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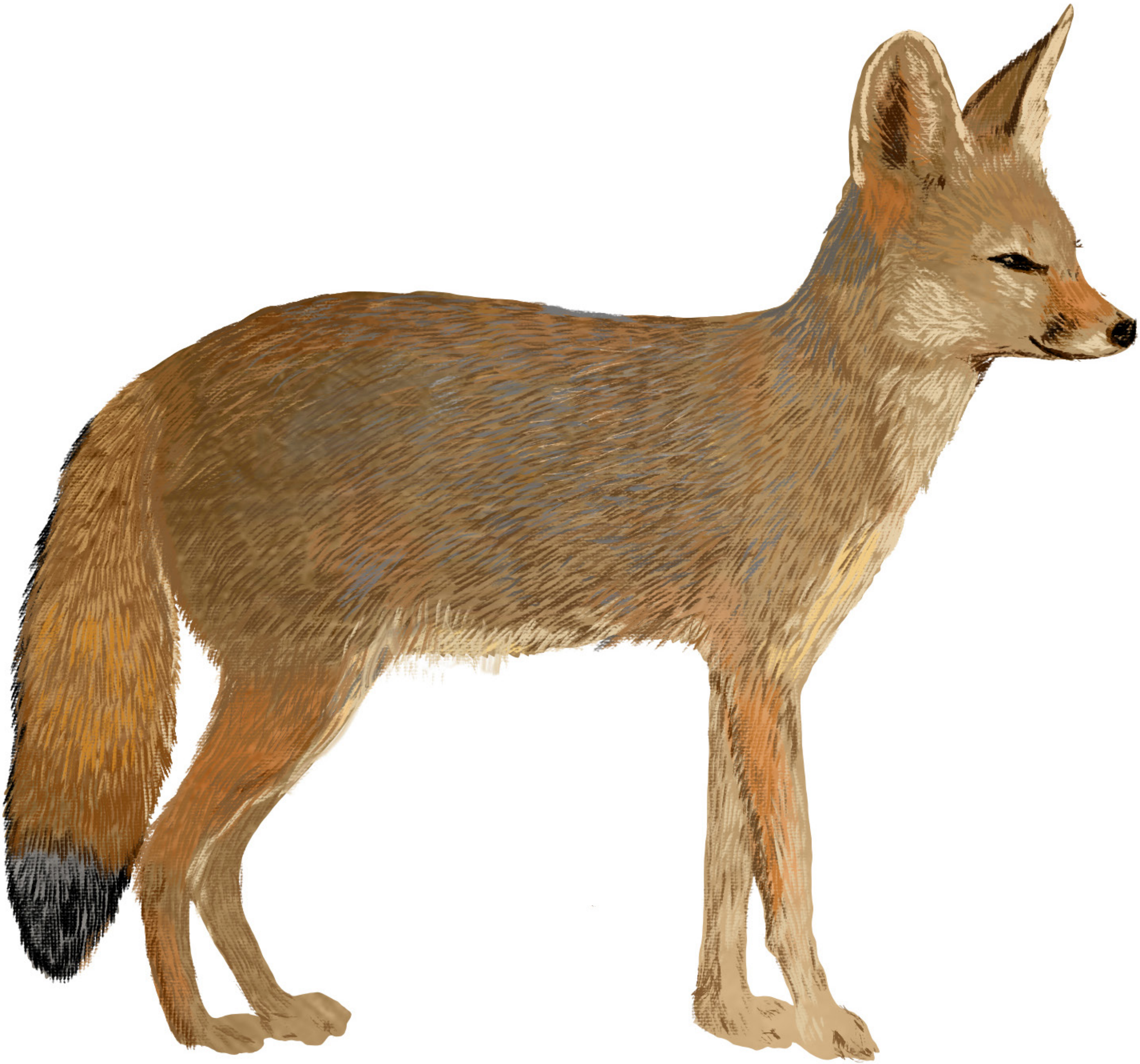

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ARTICLE

Diversity and distribution pattern of ebony trees *Diospyros* L. (Ebenaceae) in the forests of central Western Ghats, India

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Abstract: *Diospyros* trees, commonly known as persimmons or ebonies, have high economic and medicinal value. This study presents here a detailed analysis of the diversity and distribution of *Diospyros* species across 20 sites in the Western Ghats region of Karnataka, encompassing different forest types. Data collected from belt transects were used to calculate species richness and quantitative characters such as frequency, density, abundance, importance value index, basal area cover, and distribution type. Alpha and beta diversity across the different study sites were also determined. Non-metric multidimensional scaling analysis was performed to study the relationship between forest types and species composition. The results indicate *Diospyros montana* had the greatest frequency, density, basal area cover, and importance value. Agumbe and Hosagunda areas of Shivamogga district, and Makutta region of Kodagu district, showed rich diversity.

Keywords: Contagious, deciduous, diversity indices, evergreen, NMDS, richness, transects, tropical.

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Author details: H.S. Shashwathi, research scholar, Kuvempu University. Presently working on diversity, distribution, ecology and molecular authentication and phylogeny of *Diospyros* trees. Field of interest—biodiversity and conservation, plant taxonomy, ecology, bioinformatics. Dr. Y.L. Krishnamurthy, professor, Kuvempu University. Subject expert—plant biodiversity, taxonomy, documentation & conservation and fungal endophytes - enhancement of plant growth by incorporation of beneficial fungi and fungal metabolite profiling, exploration and characterization of lichens, endo-lichenic fungi.

Author contributions: H.S. Shashwathi—carried out the field work, data collection, identification, photography, software handling, data interpretation, manuscript writing. Y.L. Krishnamurthy—carried out the field work, guided for data interpretation and manuscript writing.

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INTRODUCTION

Mother nature has equally distributed her wealth all over the earth in terms of natural resources. India is one of the richest countries in its natural resources and biodiversity. The biodiversity of any area can be measured by its flora and fauna, which is higher in the Western Ghats and northeastern parts of India. The Western Ghats and the eastern Himalaya are not only regarded as the treasure of biological diversity but also, they are two important hotspots of biodiversity. Western Ghats are accomplished with different levels of biological diversity along many gradients from temperate to the tropics. Diversity in the Western Ghats in terms of plant species increases from east to west and also from north to south with an increase in rainfall (Gadgil 1996; Karthik & Vishwanath 2012).

There are many plant species in the Western Ghats which are economically and medicinally important. The Ebenaceae family is one of the valuable sources of economically important products. *Diospyros* is a genus that belongs to the family Ebenaceae. They are dioecious trees with a highly polymorphic nature and show great morphological variations among individuals. *Diospyros* species are a source of several important products such as edible fruits, medicines, and timber (Singh 2005). Some are useful as ornamentals and have local ecological importance. These trees are also known to have folklore medicinal uses, mainly in the treatment of diarrhoea, for decreasing the increased cholesterol level, improve cognitive function used for inflammatory disorders (Sirisha et al. 2018). Persimmon fruits have anti-inflammatory, anti-atherosclerosis, hypo-cholesterolemic, antioxidant, antidiabetic, and anticancer properties (Ferrara 2021). Species of *Diospyros* have been revealed to be rich in naphthoquinones and naphthol, and these phytochemicals have proved to be good taxonomic markers of this genus (Sharma 2017).

Considering the status of *Diospyros* worldwide, a total of 607 species have so far been reported, of which 300 species occur in Asia and the Pacific area, 98 species in Madagascar and the Comoro Islands, 94 species in African Mainland, 100 species in America and 15 species in Australia (Wallnöfer 2001). In India, *Diospyros* is represented by 66 taxa (Singh 2005) of which 24 species of *Diospyros* were reported in Western Ghats (Gamble 1998), and 15 species occurred in Karnataka (Saldanha 1984).

The forests of the Western Ghats are the homeland for many such endemic and precious plants. There are several plant species that are threatened due to the activities of human beings, extensive harvesting of products, and also drastic climate change. The status of many plants in the forest is undetermined due to a lot of difficulties in identification and a lack of taxonomic knowledge. *Diospyros* L. is one such genus which needs to be conserved for its importance. Diversity studies oriented to such a single genus, are rare in this region. Therefore, the study was focused on: (1) investigating species composition and richness of the *Diospyros* trees in different forest types, basal area cover, and the pattern of distribution, (2) analysis of alpha and beta diversity in different areas of the central Western Ghats region**.** Moreover, the current study provides us the basic knowledge about the present status of these trees in forests and conserves them.

MATERIALS AND METHODS

Study area

This study was carried out from 2021 to 2023 at locations in the central Western Ghats of Karnataka State in India. Major districts in this area include Uttara Kannada, Shivamogga, Chikkamagaluru, Hassan, and Kodagu, which present a range of forest types that include dry and moist deciduous, evergreen and semi-evergreen, and shola vegetation.

Field survey and sampling

Stratified random sampling was used for the sampling process. Four distinct forest types were represented by 10, 250 x 4 m belt transects. A total of 20 locations (Table 1) were investigated. Within the transects, *Diospyros* trees and allied species were counted. Every plant that had a circumference of more than 10 cm was measured at breast height. Samples were photographed and collected in order to prepare the herbariums deposited at Kuvempu University (Table 2). Utilizing floras, monographs, and other literature the identified trees were verified (Saldanha 1984; Gamble 1998; Ramaswamy et al. 2001; Singh 2005). The currently approved names for the identified tree species were assigned using an online database by means of the World Flora Online (www. worldfloraonline.org).

