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Vegetation dynamics of canopy tree species of Lendrikia Reserve Forest, Kandhamal, Odisha, India

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Abstract. *Dash A, Mishra RK, Patra BK, Dash AK, Sahu A, Biswal AK, Upadhyay VP. 2026. Vegetation dynamics of canopy tree species of Lendrikia Reserve Forest, Kandhamal, Odisha, India. Biodiversitas 27 (2): d270217. https://doi.org/10.13057/biodiv/d270217.* Sustainable management of forests, especially tropical forests, is essential to comprehend how the phytosociological attributes and diversity indices of canopy tree species affect forest structure and to propose forest management options. The moist deciduous forest covers of Lendrikia Reserve Forest (LRF), an ecologically sensitive and biodiverse area in Phulbani Forest Division, Kandhamal, Odisha, India, have not yet been assessed, though numerous studies have been conducted in various tropical forest covers of India and Odisha. To address this knowledge gap, we examined phytosociological attributes of canopy tree species in the tropical moist deciduous forests of LRF in Phulbani Forest Division. Forty quadrats (20 m × 20 m) were randomly laid within the reserve forest for the study. A total of 70 canopy tree species from 55 genera and 23 families was recorded. Across species, the basal area of the species ranged from 0.233 to 2.66 m^2 ha^{-1}, totalling to 27.6 m^2 ha^{-1}, and the density from 0.625 to 43.75 individuals ha^{-1}, totalling to 575 individuals ha^{-1}. The Shannon wiener diversity, evenness, richness, concentration of dominance, and beta diversity of species were 3.92, 0.92, 10.11, 0.26, and 6.65, respectively, indicating the heterogeneous nature of the reserve forest. In terms of Importance Value Index (IVI), *Shorea robusta* (17.74) was the most dominant tree species, followed by *Ficus religiosa* (10.51), *Terminalia anogeissiana* (9.24), *Schleichera oleosa* (8.67), *Melia azedarach* (8.41), and *Lannea coromandelica* (8.31) as co-dominants. The conservation status of tree species of the reserve, as per the IUCN Red list category, includes vulnerable (04), critically endangered (01), endangered (01), and near-threatened species (02). The present study emphasizes that the combined knowledge of phytosociological characters, along with documentation of the conservation status of canopy tree species, is essential for prioritizing conservation efforts for managing resources and ensuring the long-term sustainability of both the plant species and the forest ecosystem.

Keywords: Diversity, Eastern Ghats, Importance Value Index (IVI), phytosociology, reserve forest

INTRODUCTION

Globally, the sustainable development approach has gained wide acceptance. Lack of adequate understanding of the composition and operation of ecosystems has impeded the application of sustainable planning in ecologically critical habitats. In the Lendrikia Reserve Forest (LRF) in the Kandhamal District, India, faunal and floral components are diverse, yet little is known about the makeup of its plant life forms and plant communities. Therefore, it is important to compare communities under certain environmental stress factors from season to season and year to year using the floristic composition and phytosociological traits (Haq et al. 2023).

Numerous species of plants and animals live on earth in diverse ecosystems and habitats (Wiens 2023). Odisha State in India is considered Southeast Asia's most biodiverse area (Saxena and Brahmam 1996; Mishra et al. 2018a; Dash et al. 2020; Das et al. 2022) with 2,727 plant species comprising 1,062 genera and 228 families, of which 166 are cultivated and 2,561 are natural. The diversified plant communities of Odisha have unique characteristic features that are maintained and sustained by a variety of adaptations to the changing environment, interdependence among the various plant life forms, sustained productivity, relationships with the food chain or food web, nutrient cycling, energy flow, etc. (Mishra 2018; Behura et al. 2019; Pradhan and Ormsby 2020). In these contexts, phytosociology is the study of the characteristics, relationships, distribution, and classification of plant communities. So, it is vital to gather data on the quantitative change of each species being studied and their relationships with other species in the same community. To understand past and present changes, data collected across species both within and between communities is a prerequisite that can also be utilized in future environmental impact assessment studies. Put differently, phytosociology demonstrates the structure and organization of plant diversity, which helps to determine the distribution of individuals of various species within a community and ecosystem. Therefore, this type of research is essential for understanding the functional role that a region's plant communities play (Subashree et al. 2021; Kumar et al. 2022; Tolangay and Moktan 2024; Rathaude et al. 2025). Based on the foregoing information, research on these facets of plant communities highlights the notable variation in structural attributes of canopy tree species. Such species provide important insights into their ecological responsibilities in sustaining complex ecosystems, as reflected by IVI (Mustapha et al. 2022). Rare species are crucial for conservation, even while dominant and co-dominant species add to structural diversity (Mansingh et al. 2025). Habitat heterogeneity, which promotes overall biodiversity and ecosystem resilience, is shaped by the interaction of dominance and diversity (Hurtado et al. 2025). Therefore, more focus should be given to canopy tree species with exceptionally low IVI values (Mishra et al. 2018c; Sharma et al. 2023; Singh et al. 2024).

Odisha State is witnessing an exponential growth in a few sectors where natural harvesting for raw material resources like coal, iron, chromite ore, and bauxite is essential in highly forested regions (Upadhyay et al. 2020). Ecological data pool on dominant and codominant canopy tree species, as well as the soil moisture content, etc. must be created for determining the type of forest in an area because they control forest structure, species composition, and ecological processes (Mishra et al. 2008; Chaturvedi and Raghubanshi 2018; Ali and Wang 2021). In buttressing this view, Behera and Misra (2006), Devi and Behera (2003), and Sahoo et al. (2020) mentioned that the major part of the vegetation of Kandhamal is a tropical dry and moist deciduous type, depending on the soil moisture level as well as the composition of dominants and co-dominants in the canopy layer vegetation. The forest cover of Kandhmal, which makes up 67.37% of the district's land area and is a part of the Eastern Ghats, is abundant in biological diversity and forest resources (Behera et al. 2023). Forest cover of this district peaked in 2000 (2924.60 km²) and lost more than 459.94 km², or 15.73%, over a period of 19 to 20 years (Mishra et al. 2022). To develop a strategic conservation plan and to preserve the large patch of forest cover that has been left out, particularly in this part of Odisha and in some parts of the Eastern Ghat region of Odisha, Devi and Behera (2003), Panda et al. (2013), Sahoo et al. (2017, 2020), Dash et al. (2020), Khadanga et al. (2023) and Behera et al. (2023, 2024b) conducted phytosociological studies of plant life forms, primarily about structural attributes of canopy tree species. However, LRF in Kandhamal, an ecologically sensitive area with a diverse range of floral and faunal resources, is still lacking in this type of ecological research pertaining to phytosociological studies of canopy tree species that regulate the structural and functional characteristics of forest ecosystems. In order to bridge the above knowledge gap and to generate baseline data on canopy tree species, the present study was an attempt to address (i) the overall status of various canopy tree species in the LRF, (ii) the frequency, density, distribution patterns, species diversity, rarity, and abundance of canopy tree species in the reserve forest, and (iii) to prescribe the species that need priority conservation to improve biodiversity and ecosystem services.

