249,000 ind ha^{-1}), FT4 (209,000 ind ha^{-1}), FT3 (199,000 ind ha^{-1}) and FT8 (159,000 ind ha^{-1}) forests. *Ranunculus distans* (204,000 ind ha^{-1}) dominated (in terms of density) FT6, *Anaphalis contorta* (90,000 ind ha^{-1}) in FT1, *Geranium ocellatum* (173,000 ind ha^{-1})

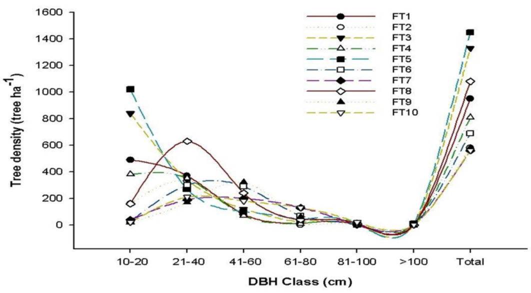

Fig. 3. Diameter class-wise distribution of stem density in different forest types.

in FT2, *Trifolium repens* (179,000 ind ha^{-1}) in FT5, and *Hemiphragma heterophyllum* (165,000 ind ha^{-1}) in FT9. *Fragaria nubicola* also dominated FT7 and FT8 in terms of IVI. Species heterogeneity ranged from 1.81 (FT10) to 3.78 (FT4) in the tree layer, from 1.86 (FT3) to 3.24 (FT4) in the shrub layer, and from 2.99 (FT7) to 5.45 (FT5) in the herb layer (Table 2).

Size class distribution

Tree density decreased with increasing diameter class. The 10-20 cm diameter class contributed the highest density and the lowest density was contributed by the > 100 cm diameter class in all forest types. Tree density in the lower diameter class (10-20 cm) was greater in FT5 (1,020 ind ha^{-1}), and the higher diameter class (61-80) was greater in FT7 and FT10 (both with 130 ind ha^{-1}) (Fig. 3).

Ecosystem services derived from the forests

Local residents venture 3-4 kilometers into the forest to gather essential resources, which include firewood, fodder, medicinal plants, fruits, vegetables, and other forest products. These materials are crucial for their daily lives, supporting both subsistence and traditional practices. These resources play a significant role in their economic and cultural activities, highlighting the community's deep connection with their natural environment.

In the Western Himalayas, fuelwood serves as the primary or sole energy source for cooking and heating in many remote households. This practice is crucial for local communities, highlighting the essential role of forest wood in the region. Forests supply essential fodder, including tree leaves and grass, for livestock. This fodder is vital for maintaining the health of cattles, which are crucial to the local economy and lifestyle by providing milk, meat, and other products. Leaf litter collected from the forest floor was first used as bedding material for cattles and then composted. The nutrient-rich compost enhances soil fertility, crucial for maintaining productive agricultural lands and supporting sustainable farming. Additionally, non-timber forest products are diverse and offer substantial benefits to local communities. In the studied forest, residents collect a variety of NTFPs, such as:

Myrica esculenta: The fruits of *M. esculenta* were collected in April and May. Fruits were consumed fresh and sold in local markets, providing both food and a source of income.

Rhododendron arboreum: The flowers of this plant were used to make juice and squash, and they also have medicinal properties, adding to their value.

Lichens**:** Lichens are found growing on the bark of trees. Lichens are harvested for use as dye and spices and are also used in pharmaceutical industries due to their medicinal properties.

Edible ferns**:** Edible ferns are foraged in forests and form an important part of the local diet. These ferns are nutritious and represent a traditional food source that has been harvested sustainably for generations.

Red soil for painting**:** Forests also supply red soil, used by local people for painting their traditional houses and kitchen hearths. This practice is both cultural and functional, enhancing the aesthetic and structural integrity of traditional homes.

Furthermore, timber remains a crucial resource despite strict governmental regulations on extraction. Forests provide wood essential for constructing furniture, agricultural implements, fencing, wood poles, and roof planks. This serves both functional and structural purposes, making it a valuable asset for local communities who rely on it to build and maintain their homes and tools. Apart from that, one of the most critical services provided by forests is the provision of fresh, clean water. Forests play a key role in the water cycle, helping to purify and regulate water supplies. This clean water is essential for drinking and irrigation, supporting the health of the local population and their agricultural activities.