Statistical analysis

Assessment of species composition and structural diversity.

Quantitative characteristics of the forest community such as frequency, density, abundance, basal area, (IVI) important value index, relative frequency, relative density, relative abundance, and dominance were computed in a Microsoft Excel spreadsheet (Cottam & Curtis 1956; Uddin et al. 2020).

Formulas used for data analysis are given below:

· Frequency = (Number of transects in which the species occurred) / (Total number of transects studied)

· Relative Frequency = (Frequency of a species) / (Total frequency of all species) × 100

· Density = (Number of individuals of the species) / (Total number of transects studied)

· Relative Density = (Density of a species) / (Total density of all species) × 100

· Abundance = (Total number of individuals of a species in all transects) / (Number of transects in which the species occurred)

· Relative Abundance = (Abundance of a species) / (Total abundance of all species) × 100

· Relative dominance = (Basal area of a species) / (Total basal area of all species) × 100

· Basal area = $(GBH)^2/4\pi$ where, GBH = girth at breast height and π = 3.1416

· IVI (Important value index) = Relative frequency + Relative density + Relative dominance

· Distribution pattern of the trees was calculated using (WI) Whitford value = Abundance/Frequency (Whitford 1949; Srinivas & Krishnamurthy 2016).

Analysis of alpha and beta diversity:

Alpha diversity was analysed by using Shannon-Wiener and Simpson's diversity indices (Magurran 1988). They were calculated with the help of ecological Past software version, 4.03. and by Microsoft Excel.

formulas used for calculation;

$$\text{Shannon} - \text{Wiener index: H} = -\sum_{i=1}^{n} P_i \ln P_i$$

where, $P_i = n_i/N$

n_i = number of individuals in the species

N = the total number of individuals of all species

Here, quantity Pi is the proportion of individuals found in the species

$$\text{Simpson's index (D)} = \sum \left(\frac{n_i(n_i-1)}{N(N-1)}\right)$$

where n_i = the number of individuals in the i^{th} species

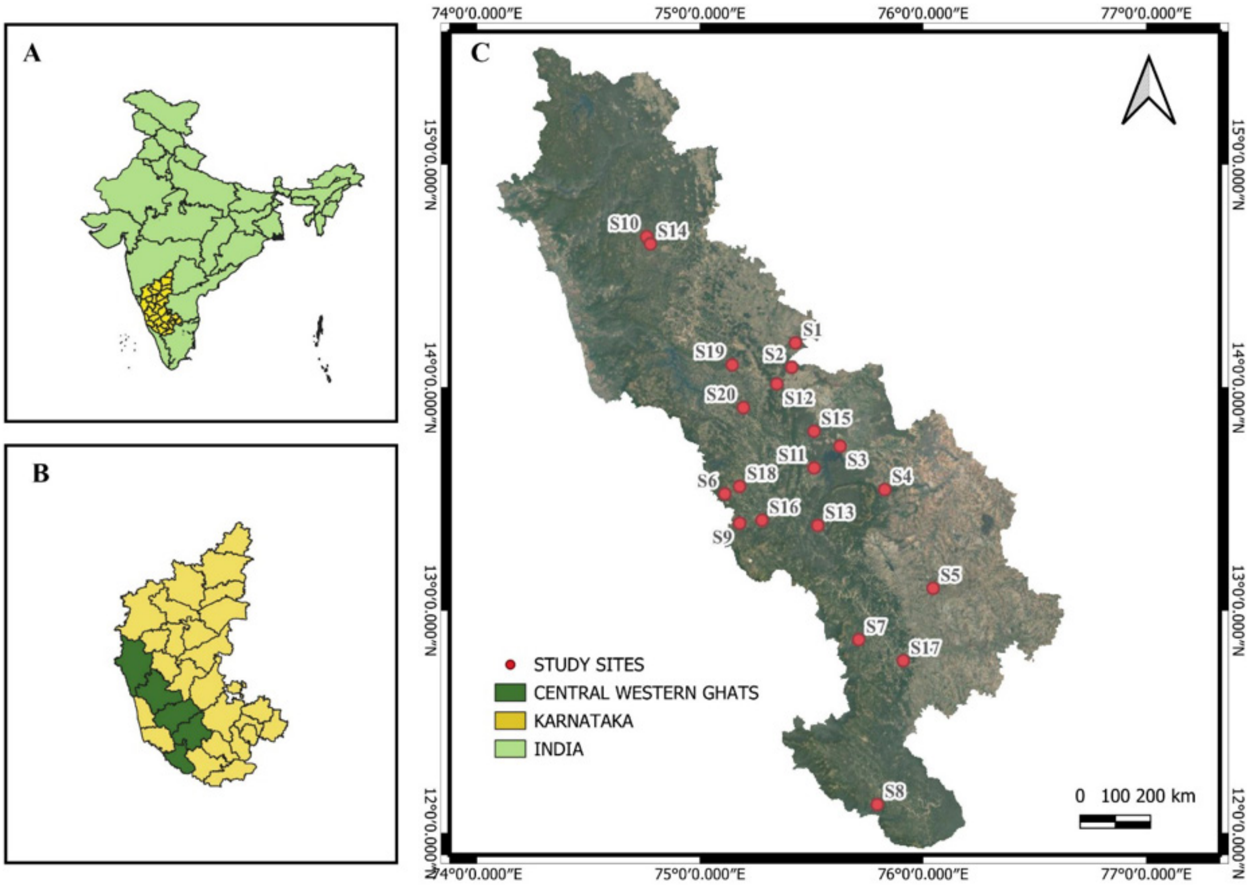

Figure 1. Map of the study area indicating investigated sites (A–C): A—India map | B—Karnataka state showing study area | C—Map of central Western Ghats including study sites.

Table 1. Details of the study sites with forest type and district.

Name of the study site	Location name	Latitude	Longitude	Forest type	District
S1	Shikaripura	14.200° N	75.427° E	Dry deciduous	Shivamogga
S2	Ayanoor	14.091° N	75.411° E	Dry deciduous	Shivamogga
S3	Shankarghatta	13.736° N	75.627° E	Dry deciduous	Shivamogga
S4	Shanthveri	13.542° N	75.827° E	Dry deciduous	Chikkamagaluru
S5	Seege Gudda	13.099° N	76.044° E	Dry deciduous	Hassan
S6	Agumbe	13.523° N	75.111° E	Evergreen	Shivamogga
S7	Sakleshpura	12.869° N	75.711° E	Evergreen	Hassan
S8	Makutta	12.130° N	75.794° E	Evergreen	Kodagu
S9	Kigga	13.391° N	75.177° E	Evergreen	Chikkamagaluru
S10	Hulekal	14.676° N	74.761° E	Evergreen	Uttara Kannada
S11	N R Pura	13.639° N	75.511° E	Moist deciduous	Chikkamagaluru
S12	Arasaalu	14.016° N	75.344° E	Moist deciduous	Shivamogga
S13	Balehonnur	13.381° N	75.527° E	Moist deciduous	Chikkamagaluru
S14	Sirsi	14.643° N	74.777° E	Moist deciduous	Uttara Kannada
S15	Mandagadde	13.803° N	75.511° E	Moist deciduous	Shivamogga
S16	Sringeri	13.404° N	75.277° E	Semi evergreen	Chikkamagaluru
S17	Arehalli	12.775° N	75.911° E	Semi evergreen	Hassan
S18	Kundadri hills	13.556° N	75.177° E	Semi evergreen	Shivamogga
S19	Hosagunda	14.101° N	75.144° E	Semi evergreen	Shivamogga
S20	Kunnur	13.910° N	75.194° E	Semi evergreen	Shivamogga

N = the total number of individuals.

A comparison of 20 distinct research sites was used to perform a beta diversity analysis. To determine beta diversity, similarity, and distance indices were calculated utilising the presence and absence data for *Diospyros* species, in the Past software version, 4.03 (Hammer et al. 2001). The Jaccard similarity index was computed to check the relationship between study sites (Newton 2007). The distribution of *Diospyros* trees in different forest types and their significance was studied by non-metric multidimensional scaling or NMDS analysis using Past software version, 4.03.

RESULTS

Species richness and structural composition

The floristic study was conducted in 20 different study sites with different forest types. A total of 4178 individuals of 189 species belonging to 130 genera and 51 families were recorded. Around 374 *Diospyros* trees were distributed among 16 species (Table 2). Other trees were identified belonging to Fabaceae (13), Rubiaceae (8), Rutaceae (7), Lauraceae (6), Meliaceae (6), Phyllanthaceae (6), Anacardiaceae (5), Apocyanaceae (5). Associated with *Diospyros*, the genera with the highest species composition were *Ficus* (7), from the Moraceae family, *Terminalia* (7) from Combretaceae, *Syzigium* (7) from Myrtaceae and *Holigarna* from Anacardiaceae (5) (Table 4).

