Article

Tree diversity, stand structure and species composition in three tropical dry deciduous forests of Madhya Pradesh, Central India

Debojyoti Raha[2], **Subashree Kothandaraman**[2,3], **Javid Ahmad Dar**[1,2], **Mohammed Latif Khan**[2]
[1]Terrestrial Ecology and Modelling Lab (TEaM Lab), Department of Environmental Science & Engineering, School of Engineering and Sciences, SRM University, Andhra Pradesh, India - 522502
[2]Forest Ecology and Ecosystems Laboratory, Department of Botany, Dr. Harisingh Gour Vishwavidyalaya (A Central University), Sagar, Madhya Pradesh, India - 470003
[3]Department of Biotechnology, KL Deemed to be University, Vaddeswaram, Andhra Pradesh, India - 522502
E-mail: javidahmad.d@srmap.edu.in, khanml61@gmail.com

Received 20 April 2023; Accepted 30 May 2023; Published online 5 June 2023; Published 1 December 2023

Abstract
Diversity, stand structure and species composition are the key elements of forest ecosystems. For the present study, three forest types: dry deciduous teak (DDTF), dry deciduous mixed (DDMF) and Boswellia (BF) forests were selected with the aim of assessing tree diversity, structure and species composition in tropical dry deciduous forests of Central India. The phytosociological survey was done by laying a total of 42 plots (14 plots in each study site). A total of 25 tree species (24 genera, 14 families) were recorded. The mean tree density was 635 trees/ha and mean basal area was 23.5 m^2/ha. The total tree density and tree basal area (juveniles and adults) were 26,688 individuals (mean 490) and 988.8 m^2 (mean 22.9 m^2) in 42 plots respectively. The mean tree adult density and basal area ranged 448 (BF) - 529 (DDMF) individuals/ha and 19.5 (DDMF) - 29.24 (BF) m^2/ha respectively. The tree species richness ranged 14 (DDTF) - 23 (DDMF). The Shannon's index values for the total trees (adults + juveniles) were 1.15, 2.09 and 1.76 for DDTF, DDMF and BF forest sites, respectively. Among the 14 families recorded across three study sites, Fabaceae was the most diverse family with 7 genera and 8 species. Both species density and richness decreased with increase in diameter class. The current study would be helpful in understanding the diversity patterns, stand structural attributes and species composition in tropical dry deciduous forests of Central India for better forest management and conservation measures.

Keywords phytodiversity; structural dynamics; composition; tropical dry deciduous forests; Central India.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

India, being one of the megadiverse countries in the world covers 2.4% forested land area and hosts 7-8% of all identified species comprising 45,000 plant species and 91,000 animal species (Subashree et al., 2021). The country is well-known for its rich biodiversity areas and conservation planning amongst the few countries. Among the eight hotspots of global biodiversity, four (the Himalayas, the Western Ghats, the Indo-Burma region and the Sundaland) are found in India (Thakur et al., 2022). Being part of fragile and rich biodiversity locations on the planet, the forests of India are facing great pressures due to deforestation, fragmentation, anthropogenic activities and introduction of exotic species (Muthumperumal and Parthasarathy, 2010; Pragasan and Parthasarathy, 2010; Gandhi and Sundarapandian, 2017; Singh and Chaturvedi, 2018, Tamilselvan et al., 2021; Kumar et al., 2022; Sharma et al., 2023). Therefore, India has sufficient cause to explore the biodiversity information (Thakur et al., 2022) as they generate knowledge on species of an area, a region or community, their distributional patterns and alternatives within floristic structure (Kershaw, 1964; Misra, 1968). Tree diversity is a key component in any forest ecosystem (Rennolls and Laumonier, 2000) and its quantitative analysis delivers the necessary data for conservation planning and policy management (Phillips et al., 2003).

The tropical dry deciduous forest, which accounts for nearly 40% of the country's total forest cover (Ministry of Environment, Forests and Climate Change, 2011) is transforming rapidly into dry deciduous scrub, dry savannah and dry grassland (Champion and Seth, 1968; Singh and Singh, 1989), and many species are locally depleted (Sagar and Singh, 2004). The consequence of deforestation and degradation of tropical forests include the loss of biological diversity, watershed protection and non-timber forest products (NTFPs), and loss of means of existence for the people whose livelihood depends on the forest (Lamb et al., 2005; Lolila et al., 2023). Among these, the loss of biological diversity is perhaps the most important consequence as it influences all ecological services and the livelihood of forest dwellers (Sagar and Singh, 2006). Thus, tropical dry forests are one of the most threatened ecosystems in the world and demands urgent conservation measure to improve biological diversity, tree cover as well as forest health and productivity.

The tropical dry deciduous forest of the Sagar district has been managed by the Madhya Pradesh Forest Department. The region is currently experiencing a large-scale human disturbance through illegal cutting, mining (rock phosphate and iron), and illegal NTFP extraction. In the last few decades, due to intense anthropogenic activities, the dry deciduous forest cover in certain parts of central India is being degraded into species-poor dry deciduous scrub and grasslands (Sagar and Singh, 2005). This scenario requires an in-depth analysis of these forests with regards to the floristic diversity, structure and composition. Therefore, the present study is significant in generating useful baseline data in order to conserve and manage the vegetation of the tropical dry forest ecosystem of this region and elsewhere in the tropical dry forests in India. The objective was to describe the tree vegetation structure, composition and species diversity of three different dry deciduous forest types of district Sagar, Madhya Pradesh, India.

2 Materials and Methods

2.1 Study area

The present study was undertaken in three tropical dry deciduous forest types viz., dry deciduous teak forest (DDTF, Site I), dry deciduous mixed forest (DDMF, Site II) and *Boswellia* forest (BF, Site III) in Sagar, Madhya Pradesh (Table 1, Fig. 1) which are a part of lower Vindhyan range of Central India, and is situated at an average height of 420 m a.s.l. The area has a hot dry summer from April to June, followed by a monsoon season from July to September and a cool and relatively dry winter from October to March. The area receives an annual average rainfall of 1187.6 mm of which the rainy months contribute approximately 90%. The mean annual minimum and maximum temperatures vary between 10°C (January) and 42.7°C (May) respectively (WorldClim, 2020). As per Champion and Seth's Classification (Champion and Seth, 1968), the forest in the area belongs to group 4b. Vegetation was enumerated in three forest ranges of Sagar district, viz. Shahgarh, Nanakpur and Heerapur by laying 14 plots of 60 m × 20 m in each study site/forest type following standard methods (Misra, 1968). In each plot, the diameter of all the tree individuals (≥ 10 cm diameter at breast height of 1.37 m (DBH)) were recorded. The predominant tree species in the study sites of the three different forest types are *Tectona grandis*, *Butea monosperma* and *Lagerstroemia parviflora* in DDTF, *Tectona grandis*, *Terminalia tomentosa* and *Lagerstroemia parviflora* in DDMF, and *Boswellia serrata*, *Tectona grandis* and *Lagerstroemia parviflora* in BF.

