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AN INSIGHT INTO WOODY SPECIES IN SUB-TEMPERATE FOREST ECOSYSTEM IN DARJEELING HIMALAYA, INDIA: AN EVALUATION OF SPECIES COMPOSITION AND DIVERSITY

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The present study aims to determine woody species composition and diversity in sub-temperate forests of Darjeeling Himalaya. In order to collect data, sample plots sized 20 m × 20 m were deployed and the diameter at breast height (DBH) of all woody species was measured. A total number of 609 individuals belonging to 30 families under 41 genera and 51 species were encountered. The most frequently occurring species were *Cryptomeria japonica, Lithocarpus fenestratus, L. pachyphyllus, Quercus glauca, Eriobotrya dubia, Syzygium kurzii, Alnus nepalensis, Exbucklandia populnea* and *Magnolia lanuginosa*. The values of Shannon and Menhinick indices were 3.870 and 2.067 respectively. Similarly, dominance was estimated as 0.022 while evenness showed a value of 0.984. Furthermore, the total basal area estimated was 186.632 m^2 ha^{-1} and the importance value index ranged from 2.013 to 16.855. Moreover, dominance-diversity (d-d) curve showed a log-normal species distribution. The regeneration status of dominant woody saplings revealed that 40% showed good regeneration, 20% had poor regeneration while 40% lacked regeneration. These findings provide an enhanced understanding of woody stands diversity and composition in the study area.

Keywords: Conservation, distribution, eastern Himalaya, importance value index, regeneration

INTRODUCTION

The Himalayas are the world's youngest and richest mountain ecosystems with remarkable biodiversity and forest types (Dar & Sundarapandian 2016, Kumari et al. 2017). The forest vegetation gradient in the Himalayas vary from species rich tropical dry-deciduous forests in the lower altitude to alpine meadow at higher elevations (Champion & Seth 1968, Singh et al. 1994, Gairola et al. 2011b, Kumari et al. 2017). The structure of woody species in Himalayan forest varies considerably from one location to another due to variation in altitude, slope orientation, nature of soil and intensity of disturbances (Chettri & Shrestha 2019). The Himalayan ecosystems, due to their exclusive and inimitable biodiversity, have been placed amongst 36 recognised Global Biodiversity Hotspots (Myers et al. 2000, Dar & Sundarapandian 2016, Dar & Parthasarathy 2021). The Indian Himalayan Region (IHR) covers a large portion of the Himalaya biodiversity hotspot harbouring 18,440 plant species which includes 1,748 medicinal plants, 675 wild edible plants and 118 essential oil-yielding plants (Stephan et al. 2015). The temperate forests appear to be widely distributed over the mid-altitudinal belt of the Himalaya and are characterised by Oak and Conifers (Gairola et al. 2011b). These forests are generally marked by climatic contrast between warm summer and cold winter (Yam & Tripathi 2016). In India, temperate forest represents 6.74% of the total geographical area and 12.84% of the Himalayan region (FSI 2019). Temperate forest composition shows variation in response to physiographic cofactors and microclimates that have direct association with soil moisture and distribution of vegetation (Sharma et al. 2009, Gairola et al. 2012, Saha et al. 2018, Tiwari et al. 2020). Along with conservation, these forests also play a significant role in global carbon sequestration, climate change, protecting the soil, building soil nutrients reservoir and providing services to human (Gairola et al. 2011a). Unfortunately, the fragile temperate forest ecosystems are now facing threats by environmental degradation and climate change than any other mountain forests of the world (Sharma et al. 2008, Pandey 2017, Chauhan et al. 2020, Dhamala et al. 2020, Pokhriyal et al. 2020). The loss of biodiversity resources will lead to several consequences, both ecologically and environmentally (Saikia et al. 2017). Therefore, knowledge on the plant community, diversity, population, distribution, regeneration and environmental impacts are fundamental for the conservation and proper management of these forests (Gairola et al. 2011b, Pandey et al. 2016, Thakur et al. 2021).

Species, as indicated by Odum (1959), is considered as the vital analytical features of a plant community (Malik et al. 2014, Singh et al. 2016, Bhat et al. 2020). Species composition and diversity patterns are essential ecological attributes of forest ecosystem and knowledge of these are prerequisite for the precise evaluation of biodiversity (Timilsina et al. 2007, Shaheen et al. 2012, Zhang et al. 2013, Thakur et al. 2021). Trees are the key structural components of the forest ecosystems and provides ample of ecosystem services (Hall et al. 1976, Huston 1994, Huang et al. 2003, Kikim et al. 2012, Sharma & Kant 2014, Pala et al. 2016, Rawat et al. 2018, Rawat et al. 2020). Woody species composition in forest ecosystems are largely determined by the ecological characteristics, habitat, history of disturbance, diversity and regenerative status of species (Singh et al. 2016). In forest, trees underpin the overall physical structure of habitat and thus, leads to variations in the environmental heterogeneity and structural complexity ((Jones et al. 1997, Singh et al. 2016). As a key structural component for forest ecosystem, regular monitoring and proper management of trees is crucial in order to understand different chronosequences of succession to conserve species and habitat diversity (Turner 1979, Attua & Pabi 2013, Naidu & Kumar 2016). However, woody species of forest ecosystem are seriously threatened due to anthropogenic drivers such as changes in land use for agriculture, timber extraction for source of energy and building material (Senbeta & Teketay 2003, Soromessa et al. 2004, Amsalu et al. 2007, Alemu et al. 2012, Bewket & Abebe 2013, Kindu et al. 2013, Meshesha et al. 2013, Mishra et al. 2013). Various parameters viz., time, altitude, slope, aspect, soil, humidity and precipitation play a pivotal role in determining the woody species composition and consequently forest structure (Sharma et al. 2009, 2010, Gairola et al. 2011b). Moreover, a positive influence of precipitation on diameter of tree and the basal area of forest has been demonstrated (Walther et al. 2010, Toledo et al. 2011).