The number of individuals and species composition of *Diospyros* trees were used to examine the species richness of 20 distinct study areas. S6-Agumbe exhibits the highest species richness. Eight *Diospyros* species with an overall 97 individuals were represented at the Agumbe region namely *Diospyros saldanhae* (25), *D. ebenum* (10), *D. candolleana* (8), *D. paniculata* (26), *D. sylvatica* (14), *D. ferrea* (7), *D. oocarpa* (2), *D. pruriens* (5) were documented.

With five species and 19 individuals of *Diospyros*, the S19-Hosagunda region had the highest species richness, next to S6. The species documented were *D. candolleana* (1), *D. crumenata* (6), *D. montana* (4), *D. sylvatica* (4), and *Diospyros ridleyi* (4) (Ramesh & Franceschi 1993; Vasudeva 2007). *Diospyros crumenata* is one of the endangered species found within the transect.

S8-Makutta also showed better species richness with five species and 14 individuals. The species observed

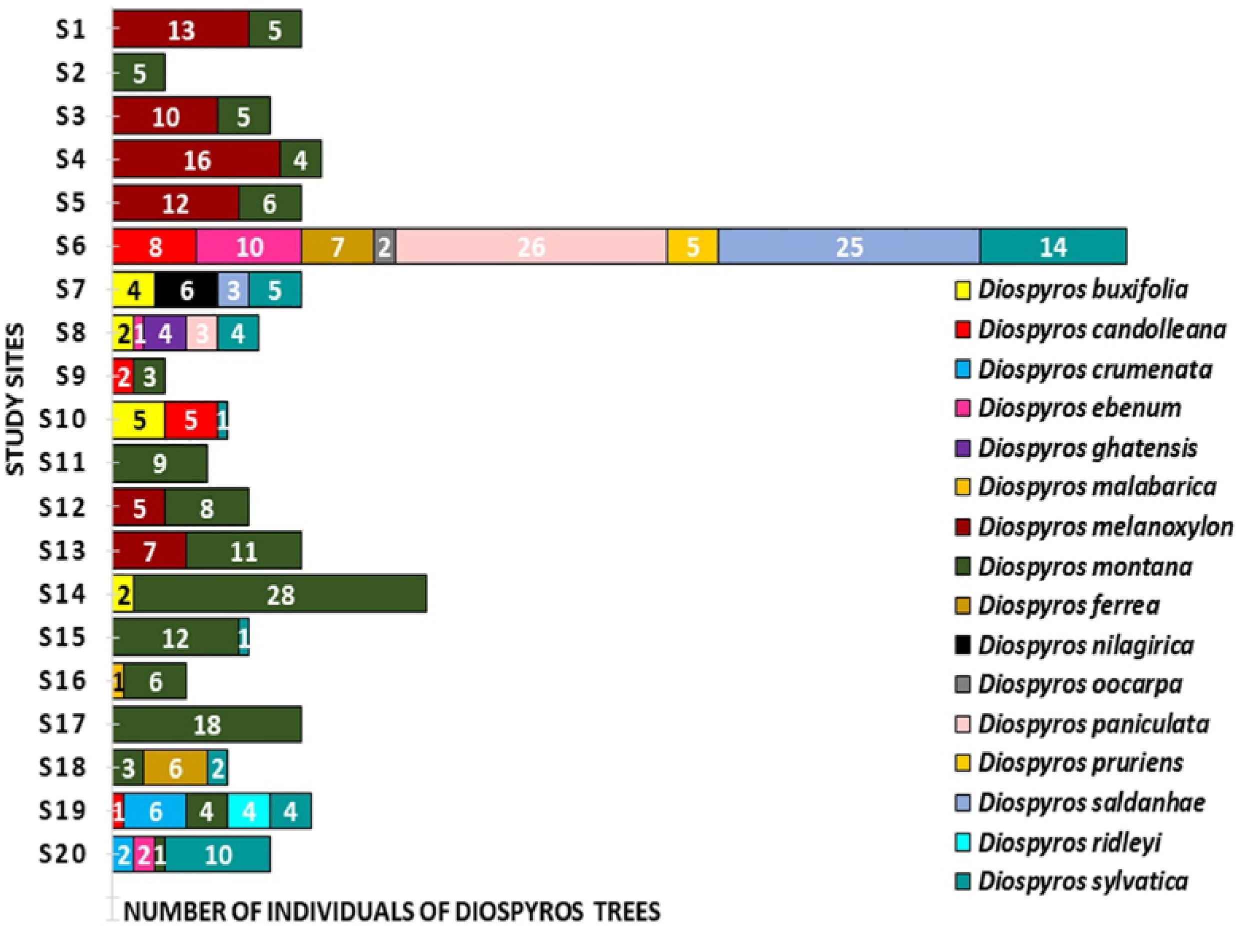

Figure 2. *Diospyros* species composition along with the number of individuals in different study sites.

were *D. buxifolia* (2), *D. ebenum* (1), *D. ghatensis* (4), *D. paniculata* (3), *D. sylvatica* (4).

S17 -Arehalli (18), S11-N.R. Pura (9), S2-Ayanoor (5) showed the least richness among study sites. Details of all 16 species of *Diospyros* and their distribution in different study sites along with the number of individuals are depicted in (Figure 2).

Frequency: *Diospyros montana* was the most frequently distributed tree species (72.50%) among 16 species according to a floristic enumeration of the study area (Figure 3) *Diospyros sylvatica*, on the other hand, also showed a high frequency value of 32.50% (Figure 3) and was not present in dry deciduous forests, but was observed in eight study sites of evergreen forests. *Diospyros nilagirica*, *D. malabarica*, and *D. ridleyi* exhibited the lowest frequency value of 2.50% and were limited to one study site each.

Density: *Diospyros montana* was the most densely observed species with a value of 3.20. *Diospyros melanoxylon* was also distributed densely next to *Diospyros montana* with a value of 1.58. *Diospyros melanoxylon* was recorded in six sites among 20 and restricted to deciduous forests. Least density was reflected by *Diospyros malabarica* with the value 0.03 (Figure 3).

Abundance: *Diospyros paniculata* was found to be the most abundantly distributed species (9.67). *Diospyros saldanhae* was also an abundant species with a value of 9.33. These trees were observed only in two sites each among 20 sites and were purely evergreen trees. *Diospyros malabarica* (1.00) and *Diospyros oocarpa* (1.00) were the trees with the least abundance among *Diospyros* trees (Figure 3).

Importance value index (IVI): The importance value index is a measure that indicates the importance of individual species in the forest which is the relative measure of density, dominance, and frequency. The importance value index of *Diospyros* trees ranges from 0.11–6.51. Among *Diospyros, D. montana* was noted with the highest IVI (6.51). The lowest value of IVI was reflected by *D. malabarica.* Importance value index of all 16 *Diospyros* trees is shown in Figure 3.

Basal area: The basal area covered by *Diospyros montana* was 104.103 m^2/ha, which is the highest among *Diospyros* species. This was followed by *Diospyros melanoxylon* with a basal area value 26.21 m^2/ ha. *Diospyros malabarica* has the least basal area value of 0.0002 m^2 / ha among *Diospyros* species (Figure 4)

Table 2. Checklist of the *Diospyros* trees observed in study sites.

	Species name	Collection ID	Herbarium ID
1	*Diospyros buxifolia* (Blume) Hiern	ABDIO1	KUAB805
2	*Diospyros candolleana* Wight	ABDIO2	KUAB806
3	*Diospyros crumenata* Thwaites	ABDIO3	KUAB807
4	*Diospyros ebenum* J.Koenig ex Retz.	ABDIO4	KUAB808
5	*Diospyros ghatensis* B.R.Ramesh & D.DeFranceshi	ABDIO5	KUAB809
6	*Diospyros malabarica* (Desr.) Kostel	ABDIO6	KUAB810
7	*Diospyros melanoxylon* Roxb.	ABDIO7	KUAB811
8	*Diospyros montana* Roxb.	ABDIO8	KUAB812
9	*Diospyros ferrea* (Willd.) Bakh.	ABDIO9	KUAB813
10	*Diospyros nilagirica* Bedd.	ABDIO10	KUAB814
11	*Diospyros oocarpa* Thwaites	ABDIO11	KUAB815
12	*Diospyros paniculata* Dalzell	ABDIO12	KUAB816
13	*Diospyros pruriens* Dalzell	ABDIO13	KUAB817
15	*Diospyros ridleyi* Bakh.	ABDIO15	KUAB819
14	*Diospyros saldanhae* Kosterm	ABDIO14	KUAB818
16	*Diospyros sylvatica* Roxb.	ABDIO16	KUAB820

Pattern of distribution

The ratio of abundance to frequency indicates a pattern of distribution. (Whitford 1949). A value less than 0.025 indicates regular distribution, values between 0.025–0.05 imply a random type of distribution, and values more than 0.05 imply a contagious type of distribution (Ndah et al. 2013). The abundance and frequency (A/F) ratio of all the *Diospyros* species shows values >0.05 which ranges from 0.06– 2.40 (Table 3). This indicates the clumped or contagious pattern of distribution.