Table 1 Information on the three study sites (Site I, DDTF- Dry deciduous teak forest; Site II, DDMF-Dry deciduous mixed forest and Site III, BF-Boswellia forest) in Sagar, Madhya Pradesh, India.

Parameters	**Site I (DDTF)**	**Site II (DDMF)**	**Site III (BF)**
Latitude	24.21-24.22	24.13-24.24	24.24-24.24
Longitude	79.11-79.11	79.14-79.14	79.12-79.13
Altitude (m asl.)	375-440	384-405	405-438
Slope (°)	0.26-1.25	0.27-0.84	0.40-1.21
Aspect (°)	262-354	105-187	213-245
Mean annual precipitation (mm)	1105-1179	1119-1139	1108-1143
Mean annual temperature (°C)	24.4-25.4	25.0-25.3	24.9-25.2

2.2 Vegetation sampling

Vegetation analysis was carried out to understand the species distribution, population structure, diversity and the landscape characteristics of the forest land. The topographic variables (aspect, slope, altitude) were obtained by using GPS. The random grid sampling method was used following the standard protocols. Fourteen 60 m × 20 m plots were laid down in each forest type. Since the present study consisted of three different forest types, a total of 42 plots were laid down to estimate the diversity. All the trees falling under the plot ((>10 cm dbh at 1.37 m) were measured and they were grouped into different DBH classes according to Muller-Dombois and Ellenberg (1974). All tree species found in the sites were prepared and identified at the Department of Botany, Dr. Harisingh Gour Central University, Sagar from their vegetative and reproductive features using the flora of Madhya Pradesh. Photographs of plant specimens and general vegetation were taken for documentation. The photography was done by photographic camera- Nikon 3400D. All the specimens were then identified and documented with the help of experts.

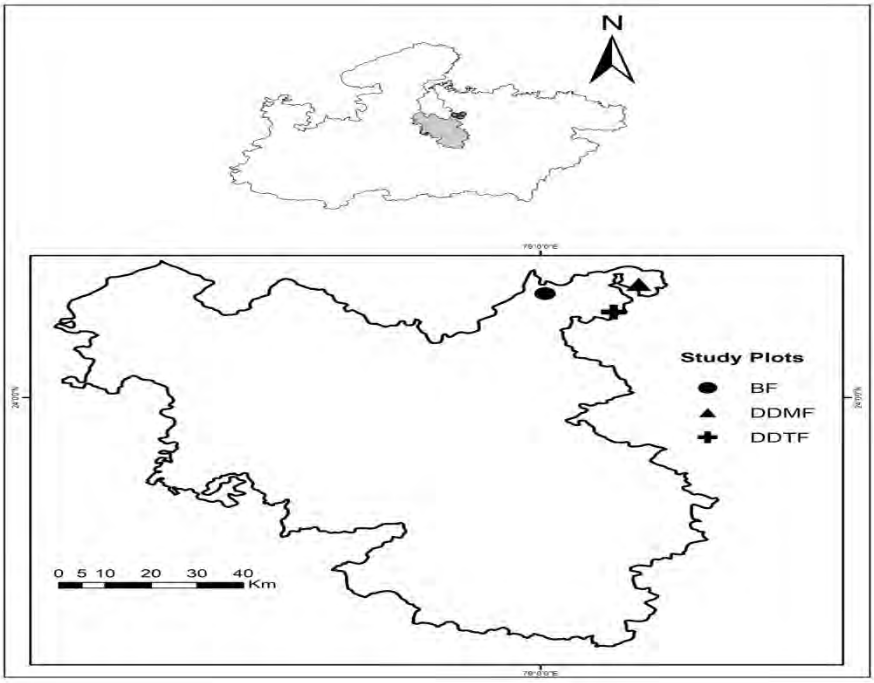

Fig. 1 Location of the study sites in Sagar, Madhya Pradesh.

Ecological data provides basic information of the studied site which helps in proper conservation and sustainable management of the local forest ecosystem.

Frequency: This refers to the degree of dispersion of an individual species in an area in terms of percentage occurrence. The frequency of a species can be obtained by the following formula:

$$\text{Frequency} = \frac{\text{Number of quadrats in which species found}}{\text{Total number of quadrats studied}} \times 100$$

Abundance: This refers to the total number of individuals of different species in a vegetative community of a given area:

$$\text{Abundance} = \frac{\text{Total number of a species in all quadrats}}{\text{Total number of quadrats in which species occured}}$$

Density: This refers to the numerical strength of a species (no. of individual) at a given area:

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}$$

Importance Value Index (IVI): The IVI is a statistical quantity which provides us the overall importance of a species in a vegetative community. The IVI was calculated by the summation of relative frequency, relative basal area and relative density (Curtis and McIntosh, 1951; Mishra, 1968):

IVI = Relative Density + Relative Frequency + Relative Abundance

Relative density (RD): RD is the proportional representation of a species in the sample area:

$$\mathrm{RD} = \frac{\text{Density of the species}}{\text{Total density of all species}} \times 100$$

Relative frequency (RF): RF is the proportion of frequency of a species in the sample area:

$$\mathrm{RF} = \frac{\text{Frequency of occurance of the species}}{\text{Total frequency of all species}} \times 100$$

Relative abundance (RA): RA is the proportion of abundance of a species in the sample area:

$$\mathrm{RA} = \frac{\text{Abundance of the species in the sample}}{\text{Total abundance of all species in the sample}} \times 100$$

2.3 Statistical analyses

Species diversity indices such as Shannon, Simpson, Fisher's alpha, Dominance, Berger-Parker, Margalef and Evenness were calculated using the Past 3.1 program (version 3.1; Øyvind Hammer, Natural History Museum, University of Oslo). SPSS Software package (ver. 20.0; SPSS, Chicago, IL) was used for statistical analyses.

3 Results

A total of 25 tree species were recorded from the three forest sites representing 24 genera and 14 families. The mean tree density was 635 trees/ha and mean basal area was 23.5 m^2/ha. The total tree density among all the 42 plots was 26,688 individuals. The tree species richness was 14 for site I, 23 for site II and 15 for site III. The most frequently occurring tree species among all the study sites is *Tectona grandis*.