Measuring the diversity is one of the ways to access the soundness of ecological ecosystems (Gairola et al. 2011a). Forest structure and composition are significantly linked to environmental gradients, such as, climatic and physiographic variables, while woody vegetation is strongly influenced by variabilty in the microclimate, altitude and aspect (Pande et al. 2002, Gairola et al. 2008, Ahmad et al. 2010). Thus, continuous assessment of the forest structure and composition is crucial to understand the population, regenerative status and diversity of species (Mishra et al. 2013, Singh et al. 2016, Dash et al. 2021, Das et al. 2021). Knowledge of forest structure and diversity therefore is useful for identifying ecologically and economically essential plants taxa (Addo-Fordjour et al. 2009). In a forest, study on population structure provides a key insight whether or not a particular population has a stable distribution (Tesfaye et al. 2010).

The Darjeeling Himalaya comprises an integral part of eastern Himalaya that supports rich and unique biodiversity. Of the total geographical area, 74.62% comes under forests that support two national parks and three wildlife sanctuaries (ISFR 2021). The microclimatic variations in the region have resulted in establishing mosaic forest types (Das 2004). Forest inventory data provides information on species richness and diversity that are useful tools in conservation of biodiversity. Detailed knowledge about the woody species composition and diversity is still lacking in the study area. Therefore, the present study was conceptualised with an aim to inventorise the woody species composition and diversity in sub-temperate forest ecosystem, to understand the regeneration status of woody saplings and to provide baseline information for the conservation and management plan of the forest.

MATERIALS AND METHODS

Study area

The present study is focussed on Darjeeling eastern Himalaya that extends from 27° 13' to 26° 27' N latitude and 88° 53' to 87° 59' E longitude and forms an integral part of eastern Himalayan Biodiversity hotspot. The area remains bordered by Bhutan in the east to Nepal in the west and Sikkim towards the north (Figure 1). The extensive climatic conditions and elevation gradients characterises the area into five major vegetation types, from tropical vegetation at the lowest to sub-alpine vegetation at highest elevation (Bhujel 1996). The mid elevational sub-temperate vegetation ranges from 1200 to 1850 metre above sea level (masl) and encompasses a mixture of both the temperate and the sub-tropical flora. The region falls under Cwb (subtropical highland climate) category as per Koppen climate classification system exhibiting a temperate climate with warm summer and dry winter (De et al. 2016, Sarkar et al. 2016). The average monthly temperature varies with a minimum of 2 °C during winter to a maximum 24 °C in the month of August with an average annual precipitation of about 3373 mm.

Sampling design and data collection

The phytosociological assessment of the woody species was carried out by laying random quadrats of 20 m × 20 m (0.04 ha). Number of individuals of each species within the respective quadrats was enumerated. The circumference at breast height (CBH) of each tree ≥ 15 cm was measured with a diameter tape at 1.37 m above the ground. The diameter at breast height (DBH) was then extracted using the formula, DBH = CBH/π. Tree stands were classified into successive diameter classes, viz., 15–30 cm, 30–45 cm, 45–60 cm, 60–75 cm and > 75 cm. The coordinates and elevation of the quadrats laid were determined using GPS. Different volumes of suitable floras and literatures were used to identify the woody species (Cowan & Cowan 1929, Hara 1966, 1971, Ohashi 1975, Grierson & Long 1983, 1984, 1987, 1991, 2001, Noltie 1994). Additionally, the specimens were taken to Calcutta University Herbarium (CUH) for further confirmation and proper nomenclature of the taxa was maintained following World Flora Online (WFO 2022).

Vegetation analysis

For vegetation analysis, the number of woody species recorded was used to extract the frequency (F) which refers to the dispersion or occurrence of species in a given sampling unit. The density (D) is defined as the total number of individual species occurring within a given quadrat and expressed in per unit area basis while basal area refers to cross-sectional area of each woody species measured at breast height. Furthermore, basal area is deployed to ascertain the dominance (Do) of a tree species which determines the degree of one species having a significant influence or control on other species in a particular forest type (Curtis & McIntosh 1950, Phillips 1959, Misra 1968).

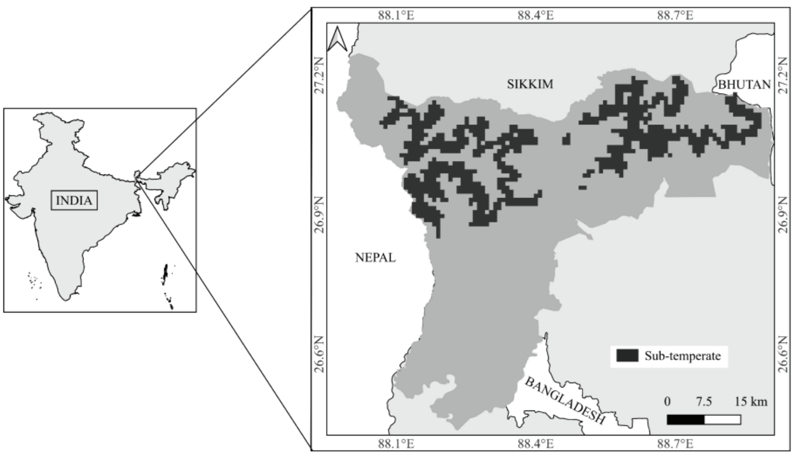

Figure 1 Map of the study area

$$\text{Frequency (F\%)} = \frac{\text{number of qadrats in which a species occured}}{\text{total number of quadrats studied}} \times 100$$

$$\text{Density (D)} = \frac{\text{total number of individual of a species in all quadrats}}{\text{total number of quadrats studied}}$$

$$\text{Basal area (BA)} = \frac{\pi\,(\text{DBH})^2}{4}$$

$$\text{Dominance (Do)} = \frac{\text{basal area of species}}{\text{area sampled}}$$