Impact of anthropogenic activities across various forest types

The average disturbance index based on cut stump density was recorded at 10.60%, ranging from 6.45% in the Mainly *Quercus floribunda* forest (FT9) to 18.18% in the Mixed broad-leaved forest (FT4). Based on the total basal cover (TBC) of cut stumps, the average disturbance index was 6.03%, with values ranging from 2.90% in FT9 to 11.59% in the Mixed *Quercus leucotrichophora* forest (FT1). The highest cut stump density was observed in the Mixed broad-leaved forest (18.18%, FT4), Mixed *Quercus leucotrichophora* forest (17.39%, FT1), and Mainly *Quercus semecarpifolia* forest (11.11%, FT10). Conversely, the lowest value was recorded in Mainly *Quercus floribunda* forest (6.45%, FT9), Conifer mixed broad-leaved forest (6.75%, FT6) and Pure *Acer caesium* forest (7.69%, FT8) (Table 3).

The total basal cover (TBC) of cut stumps was highest in FT1 (11.59%), FT7 (10.28%), and FT4 (9.95%). Conversely, the lowest cut stump TBC value was observed in FT9 (2.90%), followed by FT5 (3.01%) and FT8 (3.80%). The lopping percentage ranged from 7.28% to 29.73%. The highest lopping percentage was observed in Mixed *Quercus leucotrichophora* forest (FT1) at 29.73%, followed by Mixed broad-leaved forest (FT4) at 25.01%, and Mixed broad-leaved forest (FT3) at 21.88%. The lowest lopping percentage was found in Mainly *Abies pindrow* forest (FT7,7.28%), Conifer mixed broad-leaved forest (FT6, 7.57%), and Mainly *Quercus floribunda* forest (FT9 8.33%).

Table 3. Disturbance indices of studied forest types.

Forest type	Elevation (m asl)	Disturbance category	Cut DEN%	TBC Cut%	Lop int %
FT1	1500-1650	FD	17.39	11.59	29.73
FT2	1550-1650	MD	10.76	4.86	17.02
FT3	1650-1950	MD	10.13	3.89	21.88
FT4	1900-2150	FD	18.18	9.95	25.01
FT5	2150-2400	MD	9.37	3.01	20.85
FT6	2400-2550	LD	6.75	6.97	7.57
FT7	2500-2600	LD	8.19	10.28	7.28
FT8	2550-2650	LD	7.69	3.80	9.83
FT9	2550-2650	LD	6.45	2.90	8.33
FT10	2650-2850	MD	11.11	5.30	10.95

Abbreviations: TBC Cut= Total basal cover percentage of cut stump; Cut DEN= Cut stump density; Lop Int= Lopping Intensity %; m asl= Meter above sea level.

DISCUSSION

Forest composition

In temperate forests, the mixed broad-leaved forest exhibited the highest mean tree species richness, with a decline observed from highly disturbed to least disturbed areas (López *et al.* 2011). Our study corroborates these findings, showing that lower-elevation forests harbor greater species richness compared to higher elevations, as proposed by López *et al.* (2011). Across various forest types, tree density ranged from 560 to 1,450 ind ha^{-1}, exceeding the previously recorded value of 235±9 to 505±21 ind ha^{-1} reported by (Malik *et al.* 2015). Conversely, shrub densities were lower than those documented in previous studies, ranging from 100 to 3,020 ind ha^{-1}, compared to 4,730±474 to 9,530±700 ind ha^{-1} in the Garhwal Himalayan region (Malik *et al.* 2015). The variation in densities may be influenced by climate, soil characteristics, disturbance regimes, management practices, species composition, and biogeographical factors, as documented in previous research (Gottschall *et al.* 2019, Hertzog *et al.* 2021). In the present study, the total basal area of trees ranged from 42.10 to 116.36 m^2 ha^{-1}, surpassing the reported range (21.72 to 95.41 m^2 ha^{-1}) in the Garhwal Himalayan region (Tiwari and Sharma 2023) and in temperate forests of Bhagirathi Catchment (25.8±2.2 to 88.1±23.6 m^2 ha^{-1}) (Tiwari *et al*. 2019). The TBC for the shrub layer ranged from 1.79 m^2 ha^{-1} to 5.54 m^2 ha^{-1}, which was greater than the value 0.36±0.024 to 0.62±0.047 m^2 ha^{-1} recorded by Malik *et al.* (2015) in the Garhwal Himalayan region. The species diversity Shannon index ($\bar{H}$) exhibited a range of values across various forest types: 1.38-2.81 for trees, 1.54-3.98 for shrubs, and 2.23-3.43 for the herb layer. These findings contrast with those Malik *et al.* (2015) reported, where the species diversity Shannon index ($\bar{H}$) ranged from 2.30 to 3.53 for trees and 2.74 to 3.78 for shrubs.