3.1 Species composition

Of all the species found across three study sites, 12 species were found among juvenile trees and 25 were found among adult trees. Tree species richness was 14 in site I, 22 in site II and 15 in site III for adult trees. For the juvenile trees, the species richness was 4 (site I), 12 (site II) and 9 (site III). A total of four species, viz. *Butea monosperma, Diospyros melanoxylon, Lagerstroemia parviflora* and *Tectona grandis* were found in both juvenile and adult stages. In the site I, the following typical dry deciduous species are prevalent viz., *Tectona grandis, Butea monosperma, Lagerstroemia parviflora, Diospyros melanoxylon* and *Anogeissus latifolia*. In the site II, the most dominant species are *Tectona grandis, Lagerstroemia parviflora, Anogeissus latifolia, Terminalia tomentosa*, and *Chloroxylon swietenia*. In site III, the most dominant tree species are *Boswellia serrata, Lagerstroemia parviflora, Tectona grandis, Anogeissus latifolia* and *Cassia fistula*. Among the juvenile trees, *Lagerstroemia parviflora* holds the highest proportion of density (stems/ha), viz. 40.61% in site I, 38.27% in site II and 47.58% in site III. Among the adult trees, *Tectona grandis* has the highest proportion of density (stems/ha) in both site I (73.61%) and site II (35.1). In site III, *Boswellia serrata* has the largest proportion of density (stems/ha) (53.44%, Table 2). Among the adult trees, *Tectona grandis* holds the highest value of Importance Value Index (IVI) in both sites I (173.7) and II (83.7). In site III, Boswellia serrata has the highest IVI value (118.0). Among the juvenile trees, *Tectona grandis* has the highest IVI value for both sites I (124.6) and II (106.4); in site III, *Lagerstroemia parviflora* has the largest IVI value (84.2). The species with lowest IVI value among the juveniles in site I, site II and site III were *Butea monosperma* (47.5), *Buchanania lanzan* (1.18) and *Flacourtia indica* (3.9) respectively. The species with lowest IVI value among the adult trees in site I, site II and site III were *Flacourtia indica* (0.85), *Bauhinia racemosa* (0.64) and *Gardenia latifolia* (0.73) respectively. The dominance-diversity curve showed a decreasing correlation among tree species in the three study sites (Fig. 2). It indicates the high IVI of *Tectona grandis* and *Boswellia serrata* (Table 3 & 4).

Table 2 Percent (%) contribution of density of tree adults (⩾10 cm DBH) and juveniles (⩽10 cm DBH) of the three study sites.

S No.	Species	Site I (DDTF)		Site II (DDMF)		Site III (BF)	
		≤10	≥10	≤10	≥10	≤10	≥10
1	*Acacia catechu* (L.f.) Willd.	-	-	-	0.22	-	-
2	*Acacia leucophloea* (Roxb.) Willd.	-	-	0.21	0.54	1.61	0.26
3	*Aegle marmelos* (L.) Correa	-	0.23	-	0.97	-	-
4	*Albizia lebbeck* (L.) Benth.	-	-	-	0.43	-	-
5	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr.	-	1.16	-	9.40	-	4.21
6	*Bauhinia racemosa* Lam.	-	-	-	0.11	-	-
7	*Boswellia serrata* Roxb. exColebr.	-	-	-	-	-	53.44
8	*Buchanania lanzan* Spreng.	-	1.74	0.21	5.72	-	1.28
9	*Butea monosperma* (Lam.) Taub.	15.76	9.95	0.42	3.24	1.61	2.17
10	*Cassia fistula L.*	-	0.35	0.42	1.30	2.42	2.68
11	*Chloroxylon swietenia* DC.	-	0.12	0.21	7.78	-	-
12	*Dalbergia paniculata* Roxb.	-	-	-	0.43	-	-
13	*Diospyros melanoxylon* Roxb.	19.39	1.97	24.74	6.16	19.35	1.02
14	*Flacourtia indica* (Burm. f.) Merr.	-	0.12	0.21	0.76	1.61	1.28
15	*Gardenia latifolia* Aiton	-	-	-	0.97	-	0.26
16	*Lagerstroemia parviflora* Roxb.	40.61	9.61	38.27	12.63	47.58	10.71
17	*Lannea coromandelica* (Houtt.) Merr.	-	0.81	-	3.89	-	2.17
18	*Madhuca indica* J.F.Gmel.	-	-	-	1.19	-	-
19	*Mitragyna parvifolia* (Roxb.) Korth.	-	-	-	1.51	-	1.28
20	*Ougeinia oojeinensis* (Roxb.) Hochr.	-	0.12	-	-	-	-
21	*Phyllanthus emblica* L.	-	0.12	1.06	0.11	4.03	0.26
22	*Tectona grandis* L.f.	24.24	73.61	33.83	35.10	20.97	16.07
23	*Terminalia tomentosa* Wight & Arn.	-	0.12	0.21	7.02	0.81	2.93
24	*Wrightia tinctoria* R.Br.	-	-	0.21	0.43	-	-
25	*Ziziphus jujuba* Mill.	-	-	-	0.11	-	-

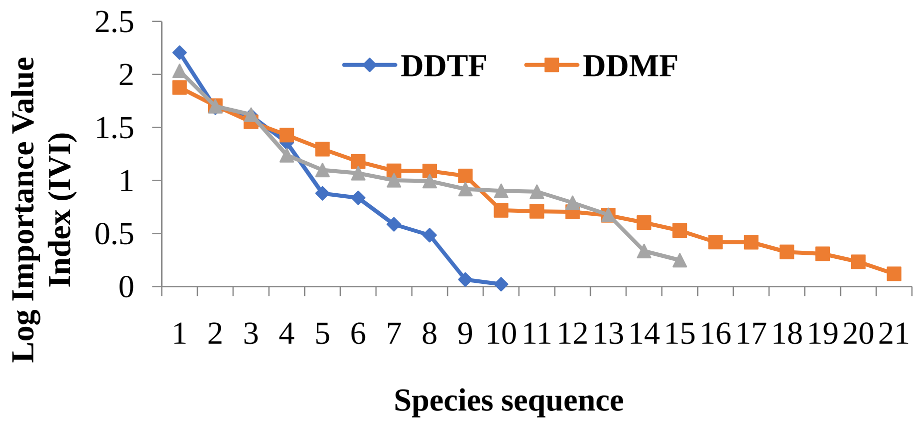

Fig. 2 Dominance-Density Curve of three study sites.

Table 3 Mean tree adult density (D, No./ha), basal area (BA, m^2/ha) and Importance value index (IVI) of the three study sites.