The importance value index (IVI) was then used to compare the complete or overall ecological significance of species in a plant community (Lamprecht 1989). The relative values as relative frequency (RF), relative density (RD) and relative dominance (RDo) were summed up to extract VI = Σ[RF + RD + RDo] for a species (Curtis 1959).

The ratio of abundance to frequency (A/F) for different species was used to understand the spatial distribution pattern of woody taxa (Whitford 1949). This ratio indicates regular (< 0.025), random (0.025–0.05) and contiguous (> 0.05) distributions (Curtis & Cottam 1956).

Significant diversity indices such as Shannon-Weaver diversity index $H' = -\Sigma(n_i/N)^2 \ln(n_i/N)$, Menhinick's species richness index $E = S/\sqrt{N}$, index of dominance $D' = \Sigma(n_i/N)^2$ and species evenness index $J = H'/\ln S$ were commonly used to analyse the diversity of woody taxa in the study area (Simpson 1949, Shannon & Weaver 1963, Menhinick 1964, Pielou 1966) .

To ascertain the resource allocation among tree species of the study sites, dominance-diversity (d-d) curves were deduced. The d-d curves were drawn by plotting IVI on the y-axis and the sequence of species from highest to lowest IVI on the x-axis for woody taxa (Whittaker 1975).

Analysis of regeneration status

The regeneration status of saplings for dominant woody plant taxa was observed during the following year with estimation of its density (Dhaulkhandi et al. 2008, Yemata & Haregewoien 2022). The study of regeneration of plant taxa is important for the management and conservation of forests (Balkrishna et al. 2020).

RESULTS

Species composition and diversity

In total, 51 woody species belonging to 41 genera and 30 families were recorded from 40 quadrats examined from the study area. With regard to species number, Lauraceae was the most common family with seven species (13.72%) under 6 genera, followed by Fagaceae with four species (7.84%) under 2 genera, while Araliaceae, Euphorbiaceae, Magnoliaceae, Meliaceae and Sapindaceae had 3 species each (5.88%). Three families, Anacardiaceae, Betulaceae and Rosaceae contributed two species each and the remaining 19 families, viz., Actinidiaceae, Asteraceae, Calophyllaceae, Cornaceae, Cupressaceae, Daphniphyllaceae, Elaeocarpaceae, Fabaceae, Hamamelidaceae, Juglandaceae, Malvaceae, Moraceae, Myrtaceae, Pandaceae, Pentaphylacaceae, Phyllanthaceae, Polygalaceae, Rutaceae and Theaceae comprised of single species each (Table 1). The species to genera ratio (S/G) and species to family ratio (S/F) were found to be 1.24 and 1.70 respectively.

The Shannon-Weaver diversity index for the woody taxa was 3.870, Menhinick index of species richness was 2.067, Simpson index for dominance was 0.022 and Pielou evenness index was 0.984. Furthermore, Shannon index value were arranged in descending order, the highest index was reported for *Cryptomeria japonica* (0.116), followed by *Eriobotrya dubia* and *Exbucklandia populnea* (0.112), while the lowest one was reported for *Acer oblongum* (0.039).

Frequency and density

In quadrat sampling, frequency of a species is defined as the probability of finding an