MATERIALS AND METHODS

Study area

The study was carried out in LRF (19°59'-20°01'N and 84°14'-84°17' E), located 60 km from Phulbani town of district Kandhamal and 300 km from Bhubaneswar, Odisha, India (Figure 1). The topography is undulating, with elevation ranging from 485 to 678 m. The spatial-temporal rainfall gradient from south to west brings corresponding changes in the vegetation. The 7.828 km² reserve forest comprises northern tropical moist deciduous and dry deciduous forests. With one dry season (December to April) and one wet season (June to October), the climate is monsoonal. The mean monthly maximum temperature ranges between 25.40°C (December) and 38.4°C (May), and the minimum between 8.6°C (December) and 22.4°C (May). The southwest monsoon brings around 88% of the yearly rainfall from June to October, with the remaining portion coming from the rare showers that fall between September and May (Figure 2). The monthly rainfall varies from 8.8 mm in December to 364.9 mm in July (Nath et al. 2018).

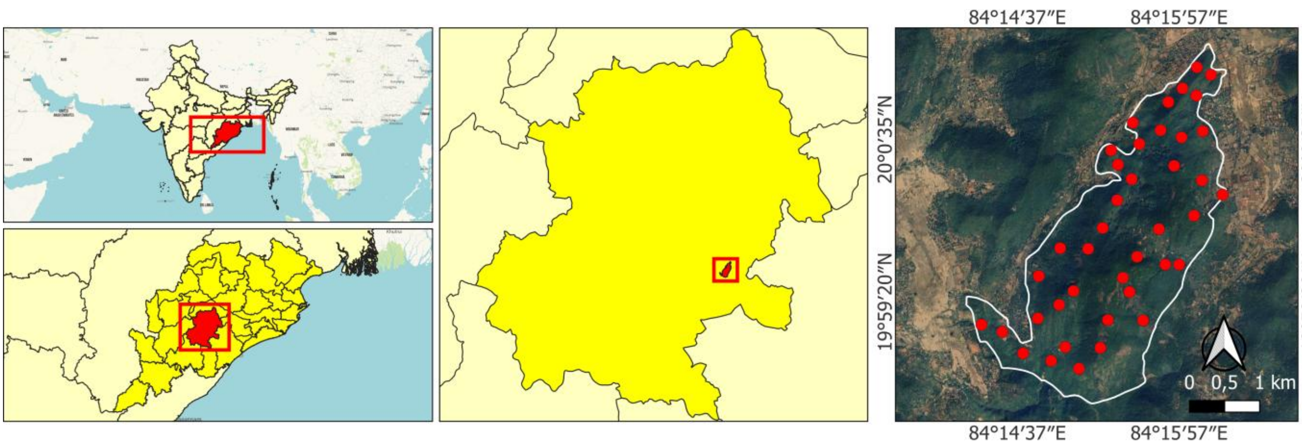

Figure 1. Location map of Lendrikia Reserve Forest (LRF) with sampling points in Kandhamal, Odisha, India

Vegetation analysis

The study was mainly focused on the canopy tree species, for which a random sampling technique was followed by placing quadrats of 20 m × 20 m. Within the quadrat, each tree was treated as an individual with ≥30 cm Circumference at Breast Height (CBH), i.e., 1.37 m above ground. Species identification was made following Saxena and Brahmam (1994-1996) and Haines (1921-1925). Furthermore, earlier herbarium records of the Botany Department, Utkal University, Bhubaneswar; Institute of Minerals and Materials Technology (IMMT), Bhubaneswar; and Maharaja Sriram Chandra Bhanjadeo University, Baripada, India, 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) and the World Flora Online (WFO 2025). IUCN's Red List of species represents a valuable resource in prioritizing conservation efforts by identifying species at risk of extinction, enabling a targeted and effective approach to safeguarding biodiversity and ecosystem health. Nine categories are used to categorize species in the IUCN Red List based on the increasing risk of extinction, such as Not Evaluated (NE), Data Deficient (DD), Least Concerned (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), and Extinct (EX) (IUCN 2023).

Analytical phytosociological parameters of canopy tree species, like Frequency (F), Density (D), and Basal Area (BA) were quantified using Mishra et al. (2021). Basal area was computed as: $(CBH)^2/4\pi$. The Importance Value Index (IVI) was calculated as the sum of the Relative Frequency (RF), Relative Density (RD), and Relative Basal Area (RBA) following Naidu et al. (2018) and Upadhyay et al. (2014). The Abundance-to-Frequency ratio (A/F) was estimated to understand the spatial distribution pattern of the species (Whitford 1949). The number of individuals was used to compute the concentration of dominance (Gatti et al. 2020) and the Shannon-Wiener species diversity (Gatti et al. 2020). The data from all the sampling plots were used to determine species evenness (Pielou 1966), richness (Özkan et al. 2024), Menhinick's Index (Özkan et al. 2024), heterogeneity Index (Whittaker 1972), and β-diversity (Whittaker 1972).

Data on phytosociological parameters of Rare, Endangered, and Threatened (RET), non-RET, and both RET and non-RET species of the reserve forest were subjected to one and two-way Analysis of Variance (ANOVA) to find out the difference among the conservation categories and phytosociological parameters. Pairwise difference among phytosociological parameters was also tested with Tukey's post hoc test. Further, two-tailed Pearson's correlation coefficients were calculated to observe the strength and direction of the relationship between phytosociological parameters of different conservation statuses of the canopy tree species. All the statistical analyses were made using ORIGIN PRO software version 2025SR1package.

RESULTS AND DISCUSSION

Species composition

A total of 70 canopy tree species from 55 genera and 23 families were identified from the reserve forest (Table 1). Across the families Fabaceae was found dominant with 21 (30%) species followed by Combretaceae (10%) with 7 species, Moraceae (7.14%) with 5 species, Anacardiaceae (5.71%) with 4 species, Myrtaceae, Malvaceae, Lamiaceae, Rutaceae, and Rubiaceae (4.29%) with three species each. These families constituted more than 50% of the reserve forest's total canopy tree species. However, most of the families, like Cornaceae, Boraginaceae, Burseraceae, Lecythidaceae, Dilleniaceae, Ebenaceae, Lythraceae, Sapindaceae, Dipterocarpaceae, and Rhamnaceae, were represented by a single species (1.43% each) (Figure 3). Floristic studies conducted in various reserve forests in Odisha (Sahoo and Panda 2015; Das et al. 2022), India (Singh et al. 2021; Meena et al. 2025), and overseas (de Souza 2023) are consistent with the higher percentage of species in Fabaceae. The dominance of Fabaceae may also be attributed to its capacity to fix nitrogen, adapt to diverse environments, and employ successful dispersal strategies (de Souza 2023; Siddiqui 2025).

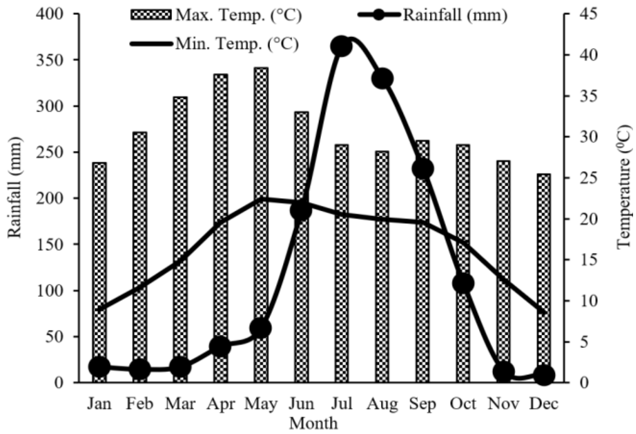

Figure 2. Month-wise mean rainfall (mm) and mean minimum and maximum temperature (°C) of LRF, India