S. No.	Species	Site I (DDTF)			Site II (DDMF)			Site III (BF)		
		D	BA	IVI	D	BA	IVI	D	BA	IVI
1	*Acacia catechu* (L.f.) Willd.	-	-	-	2.38	0.03	1.35	-	-	-
2	*Acacia leucophloea* (Roxb.) Willd.	-	-	-	5.95	0.16	1.549	2.38	0.05	1.03
3	*Aegle marmelos* (L.) Correa	2.38	0.10	1.73	10.71	0.20	5.54	-	-	-
4	*Albizia lebbeck* (L.) Benth.	-	-	-	4.76	0.08	2.15	-	-	-
5	*Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. &Perr.	11.90	0.32	7.00	103.5	1.61	30.1	39.27	0.80	18.71
6	*Bauhinia racemosa* Lam.	-	-	-	1.19	0.01	0.64	-	-	-
7	*Boswellia serrata* Roxb. ex Colebr.	-	-	-	-	-	-	498.6	23.31	118.0
8	*Buchanania lanzan* Spreng.	17.85	0.64	6.92	63.07	1.53	21.9	11.90	0.14	9.25
9	*Butea monosperma* (Lam.) Taub.	102.3	2.17	42.06	35.7	0.73	13.7	20.23	0.27	7.68
10	*Cassia fistula L.*	3.57	0.02	3.11	14.28	0.16	4.76	24.99	0.30	10.99
11	*Chloroxylon swietenia* DC.	1.19	0.05	0.95	85.68	1.19	12.34	-	-	-
12	*Dalbergia paniculata* Roxb.	-	-	-	4.76	0.27	2.65	-	-	-
13	*Diospyros melanoxylon* Roxb.	20.23	0.14	14.4	67.8	0.81	24.08	10.71	0.13	7.35
14	*Flacourtia indica* (Burm. f.) Merr.	1.19	0.01	0.85	8.33	0.11	2.40	11.90	0.13	8.88
15	*Gardenia latifolia* Aiton	-	-	-	10.71	0.25	4.10	1.19	0.03	0.73
16	*Lagerstroemia parviflora* Roxb.	98.7	1.45	41.9	139.2	2.07	39.25	101.1	1.52	34.86
17	*Lannea coromandelica* (Houtt.) Merr.	8.33	0.29	4.16	42.8	1.41	12.97	20.23	0.39	10.04
18	*Madhuca indica* J.F.Gmel.	-	-	-	13.09	0.19	4.78	-	-	-
19	*Mitragyna parvifolia* (Roxb.) Korth.	-	-	-	15.47	0.49	5.46	13.09	0.10	6.57
20	*Ougeinia oojeinensis* (Roxb.) Hochr.	1.19	0.06	0.88	-	-	-	-	-	-
21	*Phyllanthus emblica* L.	1.19	0.07	0.95	1.19	0.02	0.94	2.38	0.05	2.17
22	*Tectona grandis* L.f.	755.6	15.5	173.7	386.7	6.86	83.7	147.5	2.81	50.63
23	*Terminalia tomentosa* Wight & Arn.	1.19	0.04	1.23	77.3	2.06	22.8	27.37	0.41	12.80
24	*Wrightia tinctoria* R.Br.	-	-	-	4.76	0.02	1.85	-	-	-
25	*Ziziphus jujuba* Mill.	-	-	-	1.19	0.01	0.76	-	-	-

Table 4 Mean tree juvenile density (D, No./ha), basal area (BA, m^2/ha) and Importance value index (IVI) of the three study sites.

S. No.	Species	Site I (DDTF)			Site II (DDMF)			Site III (BF)		
		D	BA	IVI	D	BA	IVI	D	BA	IVI
1	*Acacia leucophloea* (Roxb.) Willd.	-	-	-	1.19	0.004	7.143	2.56	0.009	19.2
2	*Buchanania lanzan* Spreng.	-	-	-	1.19	0.001	1.188	-	-	-
3	*Butea monosperma* (Lam.) Taub.	33.32	0.07	47.5	2.38	0.006	8.16	2.56	0.009	19.2
4	*Cassia fistula* L.	-	-	-	2.38	0.009	6.378	3.84	0.014	23.1
5	*Chloroxylon swietenia* DC.	-	-	-	1.19	0.004	10.71	-	-	-
6	*Diospyros melanoxylon* Roxb.	41.01	0.09	73.31	139.23	0.264	58.47	42.29	0.03	33.4
7	*Flacourtia indica* (Burm. f.) Merr.	-	-	-	1.19	0.05	7.143	2.56	0.006	3.9
8	*Lagerstroemia parviflora* Roxb.	85.86	0.15	54.6	215.39	0.34	68.67	74.33	0.17	84.2
9	*Phyllanthus emblica* L.	-	-	-	5.95	0.16	11.35	6.41	0.01	47.4
10	*Tectona grandis* L.f.	51.26	0.13	124.6	190.4	0.363	106.4	33.32	0.07	63.1
11	*Terminalia tomentosa* Wight & Arn.	-	-	-	1.19	0.004	3.7	1.28	0.01	6.4
12	*Wrightia tinctoria* R.Br.	-	-	-	1.19	0.004	10.71	-	-	-

3.2 Density and basal area

The total stem density (stems/ha) was recorded highest in the study site II (799 stems/ha), followed by site I (588 stems/ha) and site III (519 stems/ha). Among the juvenile trees, the density ranged from 71 (site III) to 270 (site I) and among the adult trees, density ranged from 448 (site III) to 529 (site II). The total basal area among the three study sites ranged from 29.5 m^2/ha (site III) to 20.4 m^2/ha (site II) with the mean basal area of 23.5 m^2/ha. Plot-wise, the basal area varied from 8.99 m^2/ha to 39.52 m^2/ha with an average of 23.5 m^2/ha. Tectona grandis has the largest total basal area in the study (43.39 m^2), followed by *Boswellia serrata* (39.18 m2). *Bauhinia racemosa* has the lowest total basal area with 0.01 m2. Among the juvenile trees, the basal area ranged from 0.31 m^2/ha (site III) to 0.98 m^2/ha (site II). Among the adult trees, the basal area ranged from 19.5 m^2/ha (site II) to 29.24 m^2/ha (site III, Table 2, 3 & 4).

3.3 Diversity indices

Among all the diversity indices calculated, Shannon's index ranged from 0.81 (site I) to 1.61 (site II) with the mean of 1.27 and from 0.49 (site I) to 0.65 (site II) with the mean of 0.59 for adult trees and juveniles respectively. The Shannon's index values for the total trees (adults + juveniles) were 1.15, 2.09 and 1.76 for the study sites I, II and III respectively. The values of dominance index ranged from 0.29 (site II) to 0.59 (site I) with the mean of 0.41 and from 0.63 (site II) to 0.65 (site III) with the mean of 0.6 for adult trees and juveniles respectively. The dominance index for the total trees (adults + juveniles) were 0.47, 0.19 and 0.27 for the study sites I, II and III respectively. The Simpson's index ranged from 0.41 (site I) to 0.71 (site II) with the mean of 0.59 for adult trees and 0.29 (site I) to 0.4 (site III) with the mean of 0.35 for juveniles. The Simpson's index values for the total trees (adults + juveniles) were 0.53, 0.81 and 0.73 for the study sites I, II and III respectively. The Fisher's alpha index ranged from 2.61 (site II) to 1.25 (site I) with the mean of 2.08 for adult trees and 1.07 (sites I and III) to 0.55 (site II) with the mean of 0.9 for juveniles. The Fisher's alpha index values for the total trees (adults + juveniles) were 2.29, 4.12 and 2.55 for the study sites I, II and III respectively. The Margalef's richness index ranged from 0.91 in site I to 1.76 in site II with the mean of 1.41 and 0.48 in site I to 0.73 in site III with the mean of 0.58 for adult trees and juveniles respectively. The Margalef index for the total trees (adults + juveniles) were 1.87, 3.18 and 2.06 for the study sites I, II and III respectively. The Berger-Parker Dominance index ranged from 0.44 (site II) to 0.72 (site I) with the mean of 0.57 for adult trees and 0.59 (site III) to 0.7 (site I) with the mean of 0.66 for juvenile trees. The Berger-Parker Dominance index for the total trees (adults + juveniles) were 0.66, 0.35 and 0.46 for the study sites I, II and III respectively (Table 2, 3 & 4).

