J. Indian bot. Soc. (2024) Vol. 104 (1): 13-20
e-ISSN:2455-7218, ISSN:0019 - 4468
https://doi: 10.61289/jibs2024.01.30.1174
www.indianbotsoc.org

RESEARCH ARTICLE

Estimating tree species diversity and composition in temperate forests of Darjeeling Himalaya, India

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Abstract

The present study quantifies the diversity and richness of tree species in temperate forests of Darjeeling eastern Himalaya through stratified random quadrats. A total of 86 woody species belonging to 49 genera and 27 families were reported. Density, basal area, abundance, importance value index (IVI), girth class and Raunkiaer's frequency were used to assess the structural characteristics of forest. The Shannon diversity index, evenness index and concentration of dominance were 4.349, 0.976 and 0.014 respectively. The IVI values ranged from 0.95 to 8.36. Almost all woody species exhibited contiguous distribution patterns with 12 species random and 2 species distributed regularly. The estimated diversity indices indicated heterogeneity of the forest in its composition, structure and function. Furthermore, dominance-diversity curves were also drawn to ascertain resource sharing among various species in temperate forests.

Keywords: Diversity, eastern Himalaya, Tree species, Temperate forests

Introduction

Temperate forests occupy an area of about 5.3 million sq km worldwide representing approximately 16% of the global forest area. These forests are exposed to warm summer and cold winters and are among the most productive ecosystems on the planet, extending from lower to higher elevations (Kumari *et al.* 2017). Species diversity in temperate forests varies greatly with physiography and microclimate which are directly connected to soil moisture and the distribution of vegetation. Apart from their importance to biodiversity conservation, temperate forests also have a pivotal role in climate change, global carbon storage, protecting the soil, topographic variations and species dynamicity (Rawat *et al.* 2020). Despite their rich biodiversity, these forests are more frequently subjected to extensive biotic pressure and human impact than any other forest type. Therefore, the sustainable use and proper management of these forests are matters of concern (Sharma *et al.* 2010). Knowledge of the floristic composition and diversity of tree species is of utmost importance in assessing the structural and functional dynamics of the forest (Reddy *et al.* 2007). The species richness and diversity of trees are fundamental to total forest biodiversity, as trees provide resources and habitat for almost all other forest species (Malik *et al.* 2014). In forest ecosystems, the structure and function of the community and its species composition are the prime ecological factors that determine changes with anthropogenic and environmental variables (Gairola *et al.* 2008). Species diversity is found to be associated with climate, forest productivity, historic events, and habitat heterogeneity, which determines the structure and pattern of any forest.

The Himalayan forests are of great importance among other forests on the globe in view of their peculiar ecological feature of having a temperate atmosphere inside a tropical zone. The Indian Himalayan region (IHR) is considered a rich depository of biological and cultural diversity and supports about 18,440 species of plants, of which 25.3% are endemic species (Stephan *et al.* 2015). High biological diversity is due to variations in topography, a wide altitudinal range, and climatic conditions that cause variation in vegetation types. Kharakwal *et al.* (2015) emphasized that altitude and climatic

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How to cite this article: Tolangay D, Pradhan B, Moktan S. (2024). Estimating tree species diversity and composition in temperate forests of Darjeeling Himalaya, India. J. Indian bot. Soc., 104 (1): 13-20. Doi: 10.61289/jibs2024.01.30.1174

Source of support: Nil

Conflict of interest: None.

Received: 05/08/2023 **Accepted:** 31/10/2023 **Published online**: 30/01/2024

factors such as temperature and rainfall are the determinants of species richness. In the eastern Himalaya, the ecotone effect in transitional zones maximizes the vascular plant richness of the region (Behera and Kushwaha 2006). Behera *et al.* (2016) have analyzed that the elevational gradient of the region gives rise to a different moisture regime that favors species diversity. Shaheen *et al.* (2012) emphasized the significance of geographic variables for large-scale species distribution trends across the Himalayas. The management of the Himalayan ecosystem and the knowledge of plant community, diversity, population, distribution, regeneration, utilization, environmental impact assessment, etc. are essential in supporting the conservation and restoration of the environment (Gairola *et al.* 2011a). Several works are available from the temperate forests in India. However, studies associated with the temperate forest of the eastern Himalayan region are sporadic (Paul *et al.* 2018, Dash *et al.* 2021). The plant community structure and distribution pattern of temperate forests, particularly Himalayan forests are poorly understood (Peer *et al.* 2017). Hence, the present study has been undertaken to determine the structure and floristic composition with the aim of assessing the dominance and richness of woody taxa in the temperate forests of Darjeeling Himalaya, India.