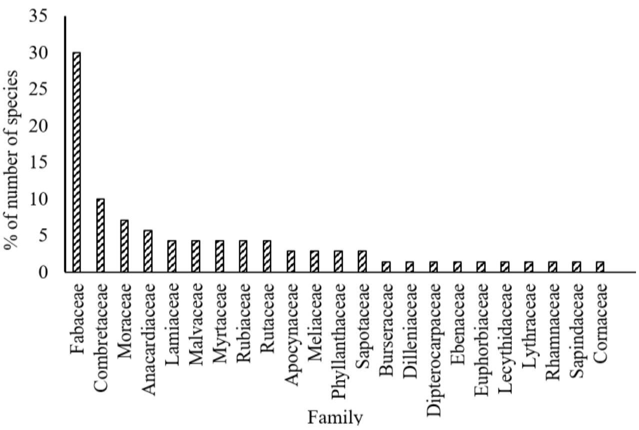

Figure 3. Percentage distribution of number of species in various families in the LRF, India

Table 1. Canopy tree species composition and IUCN status of Lendrikia Reserve Forest, Kandhamal, Odisha, India

Scientific name	Family	IUCN Status
Adina cordifolia (Roxb.) Brandis	Rubiaceae	NE
Aegle marmelos (L.) Corrêa	Rutaceae	NT
Alangium salviifolium (L.f.) Wangerin	Cornaceae	LC
Albizia lebbeck (L.) Benth.	Fabaceae	NE
Albizia procera (Roxb.) Benth.	Fabaceae	LC
Alstonia scholaris (L.) R.Br.	Apocynaceae	LC
Anogeissus acuminata Wall., 1831	Combretaceae	NE
Artocarpus heterophyllus Lam.	Moraceae	NE
Azadirachta indica A.Juss.	Meliaceae	LC
Biancaea decapetala (Roth) O.Deg.	Fabaceae	NE
Bombax ceiba L.	Malvaceae	LC
Boswellia serrata Roxb. ex Colebr.	Burseraceae	LC
Buchanania lanzan Spreng.	Anacardiaceae	NE
Butea monosperma (Lam.) Kuntze	Fabaceae	DD
Butea superba Roxb. ex Willd.	Fabaceae	NE
Careya arborea Roxb.	Lecythidaceae	NE
Cassia fistula L.	Fabaceae	LC
Chloroxylon swietenia (Roxb.) DC.	Rutaceae	VU
Cleistanthus collinus (Roxb.) Benth. ex Hook.f.	Phyllanthaceae	VU
Dalbergia latifolia Roxb.	Fabaceae	VU
Dalbergia sissoo Roxb. ex DC.	Fabaceae	LC
Delonix regia (Bojer ex Hook.) Raf.	Fabaceae	LC
Dillenia aurea Sm.	Dilleniaceae	CR
Diospyros melanoxylon Roxb.	Ebenaceae	NE
Erythrina variegata L.	Fabaceae	LC
Eucalyptus globulus Labill.	Myrtaceae	NE
Ficus benghalensis L.	Moraceae	LC
Ficus hispida L.f.	Moraceae	LC
Ficus religiosa L.	Moraceae	LC
Ficus virens Aiton	Moraceae	LC
Gardenia gummifera L.f.	Rubiaceae	LC
Gmelina arborea Roxb. ex Sm.	Lamiaceae	LC
Holarrhena pubescens (Buch.-Ham.) Wall. ex G.Don	Apocynaceae	LC
Lagerstroemia parviflora Roxb.	Lythraceae	LC
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	LC
Limonia acidissima L.	Rutaceae	NE
Madhuca longifolia var. latifolia (Roxb.) A.Chev.	Sapotaceae	NE
Mallotus philippensis (Lam.) Müll.Arg.	Euphorbiaceae	NE
Mangifera indica L.	Anacardiaceae	DD
Melia azedarach L.	Meliaceae	NE
Mimusops elengi L.	Sapotaceae	LC
Neolamarckia cadamba (Roxb.) Bosser	Rubiaceae	LC
Ougeinia oojeinensis (Roxb.) Hochr.	Fabaceae	NE
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	Fabaceae	LC
Phyllanthus emblica L.	Phyllanthaceae	LC
Pongamia pinnata (L.) Pierre	Fabaceae	LC
Prosopis cineraria (L.) Druce	Fabaceae	NE
Psidium guajava L.	Myrtaceae	LC
Pterocarpus marsupium Roxb.	Fabaceae	NT
Pterospermum acerifolium (L.) Willd.	Malvaceae	LC
Saraca asoca (Roxb.) Willd.	Fabaceae	VU
Schleichera oleosa (Lour.) Oken	Sapindaceae	LC
Senna siamea (Lam.) H.S.Irwin & Barneby	Fabaceae	NE
Senegalia catechu (L.f.) P.J.H.Hurter & Mabb.	Fabaceae	LC
Shorea robusta Gaertn.	Dipterocarpaceae	LC
Spondias pinnata (L.f.) Kurz	Anacardiaceae	LC
Sterculia urens Roxb.	Malvaceae	LC
Syzygium cumini (L.) Skeels	Myrtaceae	LC
Tamarindus indica L.	Fabaceae	LC
Tectona grandis L.f.	Lamiaceae	EN
Terminalia anogeissiana Gere & Boatwr.	Combretaceae	NE
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	Combretaceae	LC
Terminalia bellirica (Gaertn.) Roxb.	Combretaceae	LC
Terminalia chebula Retz.	Combretaceae	NE
Terminalia citrina (Gaertn.) Roxb. ex Fleming	Combretaceae	LC
Terminalia elliptica Willd.	Combretaceae	NE
Vachellia leucophloea (Roxb.) Maslin, Seigler & Ebinger	Fabaceae	NE
Vachellia nilotica (L.) P.J.H.Hurter & Mabb.	Fabaceae	LC
Vitex negundo L.	Lamiaceae	LC
Ziziphus mauritiana Lam.	Rhamnaceae	NE

Note: LC: Least Concern, NE: Not Evaluated, DD: Data Deficient, NT: Near Threatened, VU: Vulnerable, CR: Critically Endangered, EN: Endangered

The number of canopy tree species (70 species) recorded in the study was less in number to the prior reports on the forest covers of Odisha (Saxena and Brahmam 1994-1996; Das et al. 2022), tropical forest of Eastern Ghats (Naidu et al. 2023; Behera et al. 2024a), Jharkhand in Eastern India (Kumar and Saikia 2020) and Panchamari biosphere reserve in Central India (Kumar et al. 2024), which may be due to increased anthropogenic forest fires for the collection of Mahua flowers (*Madhuca longifolia* var. *latifolia* (Roxb.) A.Chev.) for traditional wine preparation, timber felling, collection of fuel wood, and other Non-Timber Forest Products (NTFPs), as evidenced in other tropical dry and moist deciduous forests of Odisha (Sahoo et al. 2020; Nag et al. 2022; Behera et al. 2024c), as well as the variation in microclimatic environmental variables such as climate, topography, and elevation (Sundarapandian and Karoor 2013). However, we observed that our record of 43 species ha^{-1} is higher than 31.67 ha^{-1} in tropical forests of Sheka biosphere reserve of southwest Ethiopia (Ameneshewa et al. 2025), 35 ha^{-1} in tropical moist deciduous forests of Kadigarh National Park, Bangladesh (Das 2024) and, 41 ha^{-1} in tropical dry forests of Central India (Rathaude et al. 2025) but similar to tropical dry deciduous forests of Eastern India, where the range of species varied from 31 to 52 ha^{-1} (Mansingh et al. 2025). Our analysis indicates that the number of species per ha^{-1} was lower than 62 to 73 ha^{-1} for the Suruli Falls area of the Nokrek Biosphere Reserve (Sangma and Mishra 2017).