Forest resource utilization

The forests in this region provide various resources that are essential for sustenance, including food, fodder, timber, and wild edibles. Many households in the study area own livestock, and women from the villages spend approximately 2 to 4 hours collecting these forest resources daily, which forms a significant part of their daily routine. Forests in the Garhwal Himalaya region are vital for local livelihoods, offering year-round green fodder, timber, fuelwood, and various Non-Timber Forest Products (NTFPs). These resources are crucial for supporting the rural economy and livelihoods (Negi 2022). Additionally, the use of firewood and non-timber forest products is widespread among communities in other parts of the Western Himalayan region (Nagahama *et al.* 2016). Globally, a significant proportion of harvested wood is used as fuel for cooking, heating water, and warming homes, particularly during winter (Jalas and Rinkinen (2016)). Leaf litter collected from the forest floor serves as cattle bedding, absorbing moisture from urine and helping keep animals warm in winter. After use, this litter was transferred to compost pits, where it decomposes over 5 to 6 months before being used to enrich crop fields.

In the subtropical and temperate zones of the Western Himalayas, average daily fuelwood and fodder consumption per household was found to be 14.93 kg and 63.80 kg, respectively (Singh *et al.* 2017). In the montane region of Uttarakhand, Sati and Song (2012) reported daily fuelwood consumption of around 13 kg. Dhyani and Dhyani (2016) noted that in the Kedarnath Wildlife Sanctuary, fuelwood consumption was approximately 35 kg every 2 to 3 days. Additionally, Singh *et al.* (2017) found that average fodder consumption was 1858 kg per household per month, while Malik *et al.* (2014a) reported fodder consumption of 1318 kg per household per month in the Western Himalayas. Singh *et al.* (2018) highlighted that local communities in the Rudraprayag district of Uttarakhand relied heavily on forests for fuelwood and fodder, with each household collecting around 7–10 tons of fuelwood and 8–12 tons of fodder annually.

Anthropogenic disturbance and its impact on forest ecosystems

In this study, we observed an average disturbance index of 10.60% based on the density of cut stumps, ranging from 6.45% to 18.18%. Additionally, the average disturbance index based on the total basal cover (TBC) of cut stumps was recorded at 6.25%, ranging from 2.90% to 11.59%. A higher percentage of disturbance indices was noted in the forest types (FT1, FT4, and FT10) near the human settlements, providing maximum ecosystem services. FT1 represents a forest type dominated by *Q. leucotrichophora* and *R. arboreum,* which are excellent sources of fuelwood and fodder (Singh *et al.* 2014). Shrub species such as *H. falconeri* ("dev ringal") are widely used in making traditional utensils and artwork. FT10 is close to the tourist site and is therefore disturbed by local shop owners who use fuelwood for cooking. These findings are consistent with previous regional studies, highlighting the pervasive nature of anthropogenic disturbances in the Garhwal Himalaya. For instance, Bhat *et al.* (2012) reported cut stump densities ranging from 20 to 110 ha^{-1} and a lopping percentage of 0.47% to 7.39% in a protected area of Garhwal Himalaya. Although the studied area is part of a reserve forest, conversation practices are not effectively implemented, particularly in the areas most affected by anthropogenic disturbance. Malik *et al.* (2016) reported that the density of cut stumps in the Kedarnath Wildlife Sanctuary (KWLS) ranged from 80 ± 3 to 125 ± 4 ha^{-1}, while the percentage of lopping varied between 29.78% and 46.92%.