Materials and methods

Study area

The Darjeeling Himalaya, an integral part of the Singalila range of the eastern Himalaya, is geographically and physiologically rich depository of endemic species and diverse vegetation (Devi and Sherpa 2019). Situated between 27° 13′ 10′′ N to 26° 27′ 05′′ N latitude and 88° 53′ E to 87° 59′ 30′′ E longitude, the area covers a wide elevational range extending from >130 m to 3636 m asl. The wide range of ecological conditions and altitudinal gradient has resulted in diverse vegetation types in the Darjeeling Himalaya, of which the major types are tropical (upto 500 m), sub-tropical (500 – 1200 m), sub-temperate (1200 – 1850 m), temperate (1850 – 3200 m), and sub-alpine (above 3200 m). The elevational range of temperate forest (1850 – 3200 m) in the Darjeeling Himalaya reflects three distinct sub-types of vegetation *viz.,* temperate broad-leaved forest (1850 -2400 m), evergreen-oak forest (2400-2800 m) and hemlock-rhododendron forest (2800-3200 m) (Grierson and Long 1983). Phytogeographically, the region is bounded by Sikkim in the north, Nepal in the west and Bhutan in the east (Figure 1). The climate in the study area is divided into four main seasons, *viz.* winter (December to February); spring and summer (March to May); monsoon or rainy (June to August) and autumn (September to November). The average monthly temperature varies from a maximum of 24°C in the month of August to a minimum of 2°C in January with an annual precipitation of about 2400 mm.

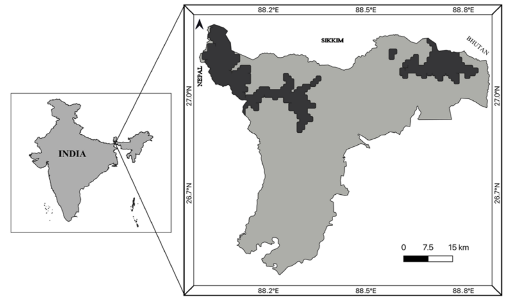

Figure 1: Map of the study area showing temperate region (shaded)

Vegetation analysis

The study was mainly focused on the tree species, for which a stratified random sampling technique was followed by placing quadrats of 20m × 20m. Trees were deemed as an individual with ≥15 cm circumference at breast height (CBH), i.e., 1.37 m above ground. The CBH was used to determine the basal area, computed as $(CBH)^2/4\pi$. The total basal area (m^2ha^{-1}) was calculated as the sum of the basal areas of all species. The location and altitude of the study sites were recorded by Garmin eTrex H handheld receiver. Species identification was done with the help of flora (Hara 1971, Grierson and Long 1983-2001). Furthermore, Lloyd Botanical Garden Herbarium and Calcutta University Herbarium (CUH) were also consulted for the correct identification of the taxa. Proper nomenclature with authorities of the species was maintained following Plants of the World Online (POWO 2022).

Frequency (F), Density (D), and Dominance (Dm) of recorded tree species were quantified using Curtis and McIntosh (1950). The Importance Value Index (IVI) was determined as the sum of the Relative Frequency (RF), Relative Density (RD), and Relative Dominance (RDm) (Curtis, 1959). The abundance to frequency ratio (A/F) was studied to understand the spatial distribution pattern of the species (Whitford 1949). The ratio of <0.025 indicates regular distribution, 0.025 – 0.050 depicts random distribution and >0.050 indicates contiguous distribution (Curtis and Cottam 1956). The recorded tree species were grouped into Raunkiaer's five frequency classes, and a comparison between normal and observed frequencies was made (Raunkiaer 1934).

Diversity of the recorded species was evaluated using several non-parametric measures in PAST version 4.03 (Hammer *et al.* 2001). Shannon index $H' = -\sum(n_i/N)^2\ln(n_i/N)$ (Shannon and Weiner, 1963); Pielou's equitability $E = H'/\ln S$ (Pielou, 1966); Margalef's index $MI = S - 1/\ln$ (Margalef, 1958); Menhinick's index $MeI = S/\sqrt{N}$ (Menhinick, 1964), and Index of dominance $Cd = \sum(n_i/N)^2$ (Simpson, 1949) was used. The species heterogeneity was determined using $H_g = \sqrt{Cd}$ (Whittaker, 1972).