3.4 Family composition

Among the 14 families recorded across three study sites, Fabaceae was the most speciose family with 7 genera and 8 species. Anacardiaceae, Combretaceae, Rubiaceae and Rutaceae were bispecific. The other 9 families were monospecific. Fabaceae, Ebenaceae, Lythraceae and Verbenaceae were represented in both stages viz. juvenile and adults in all the three study sites. Ten families were recorded among the juvenile tree species. Among these, Fabaceae is the most speciose family with 3 genera and 3 species, and the other 9 families were monospecific (Table 5).

3.5 Size class distribution

Across the three study sites, small-sized trees (10-20 cm DBH) occupied a greater proportion (from 24.12% in site III to 42.18% in site I) than other diameter classes in terms of density. Very large-sized trees (50-100 cm DBH), when compared to other diameter-class individuals comprise a very less proportion (0.07% in site II to 1.32% in site III). The species richness is found to be highest in 30-40 cm (10), 10-20 cm (20) and 20-30 cm (14) diameter classes at sites I, II and III respectively.

Table 5 Family-wise contribution of species (S), genera (G) and density (D; No./ha) of the three study sites.

S. No.	Family	No. of Species	No. of Genera	No. of individuals	IVI
1	Anacardiaceae	2	2	1112	56.31
2	Apocynaceae	1	1	40	2.03
3	Burseraceae	1	1	3352	107.83
4	Combretaceae	2	2	1768	82.61
5	Ebenaceae	1	1	2040	71.03
6	Fabaceae	8	7	1808	91.16
7	Lythraceae	1	1	4728	140.94
8	Phyllanthaceae	1	1	112	9.07
9	Rhamnaceae	1	1	8	0.75
10	Rubiaceae	2	2	280	17.07
11	Rutaceae	2	2	680	19.42
12	Salicaceae	1	1	168	11.32
13	Sapotaceae	1	1	88	4.70
14	Verbenaceae	1	1	10504	285.76

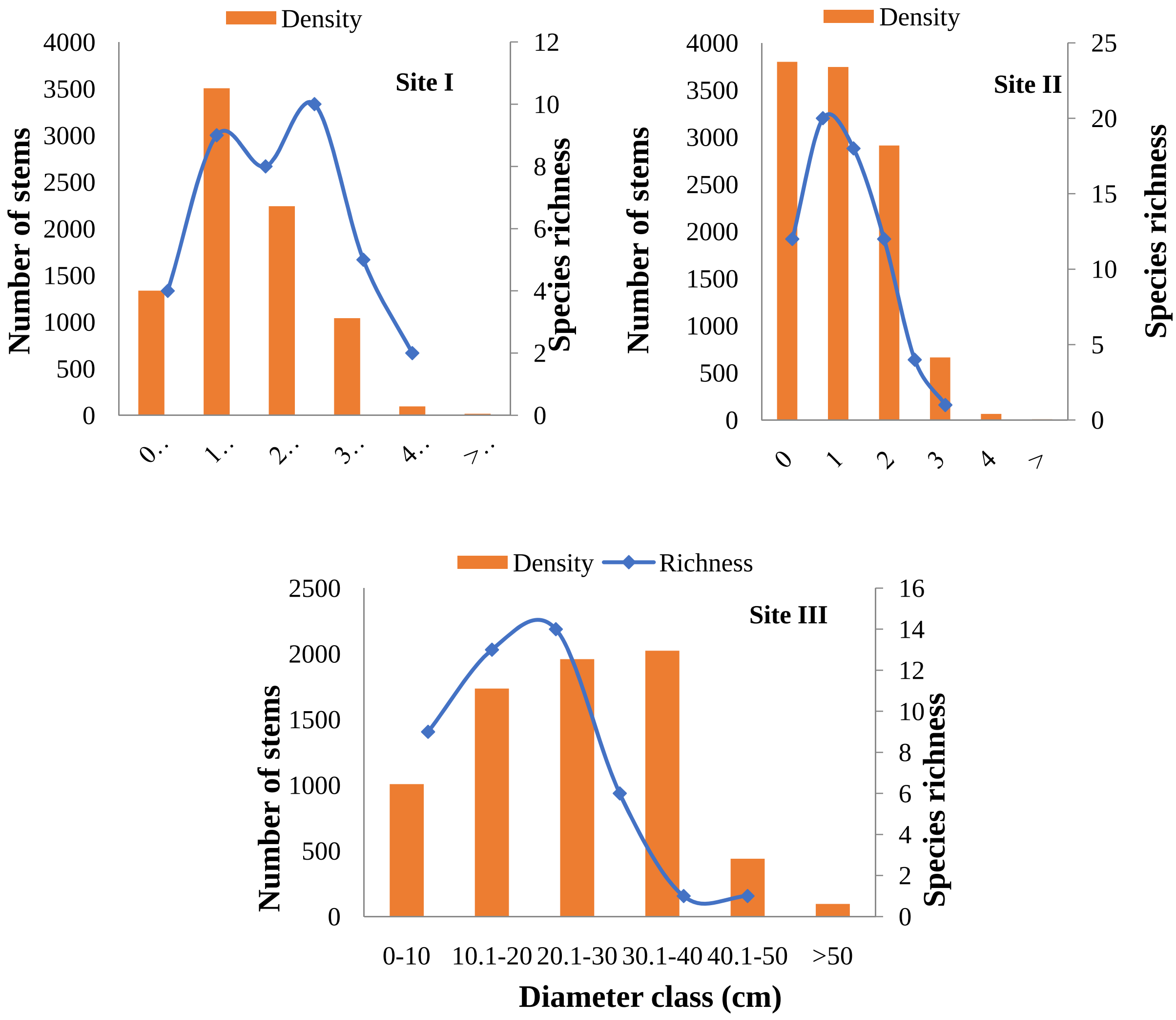

Fig. 3 Diameter class distribution of stems and species richness in the three study sites.