Similarly, Tiwari *et al.* (2019) and Tiwari and Sharma (2023) reported cut stem density percentages ranging from 90% to 175 % and 7.19% to 29.33%, lopping percentages of 10.2% to 35.9% and 8.86% to 91.49%, and litter removal percentage of 6% to 42% and 10% to 70% respectively in the temperate forests of Western Himalaya, these patterns underscore the considerable dependence of local communities on forest resources, leading to substantial anthropogenic impacts. Furthermore, Mittal *et al.* (2020) discussed the poor regeneration of *Quercus* species, which is dominant in Mixed *Quercus leucotrichophora* forest (FT1) and showed high disturbance indices in our studied forest type. This supports the notion that minor lopping disturbances can enhance species richness in the area (Mikoláš *et al*. 2021). This high level of disturbance indicates widespread human activity affecting forest composition, structure, and regeneration. These studies, including ours, collectively illustrate a clear and concerning trend of extensive human impact on forest ecosystems in the Garhwal Himalaya.

Moreover, studies highlight the urgent need to assess forest resource diversity, extraction trends, and species preference, particularly for fodder and fuel, due to rising demand and biodiversity loss in the Indian Himalayas (Chauhan *et al.* 2018). The exploitation of forest resources by rural inhabitants over generations has led to severe deforestation, underscoring the essential role forests play in supporting livelihoods (Husen 2013). Effective conservation strategies are crucial for sustainable management and the long-term resilience of these ecosystems.

CONCLUSION

Our study reveals a complex interplay between biodiversity and human impact. The diversity indices indicate a wealth of indigenous species, which not only enhance the region's biodiversity but also provide numerous resources to the local inhabitants. Forests in close proximity to human settlements were found to be more susceptible to degradation, underscoring the pronounced influence of human activities on forest ecosystems and the services they provide. Our findings emphasize the critical need for adaptive forest management and conservation initiatives that integrate community-based approaches to preserve biodiversity, sustain ecosystem functionality, and support local livelihoods, thereby ensuring the long-term resilience of these Himalayan forest ecosystems.

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REFERENCES

Ashton P, Aiba S, Zhu H, Pradhan R (2022) Further food for thought: Higher tropical mountains revisited once again. *Tropics* 31(3): 43-57. https://doi.org/10.3759/tropics.ms21-16

Balasubramanian M (2022) Economic value of cultural ecosystem services in India: A review. https://doi.org/10.5772/intechopen.98892

Batar A, Shibata H, Watanabe T (2021) A novel approach for forest fragmentation susceptibility mapping and assessment: A case study from the Indian Himalayan region. *Remote Sensing*, 13(20): 4090. https://doi.org/10.3390/rs13204090

Bhat Jahangeer A, Negi KM, Ajeet K, Todaria NP (2012) Anthropogenic pressure along altitudinal gradient in a protected area of Garhwal Himalaya, India. *J Environ Res Develop* 7(1) : 62-65.

Chakraborty A, Joshi P, Sachdeva K (2017) Capturing forest dependency in the central Himalayan region: Variations between oak (*Quercus* spp.) and pine (*Pinus* spp.) dominated forest landscapes. Ambio. https://doi.org/10.1007/s13280-017-0947-1

Chauhan JS, Gautam AS, Negi RS (2018) Natural and anthropogenic impacts on forest structure: a case study of Uttarakhand state. *The Open Environmental Research Journal* 11(1) : In press

Cottam G, Curtis JT (1956) The use of distance measures in phytosociological sampling. *Ecology* 37(3): 451–460.

Curtis JT, McIntosh RP (1950) The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* 31(3): 434–455.