Results and Discussion

Species composition

The variations in phytosociological attributes of temperate forests are accomplished by their varying environmental variables such as climate, topography, and elevation (Sundarapandian and Karoor 2013). The temperate vegetation of the Darjeeling Himalaya covers a wide altitudinal range that lies between 1850-3200 m asl, and it includes a major part of the dense forest, *Cryptomeria* and *Rhododendron* forests. The present study revealed a diversified number of 86 woody species belonging to 49 genera under 27 families (Table 1). A maximum number of 11 species under 4 genera was recorded for the family Fagaceae, followed by Ericaceae with 10 species under 3 genera and Lauraceae with 9 species under 6 genera. The families Rosaceae and Sapindaceae each had 6 species distributed under 3 and 1 genera, respectively, while Aquifoliaceae, and Pinaceae were distributed with 5 species each (Figure 2). Families such as Araliaceae, Magnoliaceae, and Symplocaceae had 4 species distributed while Betulaceae represented 3 species, Pentaphylacaceae and Rutaceae had 2 species distributed with the rest of the 14 families representing single species.

Tree density is expressed as the number of individual trees per unit area and it indicates the numerical strength of a species in a community. The total stem density estimated for the woody species was 442 individuals ha^{-1} with *Rhododendron arboreum* and *Cryptomeria japonica* showing the highest density of 11.00 individuals ha^{-1} followed by *Lithocarpus pachyphyllus* with 10.50 individuals ha^{-1} and *Rhododendron arboreum* var. *cinnamomeum* with an estimation of 10.00 individuals ha^{-1}. The lowest density with 2.00 individuals ha^{-1} was estimated for *Carpinus viminea, Celtis tetrandra, Ilex fragilis, Larix potaninii, Merrilliopanax alpinus, Osmanthus fragrans, Picea spinulosa* and *Rhododendron cinnabarinum* followed by *Gamblea ciliata* with least individuals of 1.50 per hectare. The basal area refers to the ground actually occupied by the tree stems. It is one of the important indicators of forest that determine the dominance. The total basal area estimated for the trees from the temperate region was 284.1 ±3.58 m^2 ha^{-1}. The basal area ranged from 0.1±0.00 to 15.8±0.08 m^2ha^{-1} showing highest for *Lithocarpus pachyphyllus* (15.8±0.08 m^2ha^{-1}) followed by *Lithocarpus fenestratus* (14.8±0.07 m^2ha^{-1}), and *Cryptomeria japonica* (12.3±0.05 m^2ha^{-1}) and least for *Osmanthus fragrans* (0.1±0.00 m^2ha^{-1}). The mean basal area for the woody species was 3.30 m^2ha^{-1}. The basal area recorded in the present study is lower compared to studies conducted in temperate forest types of the Western Himalaya, (Dar and Sundarapandian 2016) and in forest of the Kashmir Himalaya (Dar and Parthasarathy 2021). The total abundance estimated was 116.75 with the highest abundance for *Lithocarpus pachyphyllus* (7.0) followed by an abundance of 4.7 for *Lithocarpus fenestratus* while the lowest abundances of 4.3 and 0.3 were estimated for *Gamblea ciliata* and *Merrilliopanax alpinus* respectively.

The term Importance Value Index was introduced by Curtis and McIntosh (1951) as an index of the vegetation