4 Discussion

Tropical dry forests occupy around 42% of the world's total forested area in the tropics (Galicia et al., 2008) and the species richness of the tropical dry forest is usually lower than that of the tropical moist forest (Mooney et al., 1995; Parthasarathy and Karthikeyan, 1997). However, the occurrence of various rare and endemic species (Ceballos, 1995; Lott and Atkinson, 2002) in a tropical dry forest ecosystem makes it unique. The woody species diversity is the main component because they form the key structural components of a forest ecosystem. According to Holdridge (1967), the species richness may become doubled when dry forests are compared with moist forests. The species richness recorded in the present study in Sagar district, central Madhya Pradesh, India was 14-23 species/2.75 ha (including both juvenile and adult trees) which is similar to several studies in India (20 species/ha, Parthasarathy and Karthikeyan, 1997; 18 species/ha, Parthasarathy and Sethi, 1997; 10 species/4 ha, 4-23 species/ha, Sagar and Singh, 2006; 19-38 species/ha, Yadav and Gupta, 2006; 16 species/ha, Davidar et al., 2007; 15 species/24 ha, Sundarapandian and Subbiah, 2015; 7 species/ha, Srinivas and Sundarapandian, 2017), and other countries (20 species/ha, Campbell et al., 1992; 27 species/3 ha, Addo-Fordjour et al., 2009; 17 species/ha, Leicht-Young et al., 2010; 29 species/8 ha, Bello et al., 2013; 25 species/ha, Martinez-Adriano et al., 2016). The value obtained in the present study is lower than that of other researchers' reports across the country (57 species /ha, Parthasarathy and Karthikeyan, 1997; 33 species/2 ha, Parthasarathy and Sethi, 1997; 63 species/50 ha, Condit et al., 2000; 49 species/15 ha, Sharma and Raghubanshi, 2006; 58 species/15 ha, Sahu et al., 2008; 50 species/ha, Kumar et al., 2011). The comparison of species richness of woody vegetation is very difficult because of the variations in size class, plot size and methodology adopted. Since the local people's settlements occur scattered inside the sampled forest sites, it was evident that the reserve forests of Sagar district are under serious anthropogenic pressures.

Tree diversity, as an ecosystem indicator, provides important information on structural integrity and stability of forest ecosystems. The GlobalTreeSearch database provides an overview of total recorded tree species in the entire terrestrial surface of the earth (Beech et al., 2017). According to Slik et al. (2015), the tropical tree species can vary anywhere between 40,000 to 53,000, thereby, total tree species in the tropical forest represent 66.6-88.2% of the total tree diversity. The tree species in the Indo-Malayan biome represented 21.7% (13,029 tree species) of world tree species documented (Beech et al., 2017) and 9.4% (5,672 tree species) of tree species in the Indo-Pacific region (Slik et al., 2015) which includes Indian tree species as well. Tree quantitative inventories across tropics comprise of a wide spectrum of species richness. The higher value of species richness obtained in study site II compared to study sites I and III may be attributed to sub-plot heterogeneity in terms of soil moisture and relatively lower disturbance (Gotore et al., 2021). The habitat type and its disturbances along with biogeography bring considerable variation in species composition (Mani and Parthasarathy, 2009; Joshi et al., 2022). Dominance-diversity curves are often used to depict the dominance of a particular species and indicate how their relative abundances compare across different communities (Whittaker, 1965; Grant and Loneragan, 2003). In this study, the dominance-diversity curve showed a decreasing correlation among tree species in the three study sites, indicating the high IVI of *Tectona grandis* and *Boswellia serrata* (Fig. 2).

Generally, species diversity shows a positive relationship with microclimate, soil moisture, nutrient availability and disturbance (Bhuyan et al., 2003; Hartshorn, 1983; Rao et al., 1990). The variation in tree species richness among the study sites as well as among the sub-plots in each site, and also among other dry forest ecosystems can be attributed to variations in altitude, geography, forest micro-climatic conditions, soil type, rainfall pattern (Gentry, 1992), successional stage (Coelho, 2012), levels and types of human-originated disturbances like grazing, fires, etc. (Chaturvedi et al., 2017; Chaturvedi and Raghubanshi, 2014; Gandhi and Sundarapandian, 2014; Singh and Chaturvedi, 2018). The increase in species diversity in a forest community increases the stability of that particular community (Gentry, 1992). This also shows the ability of the species in the community to adapt and evolve against the various stresses faced by the ecosystem (Knight, 1975).

The mean stand density of adult trees enumerated in the three study sites (494 stems/ha, 529 stems/ha and 448 stems/ha in study sites I, II and III respectively) were within the range reported from various other Indian tropical forests (280-1130 stems/ha, Visalakshi, 1995; 482 stems/ha, Davidar et al., 2007; 220-620 stems/ha, Pitchairamu et al., 2008). The adult tree density reported in the study sites was also in coherence with the range (245-859 stems/ha) reported by Ashton (1964) and Campbell (1992). Study site II has the highest tree density, yet mainly comprised of low diameter-class individuals which resulted in it having the lowest basal area. On the other hand, site III has the lowest tree density comprised of a high number of large diameter-class trees that led to it having the highest basal area among the three study sites. However, variation in adult tree density among the plots in all the three study sites waa also observed. These variations may be attributed to the differences in the altitude, soil composition, species composition and level of anthropogenic disturbance among the plots as observed by Goodale et al. (2002), Fang et al. (2006), and Chaturvedi and Raghubanshi (2013). Even though the study sites are under state-managed reserve forest area, illegal cutting, collection of firewood and other NTFPs and grazing are quite common. However, the intensity of human activity was relatively high in the study site III as it is located adjacent to a nearby village, and study site II, which is situated alongside the road, although away from human settlements. Also, recurrence of annual/seasonal man-made ground fires is a common phenomenon in all the three study sites. The natural disturbances like wildfires, herbivore outbreaks, etc. along with multiple other anthropogenic pressures in the studied forest ecosystem can bring drastic changes in the forest composition in terms of both density and species richness as suggested by several researchers (Gandhi and Sundarapandian, 2014; Hughes, 2017; Sagar et al., 2003; Sundarapandian and Swamy, 2000).

The average tree basal area (mean 23.5 m^2/ha; range 20.4-29.5 m^2/ha) of the three studied sites are well within the range reported by researchers across the country from other tropical forests (3.84-104 m^2/ha, Singh and Singh, 1991; 11.1-36.9 m^2/ha, Visalakshi, 1995; 26-53.9 m^2/ha, Pitchairamu et al., 2008). The study site III has the largest basal area among the three sites. In study site II, basal area was less even though the density was the highest which could be attributed to a greater number of low diameter-class tree individuals. On the other hand, the highest basal area in the study site III can be due to the presence of many tree individuals of large diameter-class. The variation in basal area of adult trees in the three study sites might be regulated by several factors such as species composition, growth patterns of trees, intensity of disturbances, altitude, edaphic factors and microclimatic conditions as reported by Hughes (2017), Naveenkumar et al. (2017), Poorter et al. (2015) and Sundarapandian and Swamy (2000).