Danneyrolles V, Dupuis S, Fortin G, Leroyer M, Römer A, Terrail R, Arseneault D (2019) Stronger influence of anthropogenic disturbance than climate change on century-scale compositional changes in northern forests. *Nature Communications* 10(1) : https://doi.org/10.1038/s41467-019-09265-z

Darboe S (2023) "Forest is integral to life": People-forest relations in the lower river region, the gambia. Frontiers in Forests and Global Change, pp 6. https://doi.org/10.3389/ffgc.2023.1181013

Dhyani S, Dhyani D (2016) Significance of provisioning ecosystem services from moist temperate forest ecosystems: Lessons from upper Kedarnath valley, Garhwal, India. *Energy Ecology and Environment* 1: 109-121.

Gairola S, Sharma C, Ghildiyal S, Suyal S (2012) Regeneration dynamics of dominant tree species along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya. Journal of Forestry Research 23(1) : 53-63. https://doi.org/10.1007/s11676-012-0233-9

Gaur RD (1999) Flora of the District Garhwal, North West Himalaya, Transmedia.

Gottschall F, Davids S, Newiger-Dous TE, Auge H, Cesarz S, Eisenhauer N (2019) Tree species identity determines wood decomposition via microclimatic effects. *Ecology and Evolution* 9 (21): 12113-12127. https://doi.org/10.1002/ece3.5665

Hertzog LR, Vandegehuchte ML, Dekeukeleire D, Dekoninck W, Smedt PD, Lantman IvS, Lens L (2021) Mixing of tree species is especially beneficial for biodiversity in fragmented landscapes, without compromising forest functioning.

Journal of Applied Ecology 58(12): 2903-2913. https://doi.org/10.1111/1365-2664.14013

Husen A. (2013). Growth characteristics, biomass and chlorophyll fluorescence variation of Garhwal Himalaya's fodder and fuel wood tree species at the nursery stage. *Open Journal of Forestry* 3(01): 12-16. https://doi.org/10.4236/ojf.2013.31003

Hussain J, Akbar M, Ali S, Raza G, Khan A, Zafar M, Hussian F (2019) Assessing natural forest conservation in Pakistan. *Polish Journal of Environmental Studies* 29(1) : 629-640. https://doi.org/10.15244/pjoes/102785

Jalas M, Rinkinen J (2016) Stacking wood and staying warm: Time, temporality and housework around domestic heating systems. *Journal of Consumer Culture* 16(1) : 43-60.

Kent M, Coker P (1992) Vegetation Description and Analysis Belhave Press London, pp 363.

López-Pujol J, Zhang FM, Sun HQ, Ying TS, Ge S (2011) Centers of plant endemism in China: Places for survival or for speciation?. *Journal of Biogeography* 38(7) : 1267-1280.

Malik ZA, Bhat JA, Ballabha R, Bussmann RW, Bhatt AB (2015) Ethnomedicinal plants traditionally used in health care practices by inhabitants of Western Himalaya. *Journal of Ethnopharmacology* 172 : 133-144.

Malik ZA, Bhat JA, Bhatt AB (2014a) Forest resource use pattern in Kedarnath Wildlife Sanctuary and its fringe areas (a case study from Western Himalaya, India). *Energy Policy* 67 : 138-145.

Malik ZA, Pandey R, Bhatt AB (2016) Anthropogenic disturbances and their impact on vegetation in Western Himalaya, India. *Journal of Mountain Science* 13(1) : 69-82.

Mikoláš M, Svitok M, Bače R, Meigs GW, Keeton WS, Keith H, Svoboda M (2021) Natural disturbance impacts on trade-offs and co-benefits of forest biodiversity and carbon. *Proceedings of the Royal Society B* 288(1961): 20211631.

Mittal A, Singh N, Tewari A (2020) Quantitative analysis and regeneration status of forest trees species in Kumaun Central Himalaya. *Indian Journal of Ecology* 47(2) : 507-513.

Murali KS, Shankar U, Shaanker RU, Ganeshaih KN, Bawa KS. (1996) Extraction of non-timber forest products in the forests of Biligiri Rangan Hills, India. 2. Impact of NTFP extraction on regeneration, population structure, and species composition. *Econ Bot* 50: 252-269. DOI: 10.1007/ BF02907329.