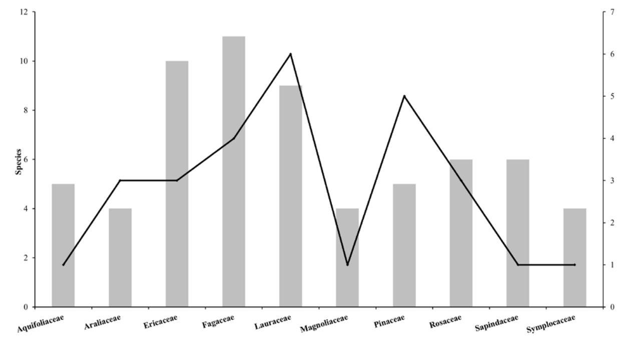

Figure 2: Dominant families of woody species

importance of a tree in a given forest ecosystem. Importance Value Index gives the overall ecological importance of each species in a community. The IVI is estimated on the basis of relative values of frequency, density, and dominance of the species and it represents a successful ecological establishment and dominance of a species in a community. A high IVI score reflects a well established and good adaptability of taxa. In the present study, the IVI values for the woody species ranged from 0.95 to 8.36 with the dominant woody species *Lithocarpus pachyphyllus* with an IVI score of 8.36, and *Magnolia campbellii* with IVI of 8.35. The other co-dominant species form the zone include *Cryptomeria japonica* (IVI: 8.25), *Lithocarpus fenestratus* (IVI: 7.93), *Rhododendron arboreum* (IVI: 7.73), *Quercus lamellosa* (IVI: 7.60), *Alnus nepalensis* (IVI: 6.30), *Symplocos glomerata* (IVI: 6.04), *Rhododendron arboreum* var. *cinnamomeum* (IVI: 6.00), and *Machilus edulis* (IVI: 5.60). The least dominating canopy in the temperate zone was *Ilex fragilis* and *Celtis tetrandra* with an IVI score of 1.22 and 0.95 respectively.

The girth (also called circumference) of the trunk is the measurement of the distance around the trunk of a tree in a plane perpendicular to the axis of the trunk. The girth class distribution for the species on the basis of measurement of circumference at breast height showed 169 individuals showed girth class within 15 – 30cm and 30 – 45cm, 154 individuals fell under the girth class 45 – 60 cm, 132 individuals showed girth class between 60 – 75 cm and highest number of 260 individuals fell under the girth class above 75 cm (Figure 3). Species such as *Lithocarpus pachyphyllus, Cryptomeria japonica, Magnolia campbellii,*