In the present study, out of the 70 canopy tree species, we identified one species as endangered (*Tectona grandis* L.f.), one as critically endangered (*Dillenia aurea* Sm.), 4 as vulnerable (*Saraca asoca* (Roxb.) W.J.de Wilde, *Chloroxylon swietenia* (Roxb.) DC., *Dalbergia latifolia* Roxb. and *Cleistanthus collinus* (Roxb.) Benth. ex Hook.f.), and two as near threatened (*Pterocarpus marsupium* Roxb. and *Aegle marmelos* (L.) Corrêa) species (Table 1). However, 54.29% (38) of canopy tree species were identified as least concerned, followed by 31.43% (22) as not evaluated, and only 2.86% (2) as data deficient in the 1.6 ha sampling plot area of the reserve forest (Table 1). The 8 threatened category species should be given a high priority for conservation due to their rarity and potential for extinction, which implies that in the future they may be endangered by both biotic and abiotic forces (Ramarumo and Maroyi 2020; Wani et al. 2022; Kumar et al. 2024).

The density of each canopy tree species is represented as the numerical strength of a species within a community. *Shorea robusta* Gaertn. had the highest density of 43.75 individuals ha^{-1} among the woody species, followed by *Eucalyptus globulus* Labill. (29.38 individuals ha^{-1}), *Terminalia anogeissiana* Gere & Boatwr. (23.75 individuals ha^{-1}), *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb. (23.13 individuals ha^{-1}), *Lannea coromandelica* (Houtt.) Merr. (21.25 individuals ha^{-1}), and *Schleichera oleosa* (Lour.) Oken (20.63 individuals ha^{-1}). The lowest density, with 1.25 individuals ha^{-1}, was estimated for *T. grandis,* followed by *Erythrina variegata* L., *Artocarpus heterophyllus* Lam., and *Psidium guajava* L., with the fewest individuals, 0.625 ha^{-1} each (Table 2). A total tree density of 575 individuals ha^{-1} in the present study exists well within the range of 276-905 individuals ha^{-1} reported for trees ≥30 cm gbh in tropical forests of the Similipal biosphere reserve (Mishra et al. 2018b), 450-729 individuals ha^{-1} in tropical moist deciduous forests of the Balasore district of Odisha (Mishra et al. 2018c), 395-573 individuals ha^{-1} in tropical deciduous forests of Northcentral Eastern Ghats of India (Naidu et al. 2018), 435-767 individuals ha^{-1} in tropical forests in Eastern Ghats of Andhra Pradesh (Naidu and Kumar 2016), 156-1089 individuals ha^{-1} in tropical forests of Pakistan (Khan et al. 2021) and is close to the value reported by Devkota et al. (2025) in tropical Terai forest of Nepal (615.87 individuals ha^{-1}) and, Behera et al. (2025) for Sal forests (545 individuals ha^{-1}) in the Kandhamal District of Odisha.

The basal area of canopy trees is a key phytosociological attribute for assessing forest biomass, structure, and dominance. With a total estimated value of 27.602 m² ha^{-1}, the species-specific basal area of the reserve forest varied between 0.23 and 2.66 m² ha^{-1} (Table 2). Across species, maximum basal area was recorded for *S. robusta* (2.66 m² ha^{-1}), followed by *Ficus religiosa* L. (1.44 m² ha^{-1}), *Melia azedarach* L. (1.44 m² ha^{-1}), *Ficus benghalensis* L. (1.11 m² ha^{-1}), and *Pterospermum acerifolium* (L.) Willd. (1.08 m² ha^{-1}), with an average basal area of 0.394 m² ha^{-1} per species (Table 2). The total basal area of 27.602 m² ha^{-1} of the study is more or less equal to moist mixed deciduous forests (27.15 m² ha^{-1}) of Odisha (Behera et al. 2025) as well as within the reported range of 2.2-34.91 m² ha^{-1} in tropical forests of Eastern Ghats, India (Naidu et al. 2023), 15.43-71.76 m² ha^{-1} in tropical dry deciduous forests of Central India (Joshi and Dhyani 2018) and 6.62-37.90 m² ha^{-1} in tropical forest covers of Pakistan (Khan et al. 2021). However, the total basal area is lower in value (34.6-76.5 m² ha^{-1}) compared to that of tropical rain forests in Amazonia (Caron et al. 2021).

Curtis and McIntosh (1951) described IVI as an important vegetation indicator that provides information on each species' social structure, dominance, rarity, and overall ecological significance or ecological establishment within a community. A high IVI value indicates that a species is well established and adaptable, whereas species with low IVI values are prioritized over those with high values because of their rarity (Mounmemi et al. 2023). In the reserve forest, across the canopy tree species, IVI values ranged from 1.22 to 17.74, with a maximum value of 17.74 exhibited by *S. robusta*, which is the leading dominant species. However, the co-dominants were *F. religiosa* (10.51), *T. anogeissiana* (9.24), *S. oleosa* (8.67), *M. azedarach* (8.41), and *L. coromandelica* (8.31). Other species having lower IVI values were *C. swietiana* (2.71), *P. marsupium* (1.88), *S. asoca* (1.68), *T. grandis* (1.47), and *Ougeinia oojeinensis* (Roxb.) Hochr. (1.26), followed by *Anogeissus acuminata* Wall., with the least IVI value of 1.22 (Table 2). High IVI values in dominant and co-dominant species likely reflect efficient resource use and effective dispersal (Pillutla and Kumari 2019), whereas low IVI values in most other species indicate that they are occasional and less abundant in the forest, highlighting the need for conservation to prevent extinction (Behera et al. 2023).

Table 2. Density, frequency, basal area, abundance, A/F ratio, IVI, species diversity, and concentration of dominance of canopy tree species at LRF, India