Diversity indices: overall diversity of study sites

Species diversity can be assessed by using some type of diversity index, which provides us with information on species richness and evenness. Alpha diversity of 20 different study sites was calculated by using two important non-parametric diversity indices namely Shannon-Wiener index (H) and Simpson's index (D).

According to the Shannon-Wiener index, S19 shows the highest value 3.96 that is Hosagunda region is enriched with good diversity. Next to S19 highest Shannon index value was observed at S8-Makutta Ghat 3.93. The least Shannon value,1.56 was observed at S2 which is the Aynoor region. The Shannon index of all the study sites is given in Figure 5. According to Simpson's index a value, near 1 denotes less diversity, and the value 0 refers to infinite diversity. In the present study Simpson index of study site 19 shows the lowest value 0.018 (Figure 5). This implies that the diversity is rich in S19 that is Hosagunda region which is followed by the S8 Makutta region also shows the lowest value of 0.0195 with good diversity (Figure 5). Among 20 study sites S2 that is Aynoor region shows the highest value of the Simpson index 0.248, which is represented by less diversity when compared to others.

Table 3. Abundance / Frequency ratio of *Diospyros* trees.

Species name	Abundance / Frequency
Diospyros buxifolia	0.21
Diospyros candolleana	0.18
Diospyros crumenata	0.80
Diospyros ebenum	0.21
Diospyros ferrea	0.58
Diospyros ghatensis	0.40
Diospyros malabarica	0.40
Diospyros melanoxylon	0.31
Diospyros montana	0.06
Diospyros nilagirica	2.40
Diospyros oocarpa	0.20
Diospyros paniculata	1.29
Diospyros pruriens	0.50
Diospyros ridleyi	1.60
Diospyros saldanhae	1.24
Diospyros sylvatica	0.10

Beta diversity

Beta diversity is a measure to determine the change in diversity among transects or environmental gradients and with species composition. Beta diversity was measured for 20 study sites using the Jaccard similarity index, to observe variation among the study sites in terms of *Diospyros* species composition. Jaccard similarity values for all the study sites were computed tabulated and given in Figure 6.

Among 20 study sites S1, S3, S4, S5, S12, and S13 exhibited a similarity index of 1.00, which indicates that these sites are 100 percent similar to each other (Figure 6). The next group with a value of 1.00 was S11, S2, and

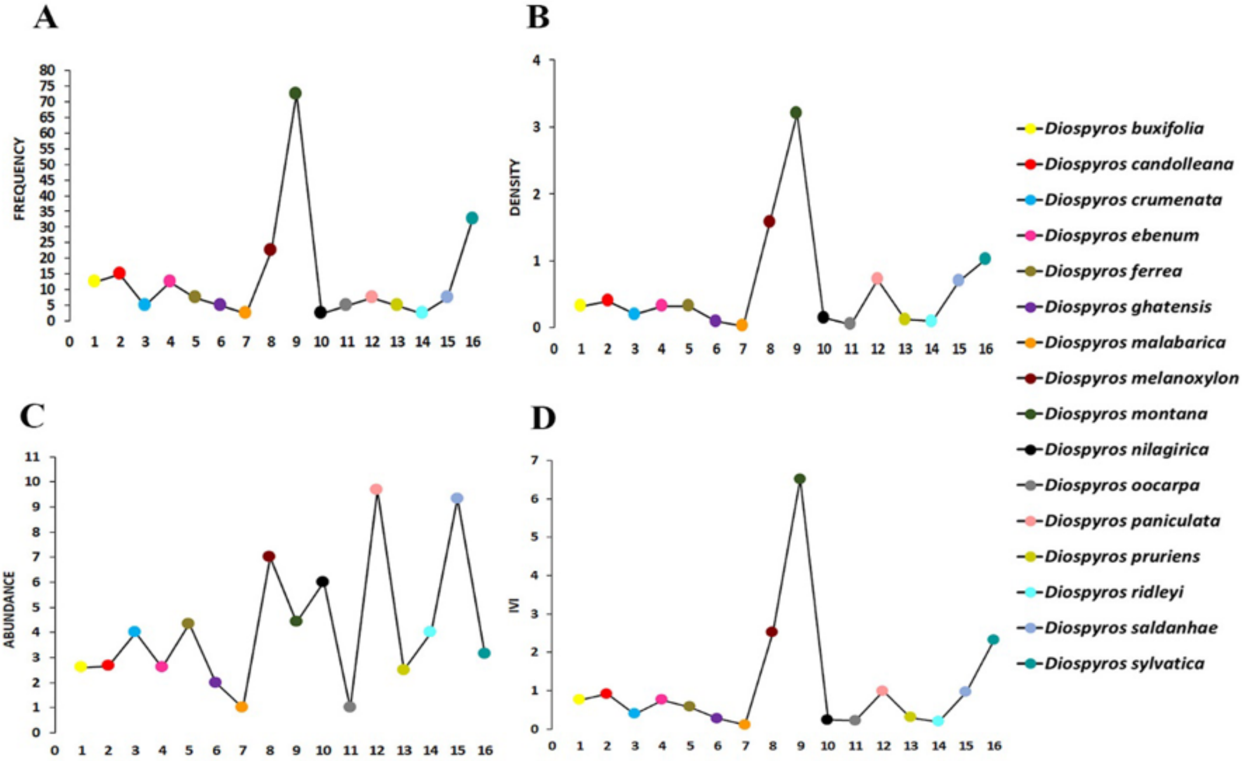

Figure 3. Quantitative characters of *Diospyros* species (A–D): A—Frequency | B—Density | C—Abundance | D—Importance value index.

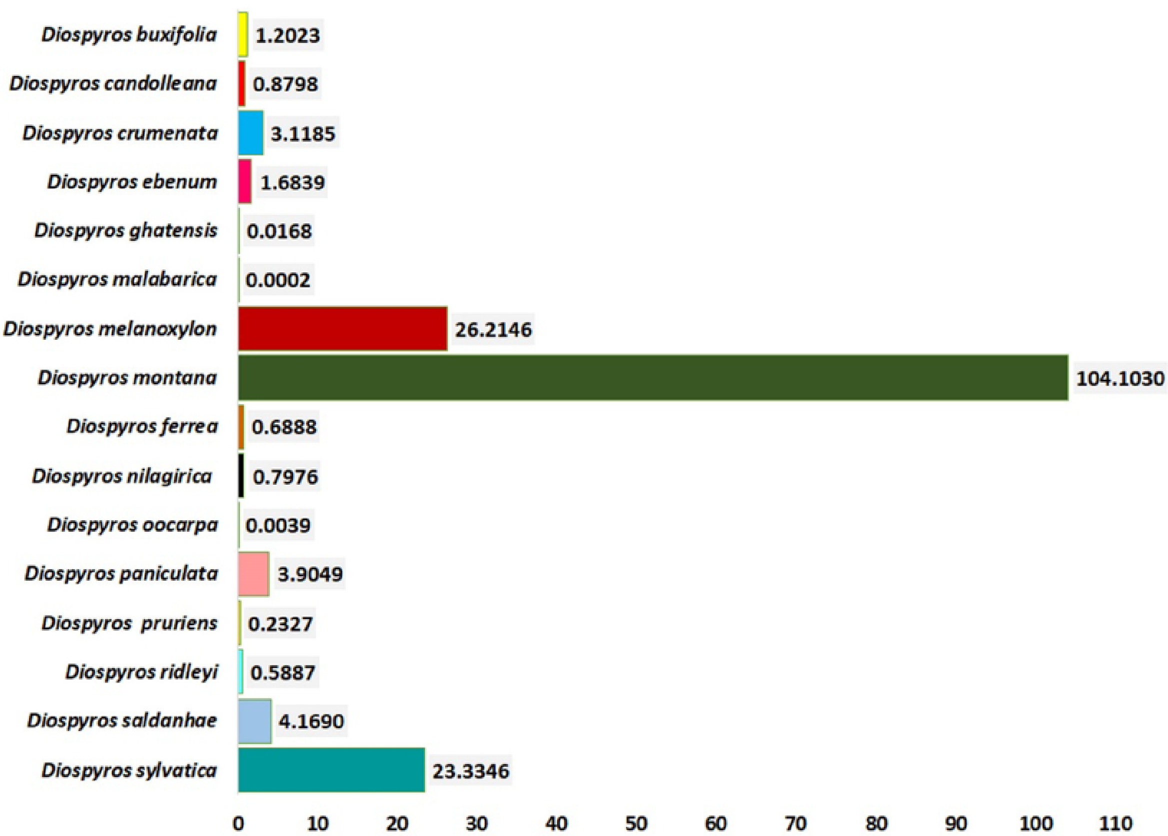

Figure 4. Chart representing basal area of *Diospyros* species.