The present study points to an immediate need for biodiversity conservation in the dry tropical forests of central India. There is an urgent need to restrict grazing and ground fires in these forests. There is also a need for better security and regulatory steps. It has been reported that dry forests have the ability to recover more easily to a mature state than wet forests do and are thus more resilient (Ewel, 1977; Murphy and Lugo, 1986). Seeding and planting of field-collected or nursery-raised seedlings of desired native species via aggressive forestry can enrich the existing vegetation at various sites enhancing the dry forest ecosystem’s resilience to various anthropogenic pressures.

5 Conclusion

The current study would be helpful in understanding the diversity patterns, stand structural attributes and species composition in tropical dry deciduous forests of Madhya Pradesh Central India for better forest management and conservation approaches.

Acknowledgement

We are thankful to the Madhya Pradesh State Forest Department for permission and providing the necessary facilities and staff support during the field work. This study was supported by Science and Engineering Research Board (SERB), Department of Science and Technology, New Delhi under Startup Research Grant (Ref. No.: SRG/2022/002286) to the corresponding author and SERB NPDF (PDF/2021/003742).

References

Addo-Fordjour et al. 2009. Liana species richness, abundance and relationship with trees in the Bobiri forest reserve, Ghana: impact of management systems. Forest Ecology and Management, 257(8): 1822-1828

Ashton PS. 1964. A quantitative phytosociological technique applied to tropical mixed rain forest vegetation. Malayan Forester, 27: 304-317

Beech et al. 2017. GlobalTreeSearch: The first complete global database of tree species and country distributions. Journal of Sustainable Forestry, 36(5): 454-489

Bello et al. 2013. Tree species diversity analysis of Kogo forest reserve in North-Western Nigeria. International Journal of Plant, Animal and Environmental Sciences, 3(3): 189-196

Bhuyan et al. 2003. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in Arunachal Pradesh, Eastern Himalayas, India. Biodiversity & Conservation, 12(8): 1753-1773

Campbell et al. 1992. A comparison of the phytosociology and dynamics of three floodplain (Várzea) forests of known ages, Rio Juruá, western Brazilian Amazon. Botanical Journal of the Linnean Society, 108(3): 213-237

Campbell et al. 1992. A comparison of the phytosociology and dynamics of three floodplain (Várzea) forests of known ages, Rio Juruá, western Brazilian Amazon. Botanical Journal of the Linnean Society, 108(3): 213-237

Ceballos G, García A. 1995. Conserving neotropical biodiversity: the role of dry forests in western Mexico. Conservation Biology, 9(6): 1349-1353

Champion HG, Seth SK. 1968. A Revised Survey of The Forest Types of India. Manager of publications. India

Chaturvedi et al. 2017. Sapling harvest: A predominant factor affecting future composition of tropical dry forests. Forest Ecology and Management, 384: 221-235

Chaturvedi RK, Raghubanshi AS. 2013. Aboveground biomass estimation of small diameter woody species of tropical dry forest. New Forests, 44(4): 509-519

Chaturvedi RK, Raghubanshi AS. 2014. Species composition, distribution, and diversity of woody species in a tropical dry forest of India. Journal of sustainable forestry, 33(8): 729-756

Coelho et al. 2012. Floristic composition and structure of a tropical dry forest at different successional stages in the Espinhaco Mountains, Southeastern Brazil. Interciencia, 37(3): 190-196

Condit et al. 2000. Spatial patterns in the distribution of tropical tree species. Science, 288(5470): 1414-1418

Curtis JT, McIntosh RP. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology, 32(3): 476-496

Davidar et al. 2007. The effect of climatic gradients, topographic variation and species traits on the beta diversity of rain forest trees. Global Ecology and Biogeography, 16(4): 510-518

Ewel JJ. 1977. Differences between wet and dry successional tropical ecosystem. Geo-Eco-Trop, 1: 103–117

Fang et al. 2006. Overestimated biomass carbon pools of the northern mid-and high latitude forests. Climatic Change, 74(1-3): 355-368

Galicia et al. 2008. Land use/cover, landforms and fragmentation patterns in a tropical dry forest in the southern Pacific region of Mexico. Singapore Journal of Tropical Geography, 29(2): 137-154

Gandhi DS, Sundarapandian S. 2014. Inventory of trees in tropical dry deciduous forests of Tiruvannamalai district, Tamil Nadu, India. Biodiversitas Journal of Biological Diversity, 15(2)

Gandhi DS, Sundarapandian S. 2017. Large-scale carbon stock assessment of woody vegetation in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats, India. Environmental Monitoring and Assessment, 189(4): 187

Gentry AH. 1992. Tropical forest biodiversity: distributional patterns and their conservational significance. Oikos, 19-28

Goodale et al. 2002. Forest carbon sinks in the Northern Hemisphere. Ecological Applications, 12(3): 891-899

Gotore et al. 2021. Woody plant assemblage and the structure of miombo woodland along a disturbance gradient in Hurungwe, Zambezi Valley, Zimbabwe. Journal of Forestry Research, 32: 1867-1877

Grant CD, Loneragan WA. 2003. Using dominance-diversity curves to assess completion criteria after Bauxite Mining rehabilitation in Western Australia. Restoration Ecology, 11(3): 103-109

Hartshorn GS. 1983. Plants. In: Costa Rican Natural History (Janzen DH, ed). 136-141, University of Chicago Press, Chicago, USA

Holdridge LR. 1967. Life Zone Ecology. Tropical Science Center, San Jose, Costa Rica

Hughes AC. 2017. Understanding the drivers of Southeast Asian biodiversity loss. Ecosphere, 8(1): e01624

Joshi et al. 2022. Species richness, diversity, structure, and distribution patterns across dominating forest communities of low and mid-hills in the Central Himalaya. Geology, Ecology, and Landscapes, 1-11

Kershaw KA. 1964. Quantitative and Dynamic Ecology. Elsevier, New York, USA

Knight DH. 1975. A phytosociological analysis of species - rich tropical forest on Barro Colorado Island, Panama. Ecological monographs, 45(3): 259-284

Kumar et al. 2011. Forest structure, diversity and soil properties in a dry tropical forest in Rajasthan, Western India. Annals for Forest Research, 54(1): 89-98

Kumar et al. 2022. Spatial pattern of tree diversity and impacts of ecological disturbances on forest structure in tropical deciduous forests of Central India. Biotropica, 54: 1363-1375

Lamb et al. 2005. Restoration of degraded tropical forest landscapes. Science, 310(5754): 1628-1632.

Leicht-Young et al. 2010. Liana habitat and host preferences in northern temperate forests. Forest Ecology and Management, 260(9): 1467-1477.