Name of plant species	D (Indivs. ha^{-1})	F (%)	BA (m^2 ha^{-1})	A	A/F	IVI	H$^{/}$	Cd
Dominants and Co-dominants								
Shorea robusta Gaertn.	43.75	45.00	2.66	23.00	0.51	17.74	0.195991	0.000302
Ficus religiosa L.	1.88	5.00	1.44	1.50	0.30	10.51	0.018671	0.000118
Terminalia anogeissiana Gere & Boatwr.	23.75	37.50	0.28	2.53	0.07	9.24	0.131628	0.000011
Schleichera oleosa (Lour.) Oken	20.63	35.00	0.35	2.36	0.07	8.67	0.119369	0.000011
Melia azedarach L.	10.63	12.50	1.44	3.40	0.27	8.41	0.073750	0.000096
Lannea coromandelica (Houtt.) Merr.	21.25	32.50	0.30	2.62	0.08	8.31	0.121883	0.000030
Diospyros melanoxylon Roxb.	18.75	32.50	0.29	2.31	0.07	7.84	0.111625	0.000019
Terminalia citrina (Gaertn.) Roxb. ex Fleming	13.75	37.50	0.34	1.47	0.04	7.72	0.089275	0.000005
Holarrhena pubescens (Buch.-Ham.) Wall. ex G.Don	16.88	32.50	0.25	2.08	0.06	7.38	0.103555	0.000011
Eucalyptus globulus Labill.	29.38	7.50	0.28	15.67	2.09	6.94	0.151944	0.001366
Ficus bengalensis L.	9.38	10.00	1.11	3.75	0.38	6.72	0.067114	0.000200
Vachellia nilotica (L.) P.J.H.Hurter & Mabb.	23.13	12.50	0.31	7.40	0.59	6.52	0.129237	0.000302
RET species								
Aegle marmelos (L.) Corrêa	3.13	25.00	0.24	0.50	0.02	4.13	0.028342	0.000001
Chloroxylon swietenia (Roxb.) DC.	1.88	12.50	0.28	0.60	0.05	2.71	0.018671	0.000011
Cleistanthus collinus (Roxb.) Benth. ex Hook.f.	4.38	42.50	0.25	0.41	0.01	6.29	0.037119	0.000001
Dalbergia latifolia Roxb.	13.13	12.50	0.29	4.20	0.34	4.70	0.086279	0.000143
Dillenia aurea Sm.	3.13	15.00	0.25	0.83	0.06	3.09	0.028342	0.000011
Pterocarpus marsupium Roxb.	1.88	5.00	0.28	1.50	0.30	1.88	0.018671	0.000118
Saraca asoca (Roxb.) W.J.de Wilde	3.13	2.50	0.24	5.00	2.00	1.68	0.028342	0.001287
Tectona grandis L.f.	1.25	2.50	0.27	2.00	0.80	1.47	0.013329	0.000625
Others								
Senegalia catechu (L.f.) P.J.H.Hurter & Mabb.	3.75	12.50	0.23	1.20	0.10	2.84	0.032821	0.000043
Vachellia leucophloea (Roxb.) Maslin, Seigler & Ebinger	4.38	7.50	0.25	2.33	0.31	2.47	0.037119	0.000143
Adina cordifolia (Roxb.) Brandis	6.88	10.00	0.41	2.75	0.28	3.78	0.052925	0.000096
Alangium salviifolium (L.f.) Wangerin	9.38	17.50	0.27	2.14	0.12	4.52	0.067114	0.000043
Albizia lebbeck (L.) Benth.	9.38	15.00	0.30	2.50	0.17	4.35	0.067114	0.000058
Albizia procera (Roxb.) Benth.	3.75	5.00	0.26	3.00	0.60	2.15	0.032821	0.000383
Alstonia scholaris (L.) R.Br.	3.75	5.00	0.43	3.00	0.60	2.77	0.032821	0.000521
Anogeissus acuminata Wall., 1831	3.75	2.50	0.35	6.00	2.40	1.22	0.032821	0.001617
Neolamarckia cadamba (Roxb.) Bosser	2.50	5.00	0.26	2.00	0.40	1.91	0.023644	0.000266
Artocarpus heterophyllus Lam.	0.63	2.50	0.35	1.00	0.40	1.65	0.007418	0.000232
Azadirachta indica A.Juss.	6.25	15.00	0.25	1.67	0.11	3.64	0.049150	0.000043
Bombax ceiba L.	14.38	17.50	0.36	3.29	0.19	5.71	0.092222	0.000058
Boswellia serrata Roxb. ex Colebr.	11.25	22.50	0.39	2.00	0.09	5.81	0.076970	0.000030
Buchanania lanzan Spreng.	6.88	10.00	0.29	2.75	0.28	3.33	0.052925	0.000096
Butea monosperma (Lam.) Kuntze	6.25	15.00	0.25	1.67	0.11	3.64	0.049150	0.000043
Butea superva Roxb. ex Willd.	5.00	7.50	0.26	2.67	0.36	2.62	0.041260	0.000170
Biancaea decapetala (Roth) O.Deg.	10.00	5.00	0.27	8.00	1.60	3.27	0.070466	0.001063
Careya arborea Roxb.	5.63	12.50	0.30	1.80	0.14	3.41	0.045266	0.000043
Cassia fistula L.	3.75	5.00	0.28	3.00	0.60	2.22	0.032821	0.000341
Senna siamea (Lam.) H.S.Irwin & Barneby	5.63	7.50	0.36	3.00	0.40	3.10	0.045266	0.000302
Dalbergia sissoo Roxb. ex DC.	6.25	10.00	0.27	2.50	0.25	3.16	0.049150	0.000076
Delonix regia (Bojer ex Hook.) Raf.	14.38	2.50	0.39	3.89	1.56	4.18	0.092222	0.000994
Phyllanthus emblica L.	4.38	5.00	0.23	3.50	0.70	2.13	0.037119	0.000572
Erythrina variegata L.	0.63	5.00	0.33	1.50	0.30	2.07	0.007418	0.000118
Ficus hispida L.f.	3.75	10.00	0.25	1.50	0.15	2.64	0.032821	0.000058
Ficus virens Aiton	5.00	5.00	0.24	4.00	0.80	2.28	0.041260	0.000861
Gardenia gummifera L.f.	18.13	12.50	0.46	5.80	0.46	6.19	0.108973	0.000302
Gmelina arborea Roxb. ex Sm.	5.00	12.50	0.26	1.60	0.13	3.17	0.041260	0.000043
Lagerstroemia parviflora Roxb.	11.25	15.00	0.25	3.00	0.20	4.51	0.076970	0.000058
Limonia acidissima L.	4.38	7.50	0.28	2.33	0.31	2.59	0.037119	0.000143
Madhuca longifolia var. *latifolia* (Roxb.) A.Chev.	10.00	22.50	0.82	1.78	0.08	5.48	0.070466	0.000019
Mallotus philippensis (Lam.) Müll.Arg.	7.50	2.50	0.24	12.00	4.80	2.45	0.056602	0.005789
Mangifera indica L.	1.88	2.50	0.36	1.00	0.40	2.18	0.023644	0.000266
Mimusops elengi L.	5.63	2.50	0.23	9.00	3.60	2.10	0.045266	0.002610
Ougeinia oojeinensis (Roxb.) Hochr.	4.38	10.00	0.29	1.75	0.18	1.26	0.037119	0.000058
Peltophorum pterocarpum (DC.) Backer ex K.Heyne	10.00	12.50	0.27	3.20	0.26	4.09	0.070466	0.000076
Pongamia pinnata (L.) Pierre	2.50	2.50	0.24	1.00	0.40	2.91	0.013329	0.000200
Prosopis cineraria (L.) Druce	4.38	2.50	0.24	7.00	2.80	1.90	0.037119	0.001706
Psidium guajava L.	0.63	5.00	0.23	2.00	0.40	1.83	0.007418	0.000266

Pterospermum acerifolium (L.) Willd.	3.75	25.00	1.08	0.60	0.02	7.30	0.032821	0.000001
Spondias pinnata (L.f.) Kurz	6.88	15.00	0.30	1.83	0.12	3.90	0.052925	0.000043
Sterculia urens Roxb.	8.13	20.00	0.25	1.63	0.08	4.49	0.060188	0.000030
Syzygium cumini (L.) Skeels	1.25	2.50	0.31	2.00	0.80	1.62	0.018671	0.000625
Tamarindus indica L.	8.13	12.50	0.57	2.60	0.21	4.84	0.060188	0.000058
Terminalia elliptica Willd.	3.75	5.00	0.25	3.00	0.60	2.11	0.032821	0.000341
Terminalia arjuna (Roxb.) Wight & Arn.	8.75	17.50	0.33	2.00	0.11	4.61	0.063690	0.000043
Terminalia bellirica (Gaertn.) Roxb.	10.63	20.00	0.33	2.13	0.11	5.23	0.073750	0.000043
Terminalia chebula Retz.	3.75	5.00	0.55	3.00	0.60	3.18	0.032821	0.000383
Vitex negundo L.	1.88	17.50	0.23	0.43	0.02	5.19	0.018671	0.000005
Ziziphus mauritiana Lam.	10.00	12.50	0.25	3.20	0.26	4.02	0.070466	0.000076
Total	575		27.60			300	3.918002	0.026113

Note: A: Abundance, BA: Basal Area, D: Density, F: Frequency, IVI: Importance Value Index, Indivs.: Individuals, H/: Species diversity, Cd: Concentration of dominance

Raunkiaer's frequency class depicts the distribution of species in a plant community. The non-RET species represented 83.87%, 14.52%, and 1.61%; all species together 82.86%, 14.28%, and 2.86%; and the RET categories 75%, 12.5%, and 12.5% for classes A, B, and C, respectively. We did not record any species in the classes D and E. Compared to Raunkiaer's normal frequency class distribution of 53%, 14%, 9%, 8%, and 16% for the respective classes (Raunkiaer 1934), we observed an A > B > C pattern for non-RET and across all species categories and an A > B = C pattern for the RET category (Figures 4.A-C).