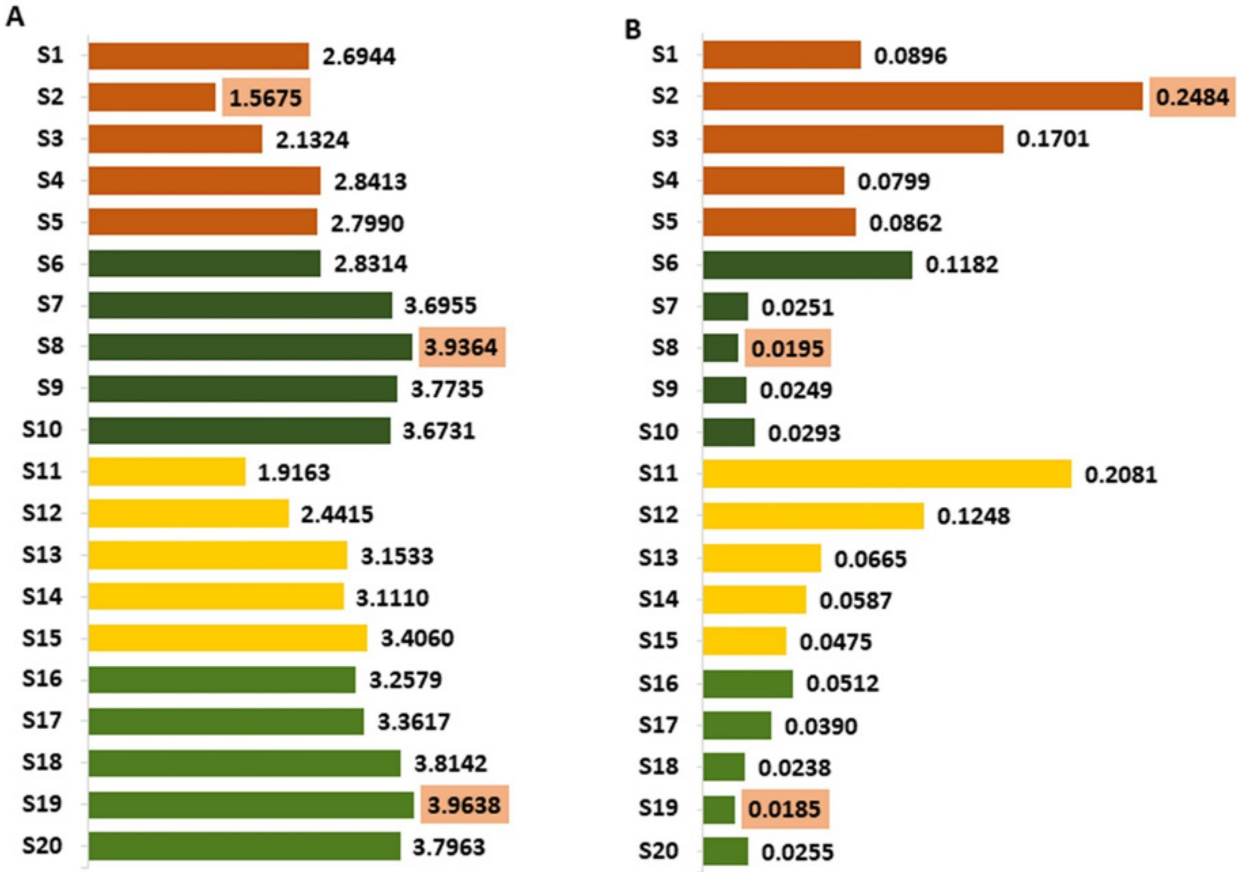

Figure 5. A—Shannon-Wiener index of all study sites | B—Simpson's index of all study sites.

S17 which are overlapping in their species composition. These both groups are study sites representing dry and moist deciduous which are very similar in species composition.

Some study sites presented a Jaccard similarity value of 0.00, indicating that these sites are completely dissimilar in their species composition. This type of trend is observed by S6, S8, S7, and S10 which exhibit the value 0.00 in relation to study sites S1, S2, S3, S4, and S5 indicating the completely dissimilar groups.

Sixty-seven percent similarity is observed between S18 and S15 with a similarity value of 0.67. The study sites S2, S11, and S17 shows value (0.50) 50% similarity with S1, S3, S4, S5, S9, S12, S13, S14, S15, S16. This predicts that only half of the species composition among these groups is similar.

Observing the tabulated Jaccard similarity index (Figure 6), study sites exhibited other similarity values like 0.40, 0.33,0.30, 0.29, 0.25, 0.22, 0.20, 0.18, 0.17, 0.14, 0.13, and 0.11 which are all less than 0.50, indicating the similarity between study sites are less than 50%. Each value in the columns and rows indicates their respective percentage similarity between the two study sites.

DISCUSSION

Tropical regions of the world are generally adorned with rich species diversity. The diversity of tree species is a basement for total biodiversity in numerous ecosystems because most of the organisms are dependent on them for food and habitat (Jayakumar & Nair 2013). Tropical forests which provide the best ecosystem services, nurture about 50–90 % of the known terrestrial plant and animal species and cover less than 10 percent of the total land area. In India, 40% of the rural population are relied on forest resources (Gopalakrishna 2015). Western Ghats of India is one such region endowed with a wide variety of ecosystems from tropical wet evergreen forests to grasslands with an enormous type of flora and fauna (Revathy et al. 2023). For several decades research on tropical forests has been conducted, yet understanding their ecology is a difficult task (Anitha et al. 2010). Every

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
S1	1.00																			
S2	0.50	1.00																		
S3	1.00	0.50	1.00																	
S4	1.00	0.50	1.00	1.00																
S5	1.00	0.50	1.00	1.00	1.00															
S6	0.00	0.00	0.00	0.00	0.00	1.00														
S7	0.00	0.00	0.00	0.00	0.00	0.20	1.00													
S8	0.00	0.00	0.00	0.00	0.00	0.30	0.29	1.00												
S9	0.33	0.50	0.33	0.33	0.33	0.11	0.00	0.00	1.00											
S10	0.00	0.00	0.00	0.00	0.00	0.22	0.40	0.33	0.25	1.00										
S11	0.50	1.00	0.50	0.50	0.50	0.00	0.00	0.00	0.50	0.00	1.00									
S12	1.00	0.50	1.00	1.00	1.00	0.00	0.00	0.00	0.33	0.00	0.50	1.00								
S13	1.00	0.50	1.00	1.00	1.00	0.00	0.00	0.00	0.33	0.00	0.50	1.00	1.00							
S14	0.33	0.50	0.33	0.33	0.33	0.00	0.20	0.17	0.33	0.25	0.50	0.33	0.33	1.00						
S15	0.33	0.50	0.33	0.33	0.33	0.11	0.20	0.17	0.33	0.25	0.50	0.33	0.33	0.33	1.00					
S16	0.33	0.50	0.33	0.33	0.33	0.00	0.00	0.00	0.33	0.00	0.50	0.33	0.33	0.33	0.33	1.00				
S17	0.50	1.00	0.50	0.50	0.50	0.00	0.00	0.00	0.50	0.00	1.00	0.50	0.50	0.50	0.50	0.50	1.00			
S18	0.25	0.33	0.25	0.25	0.25	0.22	0.17	0.14	0.25	0.20	0.33	0.25	0.25	0.25	0.67	0.25	0.33	1.00		
S19	0.17	0.20	0.17	0.17	0.17	0.18	0.13	0.11	0.40	0.33	0.20	0.17	0.17	0.17	0.40	0.17	0.20	0.33	1.00	
S20	0.20	0.25	0.20	0.20	0.20	0.20	0.14	0.29	0.20	0.17	0.25	0.20	0.20	0.20	0.50	0.20	0.25	0.40	0.50	1.00

Figure 6. Jaccard similarity index values for different study sites.

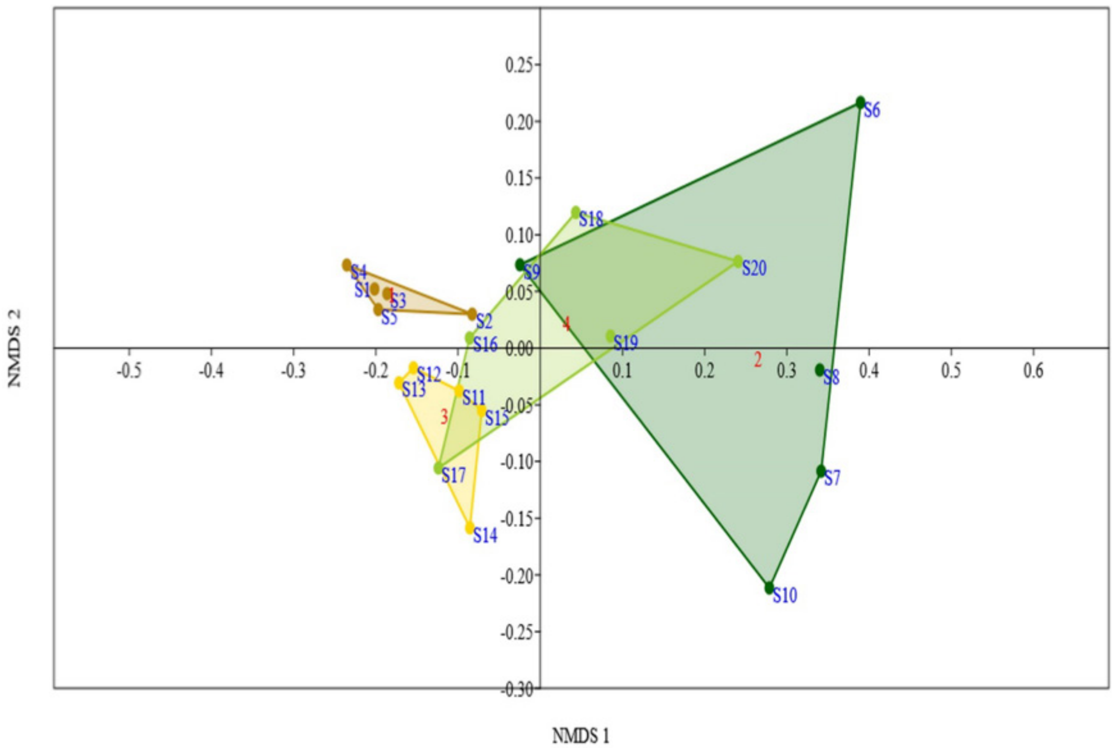

Figure 7. NMDS plot representing the relation between forest types, study sites, and species composition.