Table 1 Phytosociological attributes of woody species in the study area

Species	Family	F	RF	D	RD	Do	RDo	IVI	A/F
Acer campbellii	Sapindaceae	35	2.881	0.43	2.791	4.524	2.420	8.092	0.035
Acer oblongum	Sapindaceae	10	0.823	0.13	0.821	0.689	0.369	2.013	0.125
Acer thomsonii	Sapindaceae	10	0.823	0.15	0.985	1.377	0.737	2.545	0.150
Actinodaphne sikkimensis	Lauraceae	27.5	2.263	0.40	2.627	2.601	1.391	6.282	0.053
Aglaia perviridis	Meliaceae	22.5	1.852	0.25	1.642	1.555	0.832	4.326	0.049
Alangium alpinum	Cornaceae	17.5	1.440	0.20	1.314	1.07	0.572	3.326	0.065
Alnus nepalensis	Betulaceae	37.5	3.086	0.48	3.120	4.299	2.300	8.506	0.034
Aphanamixis polystachya	Meliaceae	22.5	1.852	0.28	1.806	2.219	1.187	4.845	0.054
Betula alnoides	Betulaceae	17.5	1.440	0.23	1.478	1.588	0.849	3.768	0.073
Bombax ceiba	Malvaceae	22.5	1.852	0.25	1.642	2.468	1.320	4.814	0.049
Brassaiopsis glomerulata	Araliaceae	30	2.469	0.35	2.299	1.771	0.947	5.715	0.039
Brassaiopsis hainla	Araliaceae	30	2.469	0.40	2.627	2.019	1.080	6.176	0.044
Calophyllum polyanthum	Calophyllaceae	20	1.646	0.23	1.478	1.555	0.832	3.956	0.056
Cinnamomum bejolghota	Lauraceae	27.5	2.263	0.30	1.970	1.415	0.757	4.991	0.040
Cryptomeria japonica	Cupressaceae	30	2.469	0.53	3.448	20.447	10.937	16,855	0.058
Daphniphyllum himalayense	Daphniphyllaceae	25	2.058	0.38	2.463	3.009	1.610	6.130	0.060
Elaeocarpus lanceifolius	Elaeocarpaceae	17.5	1.440	0.20	1.314	1.934	1.035	3.788	0.065
Engelhardia spicata	Juglandaceae	22.5	1.852	0.25	1.642	5.288	2.829	6.322	0.049
Eriobotrya dubia	Rosaceae	40	3.292	0.50	3.284	3.168	1.695	8.271	0.031
Eriobotrya petiolata	Rosaceae	35	2.881	0.38	2.463	2.275	1.217	6.561	0.031
Erythrina variegata	Fabaceae	17.5	1.440	0.23	1.478	3.494	1.869	4.787	0.073
Eurya acuminata	Pentaphylacaceae	27.5	2.263	0.38	2.463	2.515	1.345	6.072	0.050
Exbucklandia populnea	Hamamelidaceae	37.5	3.086	0.50	3.284	4.676	2.501	8.872	0.036
Ficus neriifolia	Moraceae	22.5	1.852	0.25	1.642	1.909	1.021	4.515	0.049
Glochidion acuminatum	Phyllanthaceae	22.5	1.852	0.23	1.478	1.61	0.861	4.191	0.044
Lithocarpus fenestratus	Fagaceae	30	2.469	0.40	2.627	13.219	7.071	12.167	0.044
Lithocarpus pachyphyllus	Fagaceae	27.5	2.263	0.40	2.627	12.5	6.686	11.577	0.053
Litsea elongata	Lauraceae	20	1.646	0.23	1.478	1.212	0.648	3.772	0.056
Litsea glutinosa	Lauraceae	20	1.646	0.25	1.642	2.061	1.102	4.391	0.063
Macaranga denticulata	Euphorbiaceae	27.5	2.263	0.40	2.627	4.771	2.552	7.443	0.053
Macaranga indica	Euphorbiaceae	22.5	1.852	0.28	1.806	2.917	1.560	5.218	0.054

continued

Table 1 Continued

Species	Family	F	RF	D	RD	Do	RDo	IVI	A/F
Machilus edulis	Lauraceae	27.5	2.263	0.38	2.463	4.955	2.650	7.377	0.050
Magnolia cathcartii	Magnoliaceae	22.5	1.852	0.30	1.970	9.115	4.876	8.698	0.059
Magnolia doltsopa	Magnoliaceae	20	1.646	0.28	1.806	4.092	2.189	5.641	0.069
Magnolia lanuginosa	Magnoliaceae	37.5	3.086	0.45	2.956	5.179	2.770	8.812	0.032
Monosis volkameriifolia	Asteraceae	12.5	1.029	0.15	0.985	0.213	0.114	2.128	0.096
Neocinnamomum caudatum	Lauraceae	20	1.646	0.23	1.478	1.577	0.844	3.967	0.056
Neolitsea umbrosa	Lauraceae	17.5	1.440	0.23	1.478	1.202	0.643	3.561	0.073
Ostodes paniculata	Euphorbiaceae	25	2.058	0.30	1.970	1.886	1.009	5.037	0.048
Pandanus furcatus	Pandanaceae	17.5	1.440	0.20	1.314	1.387	0.742	3.496	0.065
Polygala arillata	Polygalaceae	12.5	1.029	0.15	0.985	0.464	0.248	2.262	0.096
Quercus glauca	Fagaceae	35	2.881	0.40	2.627	12.171	6.510	12.018	0.033
Quercus griffithii	Fagaceae	25	2.058	0.28	1.806	1.68	0.899	4.762	0.044
Rhus chinensis	Anacardiaceae	17.5	1.440	0.20	1.314	0.667	0.357	3.111	0.065
Saurauia napaulensis	Actinidiaceae	12.5	1.029	0.15	0.985	1.139	0.609	2.623	0.096
Schefflera elata	Araliaceae	15	1.235	0.20	1.314	1.366	0.731	3.279	0.089
Schima wallichii	Theaceae	27.5	2.263	0.38	2.463	9.513	5.089	9.815	0.050
Syzygium kurzii	Myrtaceae	40	3.292	0.48	3.120	6.611	3.536	9.948	0.030
Tetradium fraxinifolium	Rutaceae	22.5	1.852	0.28	1.806	6.45	3.450	7.108	0.054
Toona ciliata	Meliaceae	20	1.646	0.25	1.642	0.696	0.372	3.660	0.063
Toxicodendron succedaneum	Anacardiaceae	12.5	1.029	0.18	1.149	0.43	0.230	2.408	0.112

F = frequency, RF = relative frequency, D = density, RD = relative density, Do = dominance, RDo = relative dominance, IVI = importance value index, A/F = abundance to frequency ratio individual species in a given sample area. The frequency of woody species recorded in the study area ranged between 10 to 40% (Figure 2). The five most frequent woody species were *Eriobotrya dubia*, *Syzygium kurzii*, *Alnus nepalensis*, *E. populnea* and *Magnolia lanuginosa*. The relative frequency of woody species varied from 0.823 to 3.292%. In general, 9.8% of woody species had RF of above three, 33.3% for above two, 52.9% between one and two, and 3.9% below one.