Though the frequency class distribution of canopy tree species in all three categories (RET, non-RET, and RET + non-RET) of the reserve forest does not match Raunkiaer's normal frequency class, the woody vegetation reveals a heterogeneous nature. Raunkiaer's frequency class distribution with the present study revealed that most of the species showed lower frequency values, as would be expected in a typical species-abundant forest (Mishra et al. 2006; Malik et al. 2021). The frequency distribution pattern of species had only three classes instead of five as described in the law, indicating a high level of heterogeneity like canopy tree species of the reserve forest. Analysis of the spatial distribution of the canopy tree species as a whole showed 64 species that were contiguously distributed, while only 2 species (one species each in the RET and non-RET categories) were found to be randomly distributed, and 4 species (two species each in the RET and non- RET categories) exhibited regular distribution patterns. According to Odum (1971), a contiguous pattern of distribution is the most common pattern in natural vegetation. Random distribution of species is found in a very uniform or stable habitat, whereas regular distribution is instituted in the habitat where severe competition arises among the species. The present study recorded high dominance of contiguously distributed species (91.4%), followed by 5.7% regularly distributed and 2.9% randomly distributed species in the studied reserve forest. The maximum percentage of contiguous distribution of tree species of the reserve forest may be due to the synergistic effect of several factors such as habitat specificity, limitations on seed dispersal and vegetative propagation, topography, gap formations, etc. (Das et al. 2017), while the random distribution of very few species may be due to sufficient seed dispersal and disturbances (Kumar and Saikia 2020).

Species rarity

Based on the criteria established by Krishnamurthy et al. (2010), canopy tree species of LRF were grouped into three categories, such as common, rare, and very rare species, considering their density per 1.6 ha area sampled (Tables 2 and 3). Nine species, such as *S. robusta*, *E. globulus*, *T. anogeissiana*, *A. nilotica*, *L. coromandelica*, *S. oleosa*, *Diospyros melanoxylon* Roxb., *Gardenia gummifera* L.f., and *Holarrhena pubescens* (Buch.-Ham.) Wall. ex G.Don, were classified as common species and accounted for 12.86% of the species richness. Fifty-six species, viz., *D. latifolia*, *S. asoca*, *P. marsupium*, *D. aurea*, *A. marmelos*, *C. swietiana*, etc., were under the rare species category and accounted for 80% of the species richness of the reserve forest. The other five species, like *T. grandis*, *Syzygium cumini* (L.) Skeels, *E. variegata*, *P. guajava,* and *A. heterophyllus,* were classified as very rare species and represented 7.14% of the species richness. The total species rarity (87.14%) is the sum of rare and very rare, and the locality is higher than 43% in the Kalrayan Hills of the Eastern Ghats, 41% in the tropical forests of the Eastern Ghats of northern Andhra Pradesh, 40% rarity in Barro Colorado Island, 38% in Malaysia, 59% rarity in the Jengka Forest Reserve of Malaysia, 55.4% in New Guinea, and 50% in West Java (Gandhi and Sundarapandian 2020; Hordijk et al. 2024).

Table 3. Classification of species based on the criteria fixed by Krishnamurthy et al. (2010)

Category	Number of individuals per 2 ha area
Predominant species	≥ 200
Dominant species	100-199
Common species	25-99
Rare species	3-24
Very rare species	<3

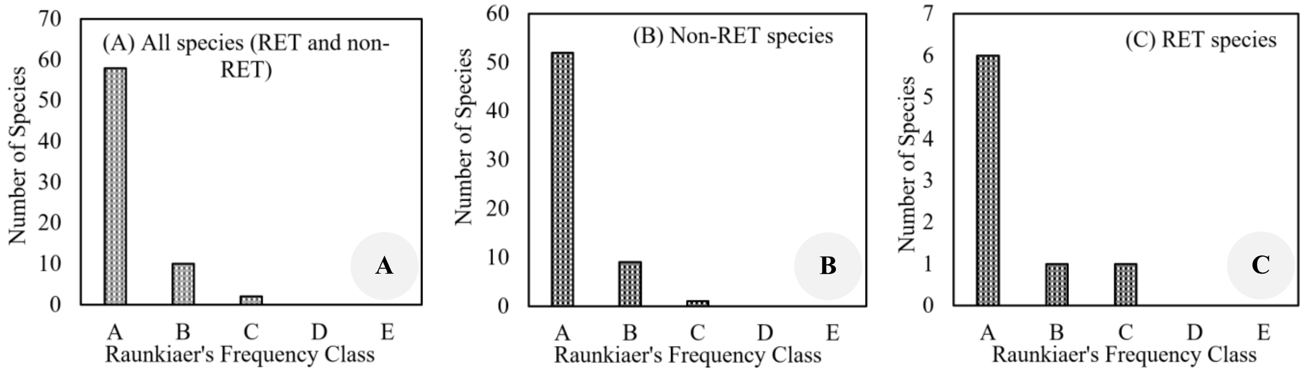

Figure 4. A-C. Raunkiaer's frequency class distribution of different conservation categories. A. Both RET and non-RET, B. Non-RET, C. RET of canopy tree species at LRF

Table 4. One-way ANOVA between phytosociological parameters of all canopy tree species (both threatened and non-threatened) at LRF, India

Source of variation	DF	Sum of squares	Mean square	F value	Probability label
Model	4	6794.83521	1698.7088	45.35301	<0.0001
Error	345	12922.06599	37.45526		
Total	349	19716.9012			

Table 5. Two-way ANOVA between conservation status and phytosociological parameters of canopy tree species at LRF, India

Source of variation	DF	Sum of squares	Mean square	F value	P value
Factor A	1	49.28233	49.28233	1.31831	0.2517
Factor B	4	3031.81015	757.95254	20.27529	<0.0001
Interaction	4	162.54218	40.63555	1.087	0.3628
Model	9	7006.65973	778.51775	20.82541	<0.0001
Error	340	12710.24147	37.38306		
Corrected total	349	19716.9012			

Note: Factor-A: Non-RET and RET species. Factor-B: Phytosociological parameters (IVI, Frequency, Density, BA, and Abundance)

Comparative phytosociological attributes of RET and non-RET canopy tree species of LRF

The comparison of community structure and plant characteristics between non-RET and RET species of LRF showed that RET species had a very small portion of the density (5.87%), basal area (8.24%), and IVI (9.47%) as compared to the non-RET species. One-way ANOVA was used to evaluate the differences between the phytosociological parameters of RET and non-RET plant species. The findings demonstrated the statistical significance of the model and the considerable differences in phytosociological characteristics between RET and non-RET species. Furthermore, the one-way ANOVA results showed that the ecological responsibilities and requirements of RET species, as well as their phytosociological profiles, differ from those of non-RET species (Table 4).