Table 4. List of other associated tree species with *Diospyros* in central Western Ghats.

Family	Genus	Species
1. Achariaceae	*Hydnocarpus*	*Hydnocarpus pentandrus* (Buch.-Ham.) Oken
2. Anacardiaceae	*Holigarna* *Lannea* *Mangifera* *Nothopegia* *Spondias*	*Holigarna arnottiana* Hook.f. *Holigarna beddomei* Hook.f. *Holigarna ferruginea* Marchand *Holigarna grahamii* Kurz *Holigarna nigra* Bourd. *Lannea coromandelica* (Houtt.) Merr. *Mangifera indica* L. *Nothopegia beddomei* Gamble *Nothopegia castanefolia* (Roth) Ding Hou *Spondias pinnata* (L.f.) Kurz
3. Annonaceae	*Meiogyne* *Monooon*	*Meiogyne pannosa* (Dalzell) J.Sinclair *Monooon fragrans* (Dalzell) B.Xue & R.M.K.Saunders
4. Apocyanaceae	*Tabernaemontana* *Wrightia* *Alstonia* *Carissa* *Holarrhena*	*Tabernaemontana alternifolia* L. *Wrightia tinctoria* R.Br. *Alstonia scholaris* (L.) R.Br. *Carissa carandas* L. *Holarrhena pubescens* Wall. & G.Don
5. Arecaceae	*Caryota* *Pinanga*	*Caryota urens* L. *Pinanga dicksonii* (Roxb.) Blume
6. Bignoniaceae	*Kigelia* *Oroxylum*	*Kigelia africana* ssp. *africana* *Oroxylum indicum* (L.) Kurz
7. Burseraceae	*Boswellia* *Canarium*	*Boswellia serrata* Roxb. *Canarium strictum* Roxb.
8. Calophyllaceae	*Mesua* *Poeciloneuron* *Calophyllum*	*Mesua ferrea* L. *Poeciloneuron indicum* Bedd. *Calophyllum apetalum* Willd.
9. Cannabaceae	*Celtis* *Trema*	*Celtis timorensis* Span. *Trema orientalis* (L.) Blume
10. Capparaceae	*Crateva*	*Crateva religiosa* G.Forst.
11. Celastraceae	*Euonymus*	*Euonymus indicus* B.Heyne ex Wall.
12. Clusiaceae	*Clusia* *Garcinia*	*Clusia* sp. *Garcinia gummi-gutta* (L.) N.Robson *Garcinia* sp. *Garcinia talbotii* Raizada *Garcinia xanthochymus* Hook.f.
13. Combretaceae	*Terminalia*	*Terminalia anogeissiana* Gere & Boatwr. *Terminalia arjuna* (Roxb. ex-DC.) Wight & Arn. *Terminalia chebula* Retz. *Terminalia elliptica* Willd. *Terminalia paniculate* B. Heyne ex Roth *Terminalia tomentosa* Mart. ex-Eichler *Terminalia bellirica* (Gaertn.) Roxb.
14. Cornaceae	*Alangium*	*Alangium salviifolium* (L.f.) Wangerin
15. Dichapetalaceae	*Dichapetalum*	*Dichapetalum gelonioides* (Roxb.) Engl.
16. Dilleniaceae	*Dillenia*	*Dillenia pentagyna* Roxb.
17. Dipterocarpaceae	*Dipterocarpus* *Hopea* *Vateria*	*Dipterocarpus indicus* Bedd. *Hopea canarensis* Hole *Hopea parviflora* Bedd. *Hopea ponga* (Dennst.) Mabb. *Hopea* sp. *Vateria indica* L.
18. Elaeocarpaceae	*Elaeocarpus*	*Elaeocarpus serratus* L. *Elaeocarpus tuberculatus* Roxb.
19. Euphorbiaceae	*Blachia* *Paracroton* *Macaranga* *Mallotus*	*Blachia denudata* Benth. *Paracroton pendulus* ssp. *zeylanicus* (Thwaites) N.P.Balakr. & Chakrab. *Macaranga peltata* Müll.Arg. *Mallotus philippensis* (Lam.) Müll.Arg. *Mallotus tetracoccus* Kurz
20. Fabaceae (Cercidoidae)	*Bauhinia*	*Bauhinia variegata* L.
Fabaceae (Caesalpinioideae)	*Acacia* *Cassia* *Xylia* *Albizia*	*Acacia* sp. *Cassia fistula* L. *Cassia* sp. *Xylia xylocarpa* (Roxb.) W.Theob. *Albizia chinensis* (Osbeck) Merr. *Albizia lebbeck* (L.) Benth. *Albizia odoratissima* (L.f.) Benth.
Fabaceae (Detarioidae)	*Humboldtia* *Saraca* *Tamarindus*	*Humboldtia brunonis* Wall. *Saraca asoca* (Roxb.) Willd. *Tamarindus indica* L.
Fabaceae (Papilionoideae)	*Dalbergia* *Erythrina* *Pongamia* *Pterocarpus* *Butea*	*Dalbergia latifolia* Roxb. *Erythrina indica* Lam. *Pongamia pinnata* (L.) Pierre *Pterocarpus marsupium* Roxb. *Butea monosperma* (Lam.) Kuntze
21. Icacinaceae	*Mappia*	*Mappia nimmoniana* (J. Graham) Byng & Stull
22. Lamiaceae	*Callicarpa* *Tectona* *Vitex*	*Callicarpa tomentosa* (L.) L. *Tectona grandis* L.f. *Vitex altissima* L.f.
23. Lauraceae	*Actinodaphne* *Beilschmiedia* *Cinnamomum* *Cryptocarya* *Litsea* *Machilus*	*Actinodaphne angustifolia* (Blume) Nees *Actinodaphne hookeri* Meisn *Beilschmiedia wightii* (Nees) Benth. ex-Hook.f. *Cinnamomum malabathrum* (Burm.f.) J.Presl *Cinnamomum* sp. *Cinnamomum verum* J.Presl *Cryptocarya wightiana* Thwaites *Litsea floribunda* (Blume) Gamble *Litsea ghatica* Saldanha *Litsea laevigata* (Nees) Gamble *Machilus glaucescens* (Nees) Wight
24. Lecythidaceae	*Careya*	*Careya arborea Roxb.*
25. Loganiaceae	*Strychnos*	*Strychnos nux-vomica* L.
26. Lythraceae	*Lagerstroemia*	*Lagerstroemia macrocarpa* Wight *Lagerstroemia* sp. *Lagerstroemia speciosa* Pers.