The term density refers to the numerical strength of a species within a given quadrat (Kent & Coker 1992). Density is significantly related to abundance of a species in determining the importance of a species. The total density calculated for the study area was 380.625 individuals ha^{-1}. The species with the highest density was *C. japonica* (13.12 individuals ha^{-1}), followed by *E. dubia* (12.5 individuals ha^{-1}), *E. populnea* (12.5 individuals ha^{-1}), *A. nepalensis* (11.87 individuals ha^{-1}), *S. kurzii* (11.87 individuals ha^{-1}), *M. lanuginosa* (11.25 individuals ha^{-1}), *Acer campbelli* (10.62 individuals ha^{-1}), *Actinodaphne sikkimensis* (10.0 individuals ha^{-1}), *Lithocarpus fenestratus* (10.0 individuals ha^{-1}), *L. pachyphyllus* (10.0 individuals ha^{-1}), *Macaranga denticulata* (10.0 individuals ha^{-1}), *Quercus glauca* (10.0 individuals ha^{-1}). The species with the lowest density was *Acer thomsonii* (3.75 individuals ha^{-1}), *Monosis volkameriifolia* (3.75 individuals ha^{-1}), *Polygala arillata* (3.75 individuals ha^{-1}), *Saurauia napaulensis* (3.75 individuals ha^{-1}) and *A. oblongum* (3.12 individuals ha^{-1}).

Basal area and importance value index

Basal area is a crucial parameter which deals with determination and classification of forest types on the basis of maturement of forest stand (Sokpon & Biaou 2002). Basal area contributes in the relative importance of the species instead of simple stem counts (Abunie & Dalle 2018). The overall basal area of woody stand in the forest was computed from the recorded DBH data. As a result, the total basal area estimated was 186.948 m^2 ha^{-1}. The basal area ranged from 0.213 to 20.447 m^2 ha^{-1}. In the present study, *C. japonica*, *L. fenestratus*, *L. pachyphyllus* and *Q. glauca* were found to have higher basal area per hectare as compared to other species. Some species like *Rhus chinensis*, *P. arillata*, *Toxicodendron succedaneum* and *M. volkameriifolia* had lower basal area per hectare.

Importance value index of sub-temperate forest was analysed to compare the ecological significance of woody taxa in community structure. The IVI of the woody species suggested that *C. japonica* (16.855), *L. fenestratus* (12.167), *Q. glauca* (12.018) and *L. pachyphyllus* (11.577) were species with higher IVI score,

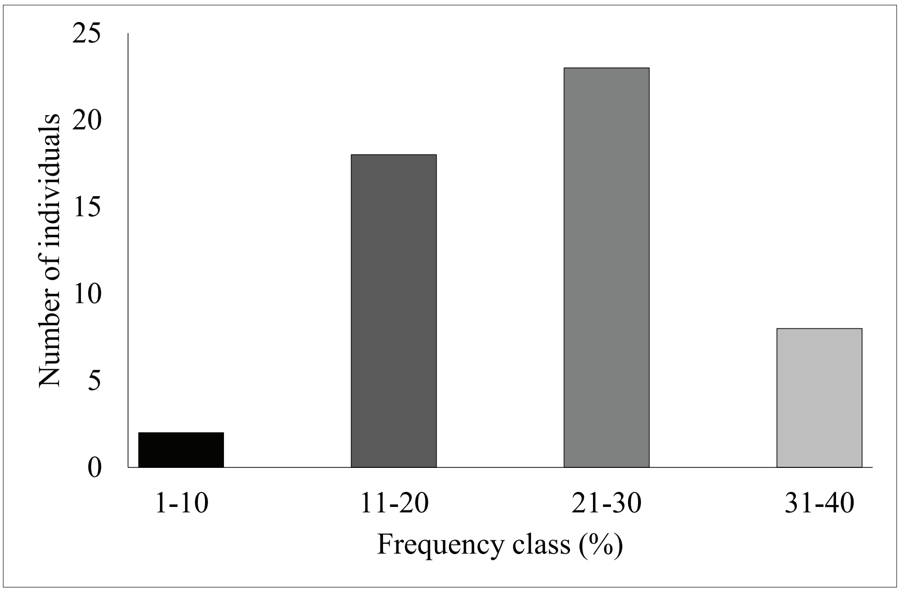

Figure 2 Frequency class distribution of woody taxa

and these woody taxa seems to be the dominant and ecologically significant species in the sub-temperate forests of the study area. Other important tree species were *S. kurzii* (9.948), *Schima wallichii* (9.815) and *E. populnea* (8.872). The least dominant and ecologically essential species was *A. oblongum* (2.013) (Table 2).

Abundance to frequency ratio (A/F)

The A/F implies that 29 species (56.86%) showed random pattern and 22 species (43.14%) exhibited contiguous nature of distribution but none of the woody species in the present study showed regular pattern of distribution. The A/F was recorded maximum for *A. thomsonii* (0.150) and minimum for *S. kurzii* (0.029).

Diameter at breast height (DBH) distribution

In the forest, DBH distribution is of great importance in determining the variations in structure of vegetation and arrangement of individual species (Condit et al. 1998). The woody species in the study area was classified into five DBH classes: 15–30 cm, 30–45 cm, 45–60 cm, 60–75 cm and > 75 cm. The number of woody species with a diameter of 45–60 cm was highest with 151 individuals representing 24.79%, followed by DBH class > 75 cm with 136 individuals (22.33%), 30–45 cm with 117 individuals (19.21%) and 15–30 cm with 115 individuals (18.88%). The minimum proportion (14.45%) of woody species with 88 individuals belonged to a diameter class between 60–70 cm (Figure 3). The DBH class exhibited an irregular pattern, which resembles a bell-shaped distribution. This indicated that the number of species was highest in the middle class. Accordingly, the number of individuals with minimum and maximum DBH class was low in comparison to the intermediate ones.