Loalila NJ, Shirima DD, Mauya EW. 2023. Tree species composition along environmental and disturbance gradients in tropical sub-montane forests, Tanzania. PLoS ONE 18(3): e0282528

Lott EJ, Atkinson TH. 2002. Biodiversidad y fitogeografía de Chamela-Cuixmala, Jalisco. Historia natural de Chamela, 83-97

Mani S, Parthasarathy N. 2009. Tree-population and above-ground biomass changes in two disturbed tropical dry evergreen forests of peninsular India. Tropical Ecology. 50(2): 249-258

Martinez-Adriano et al. 2016. Floristic survey of flowering plants in a tropical coastal ecosystem in Veracruz, Mexico. Botanical Sciences, 94(1): 185-197

Misra R. 1968. Ecology WorkBook. Oxford and IBH Publishing Company, Calcutta, India

Mooney et al. 1995. Diversity and Floristic Composition of Neotropical Dry Forests Seasonally Dry Tropical Forests (No. 581.5264 S439). Cambridge University Press, USA

Mueller-Dombois E, Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. John Wiley & Sons, New York, USA

Murphy PG, Lugo AE. 1986. Structure and biomass of a subtropical dry forest in Puerto Rico. Biotropica, 18: 89-96

Muthumperumal C, Parthasarathy N. 2010. A large-scale inventory of liana diversity in tropical forests of South Eastern Ghats, India. Systematics and Biodiversity, 8(2): 289-300

Naveenkumar et al. 2017. Biomass and carbon stocks of a tropical dry forest of the Javadi Hills, Eastern Ghats, India. Carbon Management, 8(5-6): 351-361

Parthasarathy N, Karthikeyan R. 1997. Biodiversity and population density of woody species in a tropical evergreen forest in Courtallum reserve forest, Western Ghats, India. Tropical Ecology, 38

Parthasarathy N, Sethi P. 1997. Trees and liana species diversity and population structure in a tropical dry evergreen forest in south India. Tropical Ecology, 38

Phillips et al. 2003. Efficient plot-based floristic assessment of tropical forests. Journal of Tropical Ecology, 629-645

Pitchairamu et al. 2008. Floristic inventory and quantitative vegetation analysis of tropical dry deciduous forest in piranmalai forest, Eastern Ghats, Tamil Nadu, India. Ethnobotanical Leaflets, 2008(1): 25

Poorter et al. 2015. Diversity enhances carbon storage in tropical forests. Global Ecology and Biogeography, 24(11): 1314-1328

Pragasan LA, Parthasarathy N. 2010. Landscape-level tree diversity assessment in tropical forests of southern Eastern Ghats, India. Flora-Morphology, Distribution, Functional Ecology of Plants, 205(11): 728-737

Rao et al. 1990. Community composition and tree population structure in a sub-tropical broad-leaved forest along a disturbance gradient. Vegetatio, 88(2): 151-162

Rennolls K, Laumonier Y. 2000. Species diversity structure analysis at two sites in the tropical rain forest of Sumatra. Journal of Tropical Ecology, 253-270

Sagar et al. 2003. Tree species composition, dispersion and diversity along a disturbance gradient in a dry tropical forest region of India. Forest Ecology and Management, 186(1-3): 61-71

Sagar R, Singh JS. 2004. Local plant species depletion in a tropical dry deciduous forest of northern India. Environmental Conservation, 55-62

Sagar R, Singh JS. 2005. Structure, diversity, and regeneration of tropical dry deciduous forest of northern India. Biodiversity & Conservation, 14(4): 935-959

Sagar R, Singh JS. 2006. Tree density, basal area and species diversity in a disturbed dry tropical forest of northern India: implications for conservation. Environmental Conservation, 256-262

Sahu et al. 2008. Tropical forest structure and diversity in relation to altitude and disturbance in a Biosphere Reserve in central India. Applied Vegetation Science, 11(4): 461-470

Sharma A, Patel SK, Singh GS. 2023. Variation in species composition, structural diversity, and regeneration along disturbances in tropical dry forest of Northern India. Journal of Asia-Pacific Biodiversity, 16(1): 83-95

Sharma GP, Raghubanshi AS. 2006. Tree population structure, regeneration and expected future composition at different levels of *Lantana camara* L. invasion in the Vindhyan tropical dry deciduous forest of India. Lyonia, 11(1): 27-39

Singh JS, Chaturvedi RK. 2018. Tropical dry deciduous forest: Research trends and emerging features. Springer

Singh JS, Chaturvedi RK. 2018. Tropical dry deciduous forest: Research trends and emerging features. Springer

Singh VP, Singh JS. 1989. Man and forests: a case-study from the dry tropics of India. Environmental Conservation, 16(2): 129-136

Slik et al. 2015. An estimate of the number of tropical tree species. The Proceedings of the National Academy of Sciences, 112(24): 7472-7477

Srinivas K, Sundarapandian SM. 2017. Diversity and composition of plants in tropical dry forests of northern Andhra Pradesh, India. International Research Journal of Natural and Applied Sciences, 4: 34-47

Subashree K, Dar JA, Karuppusamy S, Sundarapandian S. 2020. Plant diversity, structure and regeneration potential in tropical forests of Western Ghats, India, Acta Ecologica Sinica, 41(4): 259-284

Sundarapandian SM, Subbiah S. 2015. Diversity and tree population structure of tropical dry evergreen forests in Sivagangai district of Tamil Nadu, India. Tropical Plant Research, 2(1): 36-46

Sundarapandian SM, Swamy PS. 2000. Forest ecosystem structure and composition along an altitudinal gradient in the Western Ghats, South India. Journal of Tropical Forest Science, 104-123

Tamilselvan B, Sekar T, Anbarashan M. 2021. Tree diversity, stand structure and community composition of tropical forest in eastern Ghats of Tamil Nadu, India. The Indian Forester, 147(5): 481-489

Thakur M, Tilman D, Purschke O, Ciobanu M, Cowles J, Isbell F, Wragg P, Eisenhauer N. 2017. Climate warming promotes species diversity, but with greater taxonomic redundancy, in complex environments. Science Advances, 3: e1700866

Thakur S, Negi VS, Dhyani R, Bhatt ID, Yadava AK. 2022. Influence of environmental factors on tree species diversity and composition in the Indian western Himalaya. Forest Ecology and Management, 503: 119746

Visalakshi N. 1995. Vegetation analysis of two tropical dry evergreen forests in southern India. Tropical Ecology, 36(1): 117-127

Whittaker RH. 1965. Dominance and diversity in land plant communities. Science, 147: 250-260

WorldClim - Global Climate Data: https://www.worldclim.com/bioclim

Yadav AS, Gupta SK. 2006. Effect of micro-environment and human disturbance on the diversity of woody species in the Sariska Tiger Project in India. Forest Ecology and Management, 225(1-3): 178-189