Family	Genus	Species
27. Magnoliaceae	*Magnolia*	*Magnolia champaca* L.
28. Malvaceae	*Bombax* *Microcos* *Grewia* *Helicteres* *Kydia*	*Bombax ceiba* L. *Microcos heterotricha* (Mast.) Burret *Grewia tiliifolia* Vahl *Helicteres isora* L. *Kydia calycina* Roxb.
29. Melastomataceae	*Memecylon*	*Memecylon edule* var. *edule* *Memecylon talbotianum* D.Brandis *Memecylon terminale* Dalzell *Memecylon umbellatum* Burm.f.
30. Meliaceae	*Aglaia* *Azadirachta* *Dysoxylum* Reinwardtiod-endron *Toona* *Heynea*	*Aglaia elaeagnoidea* Benth. *Aglaia* sp. *Azadirachta indica* A.Juss. *Dysoxylum malabaricum* Bedd. ex C.DC. *Reinwardtiodendron anamalaiense* (Bedd.) Mabb. *Toona ciliata* M.Roem. *Heynea trijuga* Roxb.
31. Moraceae	*Artocarpus* *Ficus*	*Artocapus lacucha* Roxb. Ex Buch.-Ham. *Artocarpus heterophyllus* Lam. *Artocarpus hirsutus* Lam. *Ficus exasperata* Vahl *Ficus benghalensis* L. *Ficus religiosa* L. *Ficus hispida* L.f. *Ficus racemosa* L. *Ficus* sp. *Ficus tsjahela* Burm.f.
32. Myristicaceae	*Knema* *Myristica*	*Knema attenuata* (Wall. ex-Hook.f. & Thomson) Warb. *Myristica dactyloides* Gaertn. *Myristica fragrans* Houtt. *Myristica malabarica* Lam.
33. Myrtaceae	*Eugenia* *Syzygium*	*Eugenia aloysii* C.J.Saldanha *Eugenia roxburghii* DC. *Syzygium caryophyllatum* (L.) Alston *Syzygium cumini* (L.) Skeels *Syzygium gardneri* Thwaites *Syzygium laetum* (Buch.-Ham.) Gandhi *Syzygium* sp. *Syzygium xanthophyllum* (C.B.Rob.) Merr. *Syzygium zeylanicum* (L.) DC.
34. Nyssaceae	*Mastixia*	*Mastixia arborea* (Wight) C.B.Clarke
35. Oleaceae	*Chionanthus* *Tetrapilus* *Ligustrum*	*Chionanthus mala-elengi* ssp. *mala-elengi* *Tetrapilus dioicus* (Roxb.) L.A.S.Johnson *Ligustrum nepalense* Wall.
36. Phyllanthaceae	*Aporosa* *Bischofia* *Breynia* *Phyllanthus* *Glochidion* *Bridelia*	*Aporosa cardiosperma* (Gaertn.) Merr. *Bischofia javanica* Blume *Breynia retusa* (Dennst.) Alston *Phyllanthus acidus* (L.) Skeels *Phyllanthus emblica* L. *Phyllanthus assamicus* Müll. Arg. *Phyllanthus velutinus* (Wight) Müll.Arg. *Glochidion zeylanicum* (Gaertn.) A.Juss. *Bridelia retusa* (L.) A.Juss.
37. Polygalaceae	*Xanthophyllum*	*Xanthophyllum flavescens* Roxb.
38. Primulaceae	*Myrsine*	*Myrsine wightiana* Wall. ex A.DC.
39. Rhamnaceae	*Ziziphus* *Maesopsis*	*Ziziphus oenopolia* (L.) Mill. *Ziziphus rugosa* Lam. *Ziziphus xylopyrus* (Retz.) Willd. *Maesopsis eminii* Engl.
40. Rhizophoraceae	*Carallia*	*Carallia brachiata* (Lour.) Merr.
41. Rosaceae	*Prunus*	*Prunus* sp.
42. Rubiaceae	*Adina* *Neolamarckia* *Psydrax* *Canthium* *Ixora* *Catunaregam* *Oxyceros* *Randia*	*Adina cordifolia* (Roxb.) Brandis *Neolamarckia cadamba* (Roxb.) Bosser *Psydrax dicoccum* Gaertn. *Canthium coromandelicum* (Burm.f.) Alston *Canthium* sp. *Ixora coccinea* var. *coccinea* *Ixora brachiata* Roxb. *Catunaregam spinosa* (Thunb.) Tirveng. *Oxyceros rugulosus* (Thwaites) Tirveng. *Randia* sp.
43. Rutaceae	*Aegle* *Atalantia* *Chloroxylon* *Clausena* *Zanthoxylum* *Murraya* *Naringi*	*Aegle marmelos* (L.) Corrêa *Atalantia monophylla* (L.) DC *Atalantia* sp. *Chloroxylon swietenia* DC. *Clausena anisata* (Willd.) Hook.f. *Zanthoxylum rhetsa* (Roxb.) DC. *Murraya paniculata* (L.) Jack *Naringi crenulata* (Roxb.) Nicolson
44. Salicaceae	*Casearia* *Flacourtia*	*Casearia tomentosa* Roxb. *Flacourtia montana* J.Graham
45. Santalaceae	*Santalum*	*Santalum album* L.
46. Sapindaceae	*Dimocarpus* *Sapindus* *Schleichera*	*Dimocarpus longan* Lour. *Sapindus trifoliatus* L. *Schleichera oleosa* (Lour.) Oken
47. Sapotaceae	*Chrysophyllum* *Manilkara* *Madhuca* *Palaquium*	*Chrysophyllum roxburghii* G.Don *Manilkara kauki* Dubard *Madhuca longifolia* var. *latifolia* (Roxb.) A.Chev. *Madhuca* sp. *Palaquium ellipticum* (Dalzell) Baill.
48. Symplocaceae	*Symplocos*	*Symplocos cochinchinensis* S.Moore
49. Ulmaceae	*Holoptelea*	*Holoptelea integrifolia* (Roxb.) Planch.
50. Verbenaceae	*Citharexylum*	*Citharexylum spinosum* L.
51. Vitaceae	*Leea*	*Leea indica* (Burm.f.) Merr.
51 Families	**130 Genera**	**189 species**

plant species has its contribution to biodiversity. The presence or absence of plant species in the forest could not be underestimated, because balancing the forest ecosystem is dependent on every species present in the forest. Accordingly, the quantitative investigation of *Diospyros* trees revealed better diversity in some areas of central Western Ghats, Karnataka.

Species composition and richness: species richness in the community is determined by the productivity of the system and structural complexity or diverseness. The composition of species within a community suggests us flexibility and predictability of a particular environment (Upadhya et al. 2003) Wet tropical forests are characterised by their high species richness (Chandrashekara & Radhakrishnan 1994). The present study depicted 16 species of *Diospyros* trees in 20 different study sites in the central Western Ghats region which was higher than that of the 15 species reported previously in Karnataka state (Saldanha 1984). *Diospyros chloroxylon*, *D. ovalifolia*, and *D. cordifolia* which were reported by them were not observed in the present study. Other than this our study additionally reported *Diospyros ghatensis*, *D. nilagirica*, and *D. ridleyi* (Table 2).

Among the study sites, Agumbe S6 of Shivamogga district showed the highest species richness with a greater number of *Diospyros paniculata* (26) trees (Figure 2). A similar study showed that the vegetation of Agumbe is the richest along with that Ebenaceae was the dominant family and *Diospyros paniculata* is one of the dominant species in this region (Srinivas & Parthasarathy 2000). Floristic studies in the Agumbe region of Western Ghats suggested that Ebenaceae family members were frequently distributed, and documented eight species of *Diospyros* (Rao & Krishnamurthy 2021). The study also reported eight species of *Diospyros* and in addition to previous studies *Diospyros ferrea*, *D. pruriens*, and *D. sylvatica* were observed from this region.

Along with species composition some of the characteristics like frequency, density, abundance, basal area, and IVI also determine the forest structure. The percentage frequency of the *Diospyros* trees in this study varied from 2.5– 72% (Figure 3). The top ranking of frequency was depicted by *Diospyros montana* (72%). This result is higher when compared to the frequency values of *Diospyros melanoxylon* and *Diospyros embryopteris* ranging 10–40 in three different regions of Eastern Ghats, India (Sahu et al. 2019). The present study also depicts good results in comparison with the relative frequency of *Diospyros burmanica* Kz. 4.58% from central Myanmar (Kyaw et al. 2022).

The total density of *Diospyros* trees per transect varied from 0.03–3.20 in the sites studied (Figure 3). The highest density was observed by *Diospyros montana* (3.20). The present result is lesser when compared to the density of *Diospyros sylvatica* (16) (Naidu & Kumar 2016) from Eastern Ghats of Andra Pradesh and Tamil Nadu region of India respectively.

Abundance values of *Diospyros* trees range between 1.00–9.67 in the current study (Figure 3). A great value of abundance was observed by *Diospyros paniculata* (9.67). The studies on tree abundance by species and family across six elevation zones of Mahendragiri Hill Forests of Eastern Ghats, Odisha, India depicted the four Ebenaceae family members with their abundance values ranging 3–35. Among them, *Diospyros malabarica* (26) was a highly abundant species (Khadanga et al. 2023) and the range of abundance values is comparatively higher than our current study in central Western Ghats.

Analysis of the Importance Value Index can be used to identify patterns of association of dominant species in a community, which in turn represents the status of species within the community. Analysis of IVI in 20 different sites revealed that values ranged from 0.11–6.51 (Figure 3). *Diospyros montana* showed the highest (IVI, 6.51) followed by *Diospyros melanoxylon* (IVI, 2.52). (Sharma et al.2023) reported that *Diospyros melanoxylon* showed the great value of (IVI 16.01, and 20.85) in highly and moderately disturbed tropical dry forests of northern India respectively. Borah & Garkoti (2011) showed that the IVI of *Diospyros toposia* Buck- Ham. was 9.92 in the disturbed forest of Barak reserves in southern Assam, India. A species with a high importance value index (IVI) demonstrates dominance and ecological success, as well as good regeneration and ecological amplitude. These plants require conservation management, while those with a low value require significant and intensive conservation efforts (Esor et al. 2023).

Stand basal area is a parameter used in quantifying a forest stand which estimates the volume of trees and helps in understanding competition among species. Basal area of *Diospyros* trees across 20 sites of central Western Ghats showed a wide range (0.0002–104.1030 m^2/ha). Among them *Diospyros montana* (104.1030 m^2/ha) showed great basal area cover with the highest number of stems (Figure 4). Naidu & Kumar (2016) reported that *Diospyros sylvatica* one of the important species depicted 2.02 m^2/ha.

Studies of quantitative parameters revealed that among *Diospyros* trees, *Diospyros montana* is recognised to be an important species with a high importance value index. *Diospyros montana* was found to be the most frequent and densely distributed one with the contribution of the highest basal area. This particular tree may be adapted to both dry and moist environments. Hence, we can observe this tree in all types of forests from evergreen to dry deciduous forests but a greater number of trees occurred in semi-evergreen and moist deciduous forests.