Dominance diversity (d-d) curve

The dominance-diversity curve comparing the IVI ($\log_{10}$ scale) and the rank of the woody species in the present study reflected log-normal curve (Figure 4). Moreover, *C. japonica* (16.855) and *L. fenestratus* (12.167) were the species with highest IVI values, therefore, occupied the top niche and utilised the major share of resources within the community.

Regeneration status of saplings

Assessment of individual sapling count and estimation of density was carried out for the dominant woody taxa. Overall, the estimated total sapling densities recorded for dominant taxa were 321.86 individuals ha^{-1} and the mature trees as 107.48 individuals ha^{-1} in the study area. The analysis of regeneration status of saplings in the following year revealed that among the dominant taxa, 40 and 20% had good and poor regeneration, respectively. The regeneration of species like *C. japonica*, *A. nepalensis*, *S. wallichii*, *A. campbellii*, and *Q. glauca* were good. However, saplings of taxa such as *Machilus edulis*, *Magnolia cathcartii* and species of *Eriobotrya*

Table 2 Importance value index of the ten most dominant taxa in the study site

Species	RF	RD	RDo	IVI
Cryptomeria japonica	2.469	2.743	10.937	16.855
Lithocarpus fenestratus	2.469	2.090	7.071	12.167
Quercus glauca	2.881	1.791	6.510	12.018
Lithocarpus pachyphyllus	2.263	2.280	6.686	11.577
Syzygium kurzii	3.292	1.861	3.536	9.948
Schima wallichii	2.263	2.137	5.089	9.815
Exbucklandia populnea	3.086	2.090	2.501	8.872
Magnolia lanuginosa	3.086	1.881	2.770	8.812
Magnolia cathcartii	1.852	2.090	4.876	8.698
Alnus nepalensis	3.086	1.985	2.300	8.506

RF = relative frequency, RD = relative density, RDo = relative dominance, IVI = importance value index showed poor regeneration. Many of the taxa like *A. oblongum*, *Aglaia perviridis*, *Alangium alpinum*, *Calophyllum polyanthum*, *Cinnamomum bejolghota*, *Daphniphyllum himalayense*, *Elaeocarpus lanceifolius*, *Glochidon acuminatum*, *Magnolia doltsopa*, *P. arillata*, *Quercus griffithii*, *R. chinensis* and *Toona ciliata* showed poor sapling individual with extremely low or nil regeneration behaviour during the following year.

DISCUSSION

Species composition and species richness are major ecological indicators for extrapolating the biodiversity which relies upon proper management practices (Husch et al. 2002). Altogether, 51 woody species were recorded of which Lauraceae was the most species rich family with 7 species. Similarly, family Lauraceae dominated the sub-tropical karst forests in Maolan (Zhang et al. 2012). The result of the present study is comparable with the results reported from temperate forests of Shimla, Himachal Pradesh and Garhwal Himalaya (Singh & Gupta 2009, Gairola et al. 2011a). However, the value was higher than that of other temperate forests, i.e., 45 species from Japan, 40 species from Subansiri district, Arunachal Pradesh, 41 species from Lohit district, Arunachal Pradesh and 14 tree species from Anantnag district, Jammu and Kashmir