Nagahama K, Saito K, Masuda M, Ota M, Gairola H, Kala S, Rakwal R (2016) Forest commons use in India: A case study of van panchayat in the Himalayas reveals people's perception and characteristics of management committee. *Environment and Ecology Research* 4(3) : 128-139. https://doi.org/10.13189/eer.2016.040304

Naithani BD (1984–85) Flora of Chamoli. 2 Vols. Botanical Survey of India, Howrah.

Negi GCS (2022) Trees, forests and people: The Central Himalayan case of forest ecosystem services. *Trees Forests and People* 8 : 100222.

Phillips EA (1959) Methods of vegetation study. Henry Hill & Co, Inc. USA, pp 107.

Pielou EC (1966) The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* 13 : 131–144.

Ram Prakash (1986) Forest Management. International Book Distributors, Dehradun, India, pp 214.

Rather J (2015) An ethno-botanical overview of oak: A multipurpose wild tree species of the Pirpanjal Himalayas. *Forest Research Open Access* 04(02): https://doi.org/10.4172/2168-9776.1000140

Samant S (2021) Floristic diversity of the Himalaya in relation to climate change: Status, values and conservation. *Journal of Graphic Era University*. https://doi.org/10.13052/jgeu0975-1416.913

Sati VP, Song C (2012) Estimation of forest biomass flow in the montane mainland of the Uttarakhand Himalaya. *International Journal of Forest, Soil and Erosion (IJFSE)* 2(1) : 1-7.

Shannon CE, Weaver W (1963) The mathematical theory of communication. Urbana, USA, University of Illinois Press, pp117.

Simpson EH (1949) Measurement of diversity. *Nature* 163: 688.

Singh DK, Pusalkar PK (2020) Floristic diversity of the Indian Himalaya. Biodiversity of the Himalaya: Jammu and Kashmir State, pp 93-126.

Singh H, Malik ZA, Baluni P (2017) Forest resource use pattern in relation to socio-economic status (A Case Study from Two Altitudinal Zones of Western Himalaya, India). *The Indian Forester* 143(4): 334-343.

Singh RD, Tewari P, Dhaila P, Tamta KK (2018) Diversifying livelihood options of timberline resource dependent communities in Uttarakhand Himalayas: Conservation and development implications. *Tropical Ecology* 59 (2) : 327-338.

Singh SP, Singh V, Skutsch M (2010) Rapid warming in the Himalayas: Ecosystem responses and development options. *Climate and Development* 2(3): 221-232.

Singh V, Thadani R, Tewari A, Ram J (2014) Human influence on banj oak (*Quercus leucotrichophora* A. *camus*) forests of Central Himalaya. *Journal of Sustainable Forestry* 33(4): 373-386.

Thakur AK, Singh G, Singh S, Rawat GS (2011) Impact of pastoral practices on forest cover and regeneration in the outer fringes of Kedarnath Wildlife Sanctuary, Western Himalaya. *Journal of the Indian Society of Remote Sensing* 39 : 127-134.

Tiwari OP, Sharma CM (2023) Anthropogenic disturbance impact on forest composition and dominance-diversity: A case of an ecosensitive region of Garhwal Himalaya, India. *Acta Ecologica Sinica* 43 (4): 662-673.

Tiwari OP, Sharma CM, Rana YS, Krishan R (2019) Disturbance, diversity, regeneration and composition in temperate forests of Western Himalaya, India. *Journal of Forest and Environmental Science* 35(1) : 6-24.

Wei Y, Li M, Cai H, Lewis B, Yu D, Zhou L, Dai L (2013) Variation in carbon storage and its distribution by stand age and forest type in boreal and temperate forests in Northeastern china. *Plos One* 8(8) : e72201. https://doi.org/10.1371/journal.pone.0072201

Xia X, Xia J, Chen X, Fan L, Qin Y, Qin Z, Yuan W (2023) Reconstructing long-term forest cover in China by fusing national forest inventory and 20 land use and land cover data sets. *Journal of Geophysical Research: Biogeosciences* 128(4) : In press. https://doi.org/10.1029/2022jg007101