Pattern of distribution: spatial distribution pattern can be represented by abundance to frequency ratio which is known as the Whitford value (Whitford 1949). In the current study, all *Diospyros* species show A/F values of more than 0.05 which range from 0.06–2.40 (Table 3). This indicates the clumped or contagious pattern of distribution. Similarly, (Ndah et al. 2013) reported *Diospyros herienasis* (0.49) showing the contagious distribution of the species from southwestern Cameroon. Both random and contagious distribution pattern of *Diospyros melanoxylon* (0.03–0.06) was reported in different study sites from tropical dry forests of northern India (Sharma et al. 2023). Primarily due to gap phase dynamics, tropical rain forests constitute highly patchy communities. The arrangement of members of the same species together is often directly linked to a mechanism for gap formation among the species and dispersal (Upadhya et al. 2003).

Diversity indices: diversity of any community can be recorded in the form of diversity indices. The Shannon index is one such parameter that depicts the diversity and richness of an area. Normally it ranges 1.5– 3.5 and occasionally surpasses 4.5. As the Shannon index value increases or is near 4.5 then it implies rich diversity in that area. In the same way, if the value is near 1 then it indicates less diverse organisms in a particular area. Usually, the range of the Shannon index prescribed for tropical forests is 0.83–4.1 (Subashree et al. 2021). (Tadwalkar et al. 2020) reported Shannon value from the northern region of Western Ghats ranging 0–2.86. In southern Western Ghats, it was 4.49 studied by (Sathish et al. 2013). The present investigation of 20 study sites of central Western Ghats represented the Shannon index value ranging 1.56–3.96. Among the 20 study sites, the Shannon index was highest at S19- Hosagunda (3.9638) indicating the highest diversity, which was followed by S8- Agumbe (3.9364) indicating a diverse population of trees. The least value of the Shannon index was observed at S2– (1.5675) Aynoor region which implies comparatively less diversity (Figure 5).

Simpson's index known as the dominance index indicates how abundantly the species exists in a region. The dominance index for Indian tropical forests ranges from 0.21–0.92 (Subashree et al. 2021). The Simpson's dominance index in different forest types of southern Western Ghats was reported by (Joseph et al. 2021) which depicted values were 0.021 in evergreen, 0.071 in shola, 0.054 in semievergreen, 0.075 in moist deciduous, and 0.093 in dry deciduous forest types. The present study shows values of Simpson's index ranging from 0.019–0.248 (Figure 5). Values of the Simpson index near 0 indicate the highest diverse community. In terms of diversity in current research, S19 located at Hosagunda sacred groove of Shivamogga district showed the richest diversity among the study sites with the highest value of the Shannon index and the lowest value of Simpson's index which was followed by S8- Makutta region (Figure 5). Hosagunda is one of the sacred grooves consisting of Kaan Forests with a rich floristic composition. About five species of *Diospyros* were represented with better species richness and among them, *Diospyros crumenata* one of the endangered trees was recorded in the sacred groove. Earlier studies on the floristic composition of the Kaan forests of Sagara Taluk in central Western Ghats were carried out by (Gunaga et al. 2015). This study helped to understand that the Kaan forests of Sagara Taluk harbours diverse flora in evergreen and semievergreen forests. Most of the plant species reported inside the Kaans do not occur outside this habitat, indicating their endemic nature.

Beta diversity: the integration of processes related to ecology and evolution at different levels of space is an important task for figuring out how biodiversity is structured and preserved over time. In order to achieve this, the analysis of beta diversity is a promising method that makes it possible to quantify heterogeneity in the distribution of gamma and alpha diversities. This enables the assessment of how species alter over time and in response to environmental variation (Pinto-Ledezma et al. 2018). The present study concentrated on the beta diversity of 20 study sites in central Western Ghats which was calculated with the help of Jaccard's similarity index. The Jaccard similarity index of different study sites was tabulated and given in Figure 6. The Jaccard similarity values range between 0 to 1, where 0 indicates the dissimilarity between study sites and 1 indicates 100% similar study sites. In current work study site S6, S7, S8, and S10 showed similarity value 0.00 with respect to study sites S1, S2, S3, S4, S5. It is clear that S6, S7, S8, and S10 are the evergreen forest sites that are completely different in species composition from S1, S2, S3, S4, and S5 which represent dry deciduous forests. Study sites S1, S3, S4, S5, S12, and S13 depicted a similarity value of 1.00 with each other indicating 100% similarity in their species composition. In the same way, another set of study sites S2, S11, and S17 also show a similarity value of 1.00 with each other. Most of these sites mentioned above are dry deciduous and moist deciduous forests showing similarity among themselves in terms of species composition of *Diospyros.* The study sites S2, S11, S17 represented the similarity value 0.50 with the study sites S3, S4, S5, S9, S12, S13, S14, S15, S16. This infers that the former three sites are 50% similar to the later study sites. In the same way, S20 showed 50% similarity with the sites S19 and S15.

The trend shows that evergreen study sites (S6, S7, S8, S9, S10) and dry deciduous sites (S1, S2, S3, S4, S5) are completely dissimilar in the composition of *Diospyros* species. Semi-evergreen sites (S5, S16, S18, S19, S20) show less than 50% of similarity with evergreen, moist deciduous, and dry deciduous sites except S17. Moist deciduous sites (S11, S12, S13, S14, S15) show 50% or less than 50% similarity with evergreen and semi-evergreen sites. In this way, the similarity values are picturised in the Figure 6, which represents the similarity of each study site with respect to other study sites in terms of the composition of *Diospyros* species. This type of analysis is very similar to a study conducted in human-disturbed forests of Uttara Kannada, central Western Ghats by Rao et al. (2013). Another study aimed at analysis of site quality with the Jaccard similarity index in northeastern India was undertaken by Thangjam et al. (2022).

Forest types and species composition: the Western Ghats have a wide range of vegetation types due to their complex geography, altitudinal temperature decrease, and large variations in annual precipitation (1,000–6,000 mm), in addition to human influences (Rao et al. 2013). The Western Ghats are home to four main types of forests: moist deciduous, dry deciduous, semi-evergreen, and evergreen, according to different field-based analyses of vegetation groups and satellite photograph interpretation. Along with the forest types mentioned above, the parts of central Western Ghats included in the current research consist of mainly low-altitude and middle- altitude evergreen forest types (Pascal 1990). Species composition changes across the different forest types which is true in the case of *Diospyros* trees. According to (Saldanha 1984; Gamble 1998), among 16 species of *Diospyros* trees observed by us majority of trees are restricted to evergreen and semi-evergreen forests. Only *Diospyros montana* and *D. melanoxylon* are the species found in moist and dry deciduous types. *Diospyros montana* is found in both the forest types along with semi-evergreen forests. In this study *D. melanoxylon* was restricted to dry deciduous forests as before, but slight deviation was observed in study site S14 where it is a moist deciduous type of forest. *Diospyros buxifolia* which is a typical evergreen tree was found in the S14 region. The reasons for this may be rainfall and the dispersal mechanism of seeds. Species diversity of *Diospyros* is correlated with the vegetation types. NMDS analysis presents us with clear evidence regarding this (Figure 7). Study sites were classified into four groups based on forest types where group-1 dry deciduous forests, group-2 evergreen forests, group-3 moist deciduous forests, group-4 semi-evergreen forests, and dataset including the existence of *Diospyros* trees were considered for analysis. This plot indicates the four different forest types where group- 1 is dry deciduous forests which include study S1–S5. They are grouped separately in the plot because the species composition of dry deciduous forests is a peculiar one. Group- 2 indicates wet evergreen forests that include study sites S6–S10. All of them are grouped but S9 overlaps with group 4 which indicates in terms of *Diospyros* species composition this site is a similar composition to semi- evergreen site. In the same way, the group–3 indicates moist deciduous forests from S11–S15 whereas S12 overlaps with group- 4 depicting similar species composition. Group- 4 represents S16–S20 which is semi-evergreen forests. Here S19 and S20 overlap with the Evergreen Forest group indicating species diversity similar to evergreen forests. Similar floristic studies using NMDS analysis were conducted by (Bueno et al. 2017).

The analysis of species composition and diversity of *Diospyros* trees suggests that evergreen and semi-evergreen forests show the highest richness, alpha, and beta diversity than dry deciduous forests. The dry deciduous forest of the lower rainfall region is peculiar in species composition but has low tree densities and low levels of alpha diversities. Not only vegetation types community composition is also strongly influenced by elevation, and edaphic factors of the area (Mwakalukwa et al. 2014). Vegetation types, rainfall, and the dioecious nature of trees also play a very important role in the distribution of these trees. Some of the trees are not known to the world and are only used by local people. Many protected areas like sacred grooves are naturally protecting these trees. Diversity in forests is decreasing due to some anthropogenic activities and the invasion of alien species. As these trees are economically and medicinally important, few are threatened, so there is a need for conservation. Gaining knowledge about forest trees is very essential aspect and the first step in the conservation of rich diversity and sustainable utilization.

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