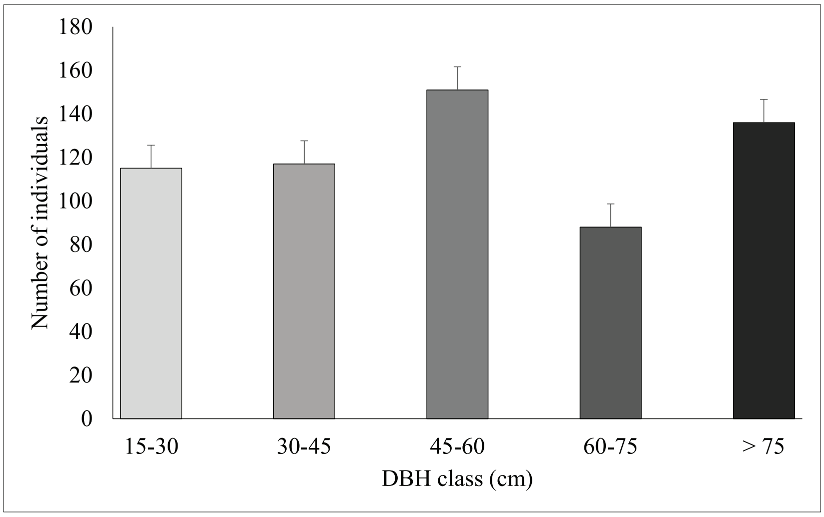

Figure 3 Diameter at breast height (DBH) class distribution of woody taxa

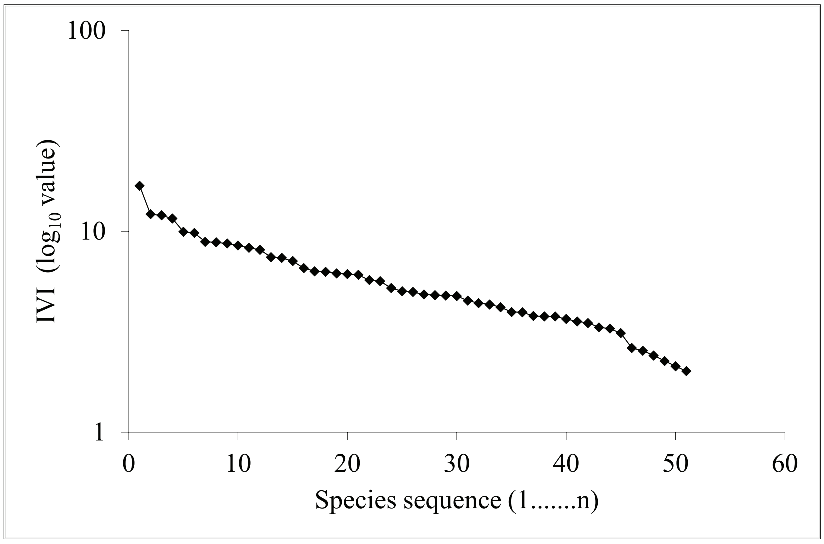

Figure 4 Dominance diversity curve

(Manabe et al. 2000, Behera et al. 2002, Rana and Gairola 2010, Dar & Sundarapandian 2016). A measurement of species diversity is an essential indicator of a community. Moreover, diversity has been identified as a useful index in ecology and conservation biology. The overall Shannon diversity and evenness indices were high with 3.870 and 0.984, respectively. Subsequently, the values for species richness were 2.067, while the dominance for all woody taxa calculated were 0.022. The Shannon index is among the most commonly used diversity index which combines species richness and relative abundance (Kent & Coker 1992). Typically, the optimal value of Shannon index generally ranges from 1.5 to 3.5, and in exception rarely exceeds the value 4.5 (Pielou 1969). As per Onyekwelu et al. (2022), a rich ecosystem with high species diversity has maximum value of Shannon index whereas an ecosystem with poor species diversity has minimum value. The values of species diversity were comparable to those reported earlier for other temperate forests (Table 3). The evenness index recorded (0.984) revealed how evenly the species are distributed within the forest. According to Sarkar & Devi (2014), the high evenness degree indicates more consistency in distribution of species. The present estimates of species richness index (2.067) were more than that of previously recorded values (Sharma et al. 2009, Bharali et al. 2011, Gairola et al. 2011a, 2011b, Dhyani et al. 2019). The dominance value (D′) recorded in the present study (0.022) was lower than the earlier reported values for temperate forests. A low value of D′ was due to high species richness (Malik & Bhatt 2015). The index of dominance is greatly influenced by the species with greatest importance value index in a community (Baduni & Sharma 1997). The rich species diversity and evenness is indicative of a high heterogeneity with a good number of native species (Gairola et al. 2011a).

Frequency and density

Frequency is a measure of approximate homogeneity and heterogeneity of a given stand type (Lamprecht 1989). The greater number of

Table 3 Comparative phytosociological attributes of different forests with present study

Region	Dha^{-1}	BA ($m^2 ha^{-1}$)	H′	E	J	D′	Source
Darjeeling Himalaya	380.625	186.948	3.870	2.067	0.9843	0.022	Present study
Chamoli	1166–1828	–	1.00–2.07	–	–	0.13–0.40	Devlal & Sharma 2008
Lohit	550–860	19.61–78.32	2.893–4.171	–	–	0.0719–0.2078	Rana & Gairola 2009
Mandal-Chopta	330–470	36.32–84.29	2.10–3.14	0.272–1.039	0.75–0.85	1.19–1.80	Sharma et al. 2009
West Siang	707–963	54.2–74.6	2.59–2.80	1.03–1.24	0.92–0.96	0.07–0.08	Bharali et al. 2011
Mandal-Chopta	380–1390	32.77–86.56	1.45–3.33	–	–	0.129–0.467	Gairola et al. 2012
Jammu and Kashmir	103–1201	19.4–51.9	0.17–1.06	2–7	0.17–0.96	0.36–0.94	Dar & Sundarapandian 2016
Rudraprayag	736.70–1152.31	59.12–101.28	1.76–2.22	0.79–1.07	–	0.14–0.25	Dhyani et al. 2019
Fakim wildlife sanctuary	432.5	42.8	3.9	11.59	0.92	0.93	Ao et al. 2020
Nanda Devi biosphere reserve	1016–1632	25.18–67.39	1.65–1.93	–	–	0.82–1.65	Maletha et al. 2022

Dha^{-1} = density per hectare, BA = basal area, H′ = Shannon-Weaver index, E = Menhinick index, J = Pielou index, D′ = Simpson index species in higher frequency classes and fewer species in lower frequency classes indicate homogeneity in forest composition, while fewer species in higher frequency and more in higher frequency classes shows heterogeneity of species composition (Shibru & Balcha 2004, Yemata & Haregewoien 2022). However, the results revealed that most of the species were found in lower frequency classes and relatively smaller number of species in higher frequency classes. This showed the existence of a high degree of floristic heterogeneity in the study area. The total density of woody species with 380.625 individuals ha^{-1} was lower compared with densities reported from temperate forests of Kumaon Himalaya and Garhwal Himalaya, but greater than the values reported from temperate forest of Central Himalaya and moist temperate from Western Himalaya (Saxena & Singh 1982, Bhandari & Tiwari 1997, Kumar et al. 2009, Semwal et al. 2010, Shaheen et al. 2012). However, the density in the present study was within the range reported from Garhwal Himalaya (Sharma et al. 2010). Variations in frequency and density between species could be associated with the variations in species characteristics, habitat preferences, economic and ecological importance of species and anthropogenic disturbances (Tadele et al. 2014).