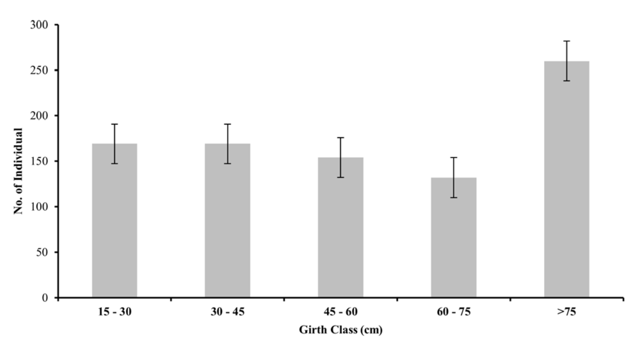

Figure 3: Girth class distribution of tree species

Table 1: Ecological attributes of the tree species from the study area

Taxa	*Family*	*F*	*Dha^{-1}*	*Dm*	*BA m^{2}ha^{-1}*	*IVI*
Abies densa Griff.	Pinaceae	18.00	5.50	6.60	6.6±0.06	4.86
Acer campbellii Hook.f. & Thom. ex Hiern	Sapindaceae	26.00	8.00	3.30	3.3±0.03	4.84
Acer hookeri Miq.	Sapindaceae	14.00	4.00	0.80	0.8±0.02	2.19
Acer laevigatum Wall.	Sapindaceae	14.00	4.50	1.90	1.9±0.03	2.69
Acer oblongum Wall. ex DC.	Sapindaceae	14.00	5.00	0.90	0.9±0.02	2.45
Acer pectinatum Wall. ex Nicholson	Sapindaceae	8.00	2.50	0.20	0.2±0.00	1.21
Acer sikkimense Miq.	Sapindaceae	8.00	2.50	0.20	0.2±0.00	1.21
Actinodaphne longipes Kosterm.	Lauraceae	22.00	7.00	2.40	2.4±0.02	4.01
Actinodaphne sikkimensis Meisn.	Lauraceae	26.00	8.00	2.00	2.0±0.02	4.38
Aglaia perviridis Hiern	Meliaceae	16.00	4.50	2.40	2.4±0.08	3.01
Alangium alpinum (C.B.Clarke) W.W.Sm. & Cave	Cornaceae	10.00	2.50	0.60	0.6±0.03	1.49
Alnus nepalensis D. Don	Betulaceae	26.00	9.00	6.80	6.8±0.04	6.30
Betula alnoides Buch.-Ham. ex D. Don	Betulaceae	22.00	6.50	2.40	2.4±0.02	3.90
Brassaiopsis hispida Seem.	Araliaceae	18.00	4.50	2.40	2.4±0.01	3.16
Brassaiopsis mitis C.B. Clarke	Araliaceae	12.00	3.50	0.50	0.5±0.01	1.83
Carpinus viminea Wall. ex Lindl.	Betulaceae	8.00	2.00	0.50	0.5±0.02	1.20
Casearia glomerata Roxb.	Salicaceae	8.00	2.50	1.20	1.2±0.02	1.56
Castanea sativa Mill.	Fagaceae	8.00	2.50	1.20	1.2±0.07	1.56
Castanopsis hystrix Hook. f. & Thom. ex A.DC.	Fagaceae	16.00	5.00	5.10	5.1±0.07	4.07
Castanopsis tribuloides (Sm.) A.DC.	Fagaceae	18.00	6.00	4.70	4.7±0.08	4.30
Celtis tetrandra Roxb.	Cannabaceae	6.00	2.00	0.20	0.2±0.01	0.95
Cinnamomum impressinervium Meisn.	Lauraceae	20.00	7.00	0.90	0.9±0.00	3.34
Cryptomeria japonica (Thunb. ex L.f.) D.Don	Cupressaceae	20.00	11.00	12.30	12.3±0.05	8.25
Daphniphyllum himalayense (Benth.) Müll. Arg.	Daphniphyllaceae	20.00	5.50	3.80	3.8±0.05	4.02
Elaeocarpus lanceifolius Roxb.	Elaeocarpaceae	18.00	5.50	4.70	4.7±0.04	4.19
Embelia vestita Roxb.	Primulaceae	16.00	4.00	0.90	0.9±0.03	2.37
Engelhardia spicata Lechen ex Blume	Juglandaceae	18.00	5.50	6.80	6.8±0.05	4.93
Eurya acuminata DC.	Pentaphylacaceae	14.00	4.50	1.40	1.4±0.04	2.52
Eurya cerasifolia (D.Don) Kobuski	Pentaphylacaceae	12.00	3.50	0.90	0.9±0.03	1.97
Exbucklandia populnea (R.Br. ex Griff.) R.W. Br.	Hamamelidaceae	14.00	8.00	6.10	6.1±0.04	4.96
Gamblea ciliata C.B.Clarke	Araliaceae	14.00	1.50	1.00	1.0±0.03	1.70
Ilex dipyrena Wall.	Aquifoliaceae	24.00	4.00	2.10	2.1±0.05	3.37
Ilex fragilis Hook.f.	Aquifoliaceae	6.00	2.00	0.90	0.9±0.04	1.20
Ilex hookeri King	Aquifoliaceae	14.00	3.00	0.30	0.3±0.01	1.79
Ilex insignis Hook.f.	Aquifoliaceae	6.00	3.00	0.50	0.5±0.01	1.28
Ilex kingiana Cockerell	Aquifoliaceae	12.00	2.50	0.80	0.8±0.01	1.71
Kydia calycina Roxb.	Malvaceae	10.00	3.00	1.20	1.2±0.04	1.82
Larix potaninii Batalin	Pinaceae	10.00	2.00	1.60	1.6±0.06	1.73
Lithocarpus fenestratus (Roxb.) Rehder	Fagaceae	8.00	9.50	14.80	14.8±0.07	7.93
Lithocarpus pachyphyllus (Kurz) Rehder	Fagaceae	6.00	10.50	15.80	15.8±0.08	8.36
Litsea elongata (Nees) Hook. f.	Lauraceae	18.00	7.00	3.00	3.0±0.02	3.93
Litsea glutinosa (Lour.) C.B.Rob.	Lauraceae	20.00	7.00	1.90	1.9±0.02	3.69
Litsea salicifolia (J. Roxb. ex Nees) Hook. f.	Lauraceae	28.00	5.50	1.40	1.4±0.02	3.75
Lyonia ovalifolia (Wall.) Drude	Ericaceae	22.00	7.00	0.90	0.9±0.01	3.48