The analysis of a two-way ANOVA comparing the conservation status and phytosociological parameters of canopy tree species (RET and non-RET) in the reserve forest indicated that phytosociological parameters are the principal factors influencing the characteristics of plant communities, as evidenced by their significant or strong variation ($F_{4,349} = 20.28$, $P < 0.0001$). Differences in the conservation status of canopy tree species, however, are insignificant and have no noticeable impact on community features ($F_{1,349} = 1.32$, $P < 0.252$). Furthermore, because of the insignificant interaction between phytosociological parameters and the conservation status of canopy tree species in LRF ($F_{4,349} = 1.09$, $P<0.363$), it was assumed that the influence of phytosociological parameters on the features of canopy layer plant communities is independent of plant conservation status (Table 5).

In addition to one and two-way ANOVA, an important tool for analysing the variations in phytosociological parameters between RET and non-RET canopy tree species is the Tukey test, a post-hoc test of ANOVA (Table-6). Even if the overall interaction is insignificant, the test's results indicated that there are, in fact, significant differences between particular pairings of phytosociological parameters of RET and non-RET species. The seeming contradiction between insignificant interaction and significant pairwise variation might be due to complex and nonlinear relationships between phytosociological parameters and the conservation status of canopy tree species and species-specific responses, i.e., different canopy tree species might respond differently to changes in phytosociological parameters, leading to significant pairwise variations.

Table 6. Tukey test of pairwise variation of phytosociological attributes between non-RET and RET canopy tree species of LRF, India

Pairs of phytosociological parameters	Mean difference	SEM	q Value	Probability	Alpha	Significance
Density and IVI	3.92857	1.03348	5.37584	0.00159	0.05	1
Frequency and IVI	8.82143	1.03348	12.0712	<0.0001	0.05	1
Frequency and Density	4.89286	1.03348	6.69536	<0.0001	0.05	1
Basal area and IVI	-3.8914	1.03348	5.32498	0.00182	0.05	1
Basal area and Density	-7.81998	1.03348	10.70082	<0.0001	0.05	1
Basal area and Frequency	-12.71283	1.03348	17.39618	<0.0001	0.05	1
Abundance and IVI	-1.0051	1.03348	1.37538	0.86742	0.05	0
Abundance and Density	-4.93368	1.03348	6.75122	<0.0001	0.05	1
Abundance and Frequency	-9.82653	1.03348	13.44658	<0.0001	0.05	1
Abundance and basal area	2.8863	1.03348	3.9496	0.04359	0.05	1

Table 7. Pearson correlation coefficient between phytosociological parameters of canopy tree species (both RET and non-RET) at LRF, India

Phytosociological parameters	IVI	Density	Frequency	Basal area	Abundance	A/F
IVI	1	0.80098***	0.75507***	0.72165***	0.40595***	-0.24783*
Density	0.80098	1	0.60723***	0.43038***	0.65594***	-0.00961
Frequency	0.75507	0.60723	1	0.28485**	0.04025	-0.43566***
Basal area	0.72165	0.43038	0.28485	1	0.4719***	-0.088
Abundance	0.40595	0.65594	0.04025	0.4719	1	0.57849***
A/F	-0.24783	-0.00961	-0.43566	-0.088	0.57849	1

Note: ***: Significant at P≤0.001

Table 8. Pearson correlation coefficient between phytosociological parameters of non-RET canopy tree species at LRF, India

Phytosociological parameters	IVI	Density	Frequency	BA	Abundance	A/F
IVI	1	0.80653***	0.77941***	0.73177***	0.41706***	-0.24077*
Density	0.80653	1	0.69246***	0.42093***	0.65107***	-0.01537
Frequency	0.77941	0.69246	1	0.32614***	0.0955	-0.42385***
Basal area	0.73177	0.42093	0.32614	1	0.46796***	-0.09618
Abundance	0.41706	0.65107	0.0955	0.46796	1	0.57183***
A/F	-0.24077	-0.01537	-0.42385	-0.09618	0.57183	1

Note: *: Significant at P≤0.05; ***: Significant at P≤0.001

Table 9. Pearson correlation coefficient between phytosociological parameters of RET canopy tree species at LRF, India

Phytosociological parameters	IVI	Density	Frequency	Basal area	Abundance	A/F
IVI	1	0.53191*	0.91205***	-0.12293	-0.28894	-0.55263*
Density	0.53191	1	0.13977	0.36953	0.48849*	-0.08932
Frequency	0.91205	0.13977	1	-0.35798	-0.55605*	-0.57885*
Basal area	-0.12293	0.36953	-0.35798	1	0.09295	-0.27787
Abundance	-0.28894	0.48849	-0.55605	0.09295	1	0.8066***
A/F	-0.55263	-0.08932	-0.57885	-0.27787	0.8066	1

Note: *: Significant at P≤0.05; ***: Significant at P≤0.001

Correlation studies made among various phytosociological parameters of non-RET species, as well as all the canopy tree species (both RET and non-RET species) of the reserve forest, showed significant positive correlation among all the phytosociological parameters except IVI with A/F, and frequency with A/F, where the correlations are negatively significant (Tables 7 and 8). However, in the RET species, IVI with A/F and frequency with A/F and density are negatively correlated, while IVI with frequency and density and abundance with A/F are positively correlated (Table 9). Positive correlations among phytosociological parameters of non-RET as well as all the canopy tree species of LRF may be the result of competitive advantage over RET species, biomass contribution, appropriate habitat conditions, widespread distribution, efficient seed dispersal mechanisms, and numerical dominance. Spatial aggregation, high local abundance, and restricted spatial dispersion are the reasons for the negative association between the IVI and A/F, as well as between frequency and A/F. However, in RET species, their habitat specialization and the pressure from competition or predation that limits their spatial aggregation may have resulted in a negative association between phytosociological parameters like IVI and A/F, frequency and A/F, and frequency and density.

Diversity indices of the woody taxa

Diversity indices are important phytosociological measures for understanding forest ecosystem structure. Species diversity is the number of species and their abundance in a community, which measures species richness and species evenness. The Shannon Diversity Index is a way to measure the quantity of information required to describe each species in a community of different forest ecosystems. It is typically high based on species adaptation and increases with community stability (Bisht et al. 2022). Forest communities were defined as rich when they had a Shannon diversity value of 3.5 or more (Jannat et al. 2020). In the present investigation, the Shannon Diversity Index for the canopy tree species ranged between 0.0074 and 0.196, with a highest value of 0.196 for *S. robusta* and the least (0.0074) for *E. variegata*, *A. heterophyllus,* and *P. guajava* (Table 2). The total estimated value of species diversity for canopy tree species (3.918) in LRF is more or less equal to Durgapur hill forest, Netrokona, Bangladesh (Rahman et al. 2019) and tropical forests in Nigeria (Stamin and Cosmulescu 2025) as well as within the range between 0.83 and 5.40, as reported by Subashree et al. (2021), Naidu et al. (2023), and Mastan and Reddy (2023) for various Indian tropical forests. Furthermore, the lower abundance value of the majority of the canopy tree species of the reserve forest could paradoxically increase species diversity, evenness, and aggregation (Kalyuzhny et al. 2023; Li et al. 2023), thereby promoting biodiversity in tropical and subtropical forests (Ehbrecht et al. 2017).