Basal area and importance value index

In the present investigation, evaluation of cross-sectional area of individual species showed that the study area was greatly dominated by fewer small woody species. Similar results have been reported for humid Afromontane forest, Yemrehane Kirstos church forest and dry Afromontane forest of Ethiopia (Bekele 1994, Abunie & Dalle 2018, Mucheye & Yemato 2020). The following taxa made the largest contribution with regard to their basal area: *C. japonica*, *L. fenestratus*, *L. pachyphyllus* and *Q. glauca*. Accordingly, the small-sized individuals contributed little to the total basal area. This indicated that the species in the study area are capable of retaining higher biomass. Analysis of IVI revealed that the sub-temperate forest was dominated by *C. japonica*, *L. fenestratus*, *Q. glauca* and *L. pachyphyllus*. High IVI is allocated to their high relative frequency, high relative density and high basal area. According to Shibru & Balcha (2004), species with the greatest importance value index is considered the most dominant of the specific vegetation. For setting priority species management and conservation practices, IVI is regarded an important measure. It also helps to determine whether the species is dominant or rare in a certain plant species (Taylor et al. 1994, Zegeye et al. 2006). Therefore, the woody species exhibiting less IVI values needs high conservation effort whereas those with more IVI values needs monitoring management (Eyasu et al. 2020).

Abundance to frequency ratio (A/F)

Hubbell et al. (1999) stated that the dispersal limitation is a major ecological factor controlling the distribution pattern of species and a ecological relationship between biotic and abiotic factors. In the present study, woody species exhibited heterogenous pattern of distribution, with 56.86% following random pattern while 43.14% showed contiguous distribution. Generally, the random distribution is observed in a homogenous environmental condition, whereas in natural condition, contiguous distribution has been accepted as a distinctive pattern of species occurrence (Odum 1971). Contiguous distribution pattern in temperate forests has been reported by various workers (Kershaw 1973, Gairola et al. 2011b, Dar & Sundarapandian 2016). Reports from the other studies have revealed that majority of species show contiguous distribution pattern in natural vegetation and negligible species follows regular distribution (Chen et al. 2008, Bahuguna et al. 2010, Dangwal et al. 2012, Kour & Sharma 2014).

Diameter at brerast height (DBH) class and dominance diversity (d-d) curve

The DBH distribution pattern of woody species is an indication of the general trend of population dynamics and regeneration status of the species in the forest (Zegeye et al. 2011). Thus, the pattern of DBH class distribution from the study represented a bell-shaped distribution pattern. This pattern shows that their regeneration status is hampered due to several disturbance factors, such as excessive deforestation by locals, livestock grazing and settlement extension (Atsbha et al. 2019). Therefore, the disturbance may be the cause of delayed regeneration and normal health status of species. A bell-shaped pattern implies poor regeneration due to an intensive competition of tree species in a forest ecosystem (Senbeta et al. 2014). In contrast, inverse J-shaped distribution of DBH classes generally show good regeneration and species recruitment (Atsbha et al. 2019).

The d-d curves are often used to explain the community organisation of species with regard to sharing of resource and niche space (Whittaker 1975). The relative importance of a species in the community is represented by the d-d curve. This curve helps in illustrating the role of a certain species to determine community structure. The interrelationships among distribution of species in each community can appear to be determined quantitatively from these d-d curves, i.e., geometric, log, log-normal and random niche-boundary types. Furthermore, little difference in d-d curve deliberates the importance of each species in a community. In the present study, the d-d curve showed log-normal distribution. The log-normal series represent high diversity condition. *Cryptomeria japonica* and *L. fenestratus* were dominant species present at the top left portions of the d-d curve. The log-normal series explains the segregation of realised niche space between various species. The log-normal distribution is an outcome of the evolution of diversity in the niche that they exploit (Whittaker 1965).

Regeneration status

The pattern of woody saplings can reveal the species regeneration profile, which is then drawn to predict their regeneration status (Malik & Bhatt 2016). In general, species regeneration is strongly affected by various anthropogenic and natural factors (Iqbal et al. 2012). In the present study, the species showing 'nil' regeneration comprised of 40% of the dominant woody taxa. Species with nil and poor regeneration may be due to the large forest canopy cover that lessen the penetration of sunlight which may inhibit species growth in the forest floor (Pokhriyal et al. 2010). The available moisture content of soil also determines the sapling recruitment potential (Tiwari et al. 2018). Another possible reason might be due to the rapidly changing climate in the Himalayan region (Telwala et al. 2013). Therefore, an efficient conservation and management action is required to enhance natural regeneration status of significant species.

CONCLUSION

Woody species are fundamental components of the forest ecosystem and influence the overall composition and diversity of a community. Documenting the structure of species diversity provides a reference for monitoring management approaches. The study confirms the need for the conservation of dominant tree species. The maintenance and preservation of these forests is crucial, not only for conservation of biodiversity, but also for meeting the small and valuable needs of the local people. An increase in human interventions such as deforestation, road construction and spread of human invasion on the forest structure negatively impacted the species composition and diversity. This necessitates the study on effects of human interventions in woody species composition and diversity. Moreover, the conservation concepts are recommended to be executed in collaboration with local people to employ management which supports local livelihoods while restoring these forests. Based on the present investigations, conservation of both species and habitat is suggested, prioritising woody species with lower IVIs and monitoring those with higher IVIs to maintain diversity. Furthermore, species showing poor or nil regeneration have to be given due consideration for conservation through reintroduction practices. Thus, further research on all aspects, especially anthropogenic influences, is imperative to have an overall information of the forest and to plan a sustainable conservation program.

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