Machilus edulis King ex Hook.f.	Lauraceae	22.00	9.50	5.30	5.3±0.04	5.60
Magnolia campbellii Hook. f. and Thom.	Magnoliaceae	36.00	8.50	10.90	10.9±0.08	8.35
Magnolia cathcartii (Hook.f. & Thom.) Noot.	Magnoliaceae	28.00	5.50	5.40	5.4±0.05	5.16
Magnolia doltsopa (Buch.-Ham. ex DC.) Figlar	Magnoliaceae	30.00	5.00	4.20	4.2±0.05	4.77
Magnolia lanuginosa (Wall.) Figlar & Noot.	Magnoliaceae	20.00	7.00	3.30	3.3±0.04	4.18
Meliosma simplicifolia (Roxb.) Walp.	Sabiaceae	16.00	4.00	0.80	0.8±0.02	2.33
Merrilliopanax alpinus (C.B.Clarke) C.B. Shang	Araliaceae	24.00	2.00	0.40	0.4±0.02	2.32
Neocinnamomum caudatum (Nees) Merr.	Lauraceae	14.00	7.00	1.90	1.9±0.01	3.26
Neolitsea umbrosa (Nees) Gamble	Lauraceae	6.00	4.50	0.60	0.6±0.01	1.66
Nyssa javanica (Blume) Wangerin	Nyssaceae	22.00	5.50	5.20	5.2±0.05	4.66
Osmanthus fragrans Lour.	Oleaceae	16.00	2.00	0.10	0.1±0.00	1.64
Photinia glabra (Thunb.) Maxim.	Rosaceae	16.00	3.50	1.40	1.4±0.02	2.43
Photinia integrifolia Lindl.	Rosaceae	8.00	3.50	1.50	1.5±0.03	1.89
Picea spinulosa (Griff.) A.Henry	Pinaceae	12.00	2.00	1.20	1.2±0.07	1.73
Pieris formosa (Wall.) D.Don	Ericaceae	14.00	5.00	0.70	0.7±0.01	2.38
Pinus roxburghii Sarg.	Pinaceae	8.00	3.00	3.50	3.5±0.06	2.48
Quercus glauca Thunb.	Fagaceae	16.00	4.50	5.90	5.9±0.05	4.24
Quercus griffithii Hook.f. & Thom. ex Miq.	Fagaceae	18.00	5.50	7.60	7.6±0.09	5.21
Quercus incana Bartram	Fagaceae	16.00	4.50	6.00	6±0.06	4.28
Quercus lamellosa Sm.	Fagaceae	22.00	9.50	11.00	11±0.10	7.60
Quercus lanata Sm.	Fagaceae	14.00	5.00	6.60	6.6±0.08	4.46
Quercus lineata Blume	Fagaceae	22.00	5.50	9.00	9.0±0.08	5.99
Rhaphiolepis dubia (Lindl.) B.B.Liu & J.Wen	Rosaceae	14.00	4.50	1.60	1.6±0.07	2.59
Rhaphiolepis petiolata (Hook.f.) B.B.Liu & J.Wen	Rosaceae	16.00	4.50	2.90	2.9±0.05	3.19
Rhododendron arboreum Sm.	Ericaceae	20.00	11.00	10.80	10.8±0.05	7.73
Rhododendron arboreum var. *cinnamomeum* (Wall. ex G. Don) Lindley	Ericaceae	30.00	10.00	4.50	4.5±0.04	6.00
Rhododendron barbatum Wall. ex G. Don	Ericaceae	14.00	5.00	1.00	1±0.02	2.49
Rhododendron cinnabarinum Hook. f.	Ericaceae	8.00	2.00	0.60	0.6±0.02	1.24
Rhododendron dalhousieae Hook.f.	Ericaceae	10.00	3.50	0.40	0.4±0.02	1.65
Rhododendron falconeri Hook.f.	Ericaceae	10.00	3.50	4.00	4±0.04	2.92
Rhododendron grande Wight	Ericaceae	22.00	7.00	6.00	6±0.09	5.28
Rhododendron griffithianum Wight	Ericaceae	10.00	3.00	0.40	0.4±0.01	1.54
Skimmia arborescens T.Anderson ex Gamble	Rutaceae	8.00	3.00	0.60	0.6±0.01	1.46
Sorbus rhamnoides (Decne.) Rehder	Rosaceae	10.00	2.50	0.20	0.2±0.00	1.35
Sorbus vestita (Wall. ex G.Don) Rushforth	Rosaceae	16.00	4.00	0.90	0.9±0.02	2.37
Symplocos dryophila C.B. Clarke	Symplocaceae	20.00	6.50	4.10	4.1±0.03	4.35
Symplocos glomerata King ex C.B.Clarke	Symplocaceae	26.00	8.50	6.40	6.4±0.05	6.04
Symplocos lucida (Thunb.) Siebold & Zucc.	Symplocaceae	20.00	7.00	5.70	5.7±0.03	5.03
Symplocos ramosissima Wall. ex G. Don	Symplocaceae	24.00	8.00	1.80	1.8±0.01	4.17
Tetradium fraxinifolium (Hook. f.) T.G.Hartley	Rutaceae	20.00	6.50	6.40	6.4±0.08	5.16
Toxicodendron succedaneum (L.) Kuntze	Anacardiaceae	20.00	7.00	1.40	1.4±0.02	3.51
Tsuga dumosa (D.Don) Eichler	Pinaceae	14.00	3.50	1.60	1.6±0.05	2.36