Simpson Diversity Index is an index to measure the degree of concentration of species in a community. The Cd value across canopy tree species in the reserve forest was notably low, ranging from 0.000001 to 0.0058, with a cumulative total of 0.026 for the entire 1.6 ha area studied (Table 2). The average value of the dominance index for tropical forests of Bangladesh, Nigeria and India are 0.07, 0.92 and 0.06, respectively (Rahman et al. 2019; Lyngdoh et al. 2023; Stamin and Cosmulescu 2025) and it ranges between 0.021 and 0.92 for Indian tropical forests (Subashree et al. 2021; Lyngdoh et al. 2023). The Cd value obtained in this study is closer to the lower limit of this range. Further, the study emphasized that the recorded low Cd value across the canopy tree species in the reserve forest could be attributed to the high species richness (Joshi et al. 2023) and varying degrees of anthropogenic pressure experienced by the studied reserve forest (Bisht et al. 2022).

The recorded values of Margalef's Index and Menhinick's Index of the canopy tree species at LRF were 10.11 and 2.31, respectively (Table 10). Both indices measure species richness in the ecosystem. The scored value of Margalef's index in the present investigation is well comparable to tree layer of broad leaf forest of China (Zhu et al. 2024) and within the reported range of 3.54-11.57 for tree species in Garhwal Himalaya, India (Meena et al. 2020), but higher than those of tree species of tropical forest in Nigeria (Stamin and Cosmulescu 2025) and tropical dry forests of Northern India (Sharma et al. 2023). Similarly, Menhinick's Index of canopy tree species of LRF is well within the reported range of 0.41 to 2.63 of tropical deciduous forests in Odisha (Nag et al. 2022). In addition to Margalef's and Menhinick's Index of richness, the evenness or equitability index of canopy tree species of LRF was recorded as 0.922 (Table 10) and revealed how evenly the species are distributed within the reserve forest. Uniformly dispersed communities with similar species distributions have an evenness index close to 1 (Kumar and Saikia 2021), while dominating trees that receive the maximum light and water may suppress related species (Meng et al. 2024). Moreover, they also stated that a high evenness denotes greater consistency in the species distribution.

Species heterogeneity reflects the diversity and complexity of tree species composition in a reserve forest. The value calculated for canopy tree species of LRF was 0.162 (Table 10) and is more or less within the previously reported range (0.21-0.8) of tropical forests in India (Dar and Sunderpandian 2016). The results of the study may also suggest that the canopy tree species of the reserve forest are heterogeneous in nature, with an assortment of pioneer and climax species. One of the important but frequently overlooked aspects of community composition of various forest types is beta diversity. By fostering a diverse mosaic of plant communities inside forests, increased beta diversity can enhance ecosystem resilience (Mohanty et al. 2005; He et al. 2020). The βd reported in this study for canopy tree species was 6.64 (Table 10). The reported βd value of the present study is well comparable to previously reported values of βd (4.83-6.48) of mixed broadleaf forest of Kedarnath Wildlife Sanctuary, Western Himalaya (Malik and Bhat 2015), and mixed broadleaf forest (2.3-5.1) of Uttarakhand (Rawal et al. 2018). It is also one of the potential diversity indices that played a significant and crucial role with respect to deriving a proper management plan to maintain the vegetation diversity of protected and reserve forests.

The dominance diversity (d-d) curve for canopy tree species of LRF is shown in Figures 5.A-C. The d-d curves are often used to explain the relationship between species distribution in a community and to interpret community organization with resource sharing and niche space. As a relative indicator of the ecological niche and the associated resource allocation within the plant community, IVI is one of the phytosociological attributes predicted on the idea that there is some correlation between the space used by a species in a community and the fraction of community resources that is allotted to it (Bhat et al. 2020; Shahzad et al. 2024). In the present study, the d-d curve for canopy tree species of LRF was log-normal type, which revealed that the dominant species utilize the maximum proportion of resources and occupy the top niche. Furthermore, a log-normal distribution could contribute to resource conservation (Rana et al. 2022) and indicate high species diversity (Rana et al. 2022).

Table 10. Diversity indices of various conservation status categories of canopy tree species at LRF, India

Canopy tree species conservation status	H'	Cd	β-diversity	EI	MI	MeI	HI
RET	0.259	0.0022	5.674	0.125	1.78	1.12	0.05
Non- RET	3.66	0.024	6.75	0.887	9.01	2.103	0.155
RET + Non-RET	3.918	0.261	6.646	0.922	10.11	2.308	0.162

Note: EI: Evenness Index, MI: Margalef's Index, MeI: Menhinick's Index, HI: Heterogeneity Index

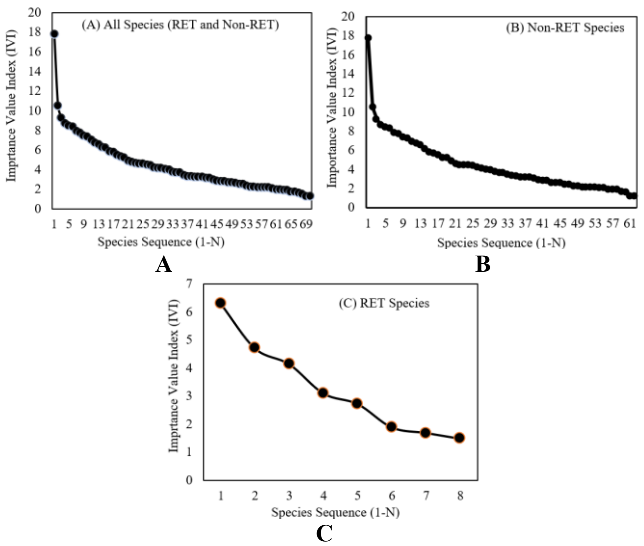

Figure 5. A-C. Dominance diversity (d-d) curve of various conservation categories. A. Both RET and non-RET, B. Non-RET, C. RET of canopy tree species at LRF, India

In addition, the high Shannon-Wiener Diversity Index (H') and low Simpson Index (Cd) of canopy tree species in the LRF also confirm the findings of the d-d curve. The steep initial gradient of each d-d curve shows that only a few species account for most canopy tree abundance in moist mixed deciduous forests (Mastan and Reddy 2023), whereas the gentle tail gradient represents species that are either more abundant elsewhere or sparse throughout the forest (Avolio et al. 2019).

In conclusion, the study on the ecology of canopy tree species in the tropical moist deciduous forest of LRF, Kandhamal, Odisha, revealed high species diversity, uniqueness, and conservation potential. Phytosociological parameters and diversity indices varied with environmental variables and anthropogenic activities. Notably, a few non-RET species like *S. robusta*, *F. religiosa*, *T. anogeissiana*, *M. azedarach*, *V. nilotica*, *L. coromandelica*, *S. oleosa*, *D. melanoxylon*, *G. gummifera*, and *H. pubescens* are expanding, while RET and other non-RET species struggle to maintain their population, highlighting the need for conservation efforts. To address this, species-wise data on diversity and distribution patterns will guide habitat restoration and reforestation efforts to boost the reserve forest's biodiversity. Policymakers can use this data to balance forest utilization and conservation, benefiting local populations and maintaining ecological integrity. Encouraging local communities to participate in awareness campaigns can help in preventing species extinction. Finally, it is advisable to point out that the study may also help in designing future long-term monitoring studies and assessing the effects of ongoing and future climate change and disturbances. We also recommend that further research on the impact of disturbances on vegetation can be taken up through a multivariate approach to plug the research deficit (e.g., regeneration and impact of disturbance on vegetation) as a sequel to the present study.

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