[Foot Note: F- frequency; D- density; Dm-dominance; BA-basal area; IVI-importance value index]

Quercus lamellosa showed maximum girth class above 100cm while species with moderate girth class includes *Alnus nepalensis, Engelhardia spicata, Abies densa, Quercus lanata, Exbucklandia populnea, Symplocos glomerata* and *Quercus incana*. The minimum girth class was exhibited by the species like *Ilex hookeri, Acer pectinatum, Acer sikkimense, Celtis tetrandra, Sorbus rhamnoides* and *Osmanthus fragrans*. The girth class distribution of the present study indicates that these forests are mature forests which have more than 80% of the trees with higher girth class.

Raunkiaer's frequency depicts the distribution of species in a vegetation community. The comparison of the observed frequency with Raunkiaer's frequency class represented 77 % and 23 % respectively for class A and B with none in the class C, D and E compared to the Raunkiaer's frequency distribution of 53 %, 14 %, 9 %, 8 %, and 16 % for respective classes exhibiting A>B pattern (Figure 4). Since the occurrence does not match with the Raunkiaer's frequency class, the woody vegetation reveals a heterogeneous nature. Raunkiaer's distribution with the present study revealed that most of the species showed lower frequency values as would be expected in typical species abundant forest (Odum 1971). The frequency distribution pattern of species had only two classes instead of five as described in the law which indicates high level of heterogeneous nature and deviation from the normal frequency distribution as described by Raunkiaer (1934). An analysis of the spatial distribution pattern of the canopy showed 72 species that were contiguously distributed while 12 species were found to be randomly distributed and only 2 species exhibited regular distribution pattern. According to Odum (1971), contiguous pattern of distribution is the most common pattern in natural vegetation.

Diversity indices of the woody taxa

In ecological studies, diversity indices are important parameters because these help in understanding the structure of forest ecosystems. Species diversity is defined as the measurement of the number of species and the abundance of each species in a given community. It represents species richness and species evenness. Shannon's diversity index is a way to measure the amount of information needed to describe every species in a community, and Simpson's diversity index is an index to measure the degree of concentration of species in a community. In the present study, the Shannon diversity index for the tree species was estimated as 4.349. The Shannon-Wiener diversity index value for the Himalayan temperate forests lie within the reported range of 1.16 – 3.40 (Risser and Rice 1971). The diversity value of the present study (4.349) is higher than the value (1.00 – 2.07) reported by Devlal and Sharma (2008), while the values are similar to other studies conducted by Pokhriyal *et al.* (2009) for the forests of Garhwal Himalaya, Shaheen *et al.* (2012) for the moist temperate forest of the Kashmir, Malik and Bhatt (2015) in the Western Himalaya to name a few. The values of Margalef's index and Menhinick's index were recorded as 12.53 and 2.892, respectively. The Margalef's index and Menhinick's index values obtained are higher than those reported for the Garhwal Himalaya (0.17 – 1.14) and (0.27 – 0.80) respectively by Sharma *et al.* (2009) and (2.59 – 4.11) and (1.60 – 1.99), respectively by Malik *et al.* (2014) for the Kedarnath Wildlife Sanctuary. The score for the evenness index was 0.976 while Simpson's concentration of dominance value was estimated as 0.014 (Table 2). The value of concentration of dominance was less compared to the earlier works reported for temperate forests, while it is closer to the values of *Abies pindrow* (0.0007 – 0.0898), *Quercus floribunda* (0.0441), *Q. leucotrichophora* (0.004 – 0.170), *Lyonia ovalifolia* (0.0007 – 0.0123) and *Rhododendron arboreum* (0.0012 – 0.0101) in mid-altitudinal moist temperate forests of the Western Himalaya (Gairola *et al.* 2011a). The lower value of *Cd* could be due to the high species richness (Malik and Bhatt 2015). The species heterogeneity exhibited a value of 0.118. The value of species heterogeneity reported in the present study is lower than the earlier reported species heterogeneity (0.21 – 0.8) by Dar and Sundarapandian (2016) and (1.46 – 1.74) by Gairola *et al.* (2011b). The results showed that the tree species in the studied temperate forest were heterogeneous in nature.

The correlation coefficient between different indices showed a positive correlation between density and diversity indices, with density exhibiting less correlation with the A/F ratio. However, diversity showed a strong correlation with

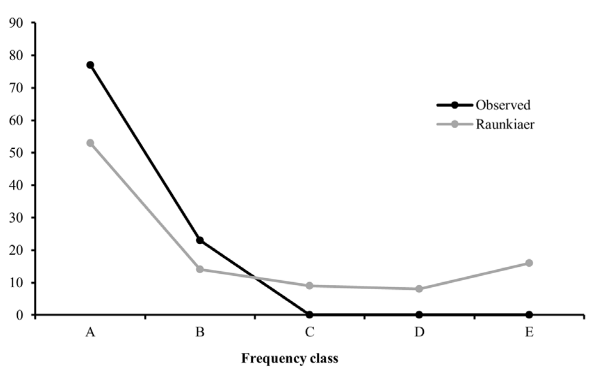

Figure 4: Comparison of Raunkiaer and observed frequency distribution

Table 2: Diversity indices estimated for trees

Indices	Values
H'	4.349
E	0.976
MI	12.53
MeI	2.892
Cd	0.014
Hg	0.118

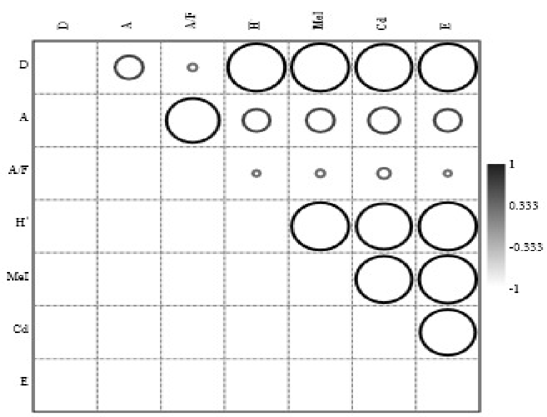

Figure 5: Correlation between different diversity parameters

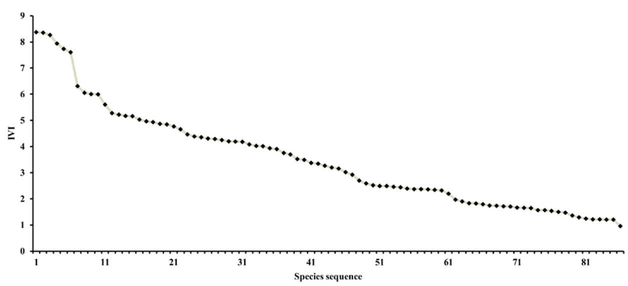

Figure 6: Dominance-diversity curve for tree species

richness and evenness (Figure 5). The dominance-diversity (d-d) curve for tree species from the study site has been shown (Figure 6). The d-d curves are frequently used to interpret community organization with resource sharing and niche space, and these curve explain the relationship between species distribution in a community. In the present study, the d-d curve revealed that the dominant species utilize the maximum proportion of resources and occupies the top niche.

Conclusion

The current study reveals that the temperate forests of Darjeeling in the eastern Himalaya have high tree richness and diversity. The presence of rich species diversity indicates the uniqueness and potentiality of the study site for conservation. The phytosociological parameters and diversity indices are the most important ecological attributes of forest ecosystems, which show variations in response to environmental as well as anthropogenic variables. Moreover, some of the tree taxa are vulnerable due to the inconvenience of anthropogenic activities, which may significantly affect their population status and thereby the vegetation in near future. Anthropogenic activities such as fuel wood extraction, medicinal plant collection, and orchid collection for *ex-situ* conservation have been observed at the study sites. Immediate attention is needed for the effective conservation of sparsely populated species. The present study imparts extensive information on the diversity that will serve as a valuable reference for the forest assessment, thereby directing propagations and procedures for conservation actions. Furthermore, it can be concluded that the baseline information will be useful for forest managers and policy makers to formulate and implement management and conservation strategies in the area.

Acknowledgements

The authors sincerely acknowledge the Lloyd Botanical Garden Herbarium and Calcutta University Herbarium (CUH) for necessary help.

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