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Tree Diversity in the Shola Forests of Brahmagiri Wildlife Sanctuary, Karnataka, India

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Abstract

Tree species composition and structure of the shola forest ecosystem were studied through 25 random quadrats of size 20 m × 20 m across the Brahmagiri Wildlife Sanctuary, Karnataka, India. Sixty-five tree species (47 genera and 35 families) were enumerated with a stand density of 1507 (≥1 cm DBH) trees in 1 ha area. The Shannon's, Simpson and Fisher's alpha diversity indices were 3.654, 0.960 and 15.471 respectively for the area studied. The basal area of trees inventoried was 31.19 m^2 ha^{-1}. Seventeen species were endemic (26%) to the Western Ghats. *Symplocos cochinchinensis* showed dominance in terms of density, followed by *Celtis philippensis, Elaeocarpus serratus, Ligustrum robustum,* and *Cinnamomum malabatrum*. Lauraceae was identified as the most speciose family with a total of 11 species, followed by Rubiaceae (6 species). The lower diameter class (≤10cm DBH) individuals were having higher proportion (67% (1007 individuals)) than that of the adult class (500 individuals) which indicated that the forest shows a good regeneration potential. However, few species including two endemic species have poor regeneration status. This enlightens that a thorough understanding of those species' regeneration potential is warranted in order to carry out proper management plans and conservation.

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Introduction

The Western Ghats are classified as one of the eight hottest hotspots globally and are famous for their unique habitats and forest types along with their endemic biological diversity. It has faced great anthropogenic pressure in recent years owing to deforestation and degradation.[1] From river Tapti in the north, to Kanyakumari in the south, these hill ranges run the length of India's west coast. Despite occupying an area of 180,000 km^2 and

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making up 6% of India's total land area, the home to over 30% of the country's plant, herpeto-fauna, mammal, fish, and bird species. The southern Western Ghats cover an area of 7000 km², passing through the states of Tamil Nadu, Karnataka, Kerala and harbor an excellent endemic and endangered biodiversity. Most of the areas in these states are protected regions. The Western Ghats are home to a wide variety of systems, from tropical wet evergreen forests to grasslands with a tremendous variety of fauna and flora. They also comprise the distinctive shola forest ecosystem, which is made up of patches of evergreen forest scattered among montane grasslands. The Tropical Montane Forests or Shola forests are a peculiar kind of forest belonging to the Western Ghats, characterized by the presence of persistent cloud cover. The most distinguishing feature of the shola forests is "their ability to capture moisture by the condensation of cloud-borne moisture on the vegetation".[2]. The sholas are restricted to a meagre 0.14% of the Earth found between 30º N and 30º S latitudes.[2] The term 'Shola' is connected to the Tamil word 'Cholai', which is glorified in the ancient Tamil literature and culture, meaning 'grove'.

Shola forests can be found at elevations ranging from above 1500 meters to as low as 1050 meters. These habitats, which are small pockets of forest, are mostly found in valleys or depressions because there they experience the least amount of fog and mist and are surrounded by grasslands. They are found in the high-elevation hilly regions of the Southern Western Ghats. The shola trees never grow on the mountain tops. They are generally slow growing and need more time to establish themselves and are sensitive to climatic conditions. The shola trees generally show stunted growth and due to their low fire and frost tolerance, they cannot regenerate in open areas.[3] Most of the trees are clothed with epiphytes. The shola forest soils are the best at holding water than any other soil. The monsoon rains are absorbed by these forests, and the water that has been retained is slowly released throughout the year in the form of little streams that combine to produce bigger streams and rivers. Most of South India's major rivers, including the Tunga, Bhadra, Nethravathi at Gangamoola (Kudremukh National Park), Cauvery at Talakaveri (Talakaveri Wildlife Sanctuary), Kumaradhara at Pushpagiri Wildlife Sanctuary and Lakshmanthirtha at Brahmagiri Wildlife Sanctuary, originate in Sholas.

Due to their unusual level of isolation and climatic conditions, the Shola forests of the southern Western Ghats are acknowledged for their high endemism and floral and faunal species richness.[4,5] The Shola enjoys a misty and cloudy climate throughout the year. A narrow ecotone that also contains many other species divides the sholas from the nearby grasslands.[3] Although these woods are situated in relatively inaccessible places, they continue to experience anthropogenic pressure, which results in habitat degradation, loss of biodiversity, and biomass.[6] Like any other tropical forest system, the large-scale conversion of the forests for agricultural purposes[7] changes the land use pattern and leads to loss of biodiversity and invasion of alien species which make it significant for assessment and conservation. The shola grassland system harbors many fauna and flora of conservation status. The hydrological characteristics and biogeochemistry of these ecosystems are also critical. The human-induced climate change raises concern over the sustainability of these ecosystems and their endemic diversity. This signifies the need for the conservation and management of this forest area. Very few studies are available on the floristic and structural attributes of Western Ghats.[5,8,9,10,11,12,13,14,15] The range of shola forest ecosystems has been diminished in the last century mostly due to encroachment and utilization for plantation purposes or agricultural expansion.[9] Hence, it is important to carry out a floristic diversity study of shola ecosystems and their population structure as it could help in the conservation and management of shola forests of Western Ghats by understanding the species distribution patterns. As woody species are essential in determining the structural dynamics of a forest[16] and provide an insight into conservation plans,[17] the current study on the woody plant structure would enhance our knowledge on the stand structure diversity and species richness in the shola forest of Brahmagiri Wildlife Sanctuary, Karnataka, Western Ghats.

Materials and Methods

Study Area

Brahmagiri Wildlife Sanctuary (latitude 11°55' to 12° 19' and longitude 75° 44' to 76° 04') part of the Western Ghats, is named after the Brahmagiri

Hill which is the sanctuary's highest peak. The sanctuary covers 181.29 km² in total. In 1974, Brahmagiri Wildlife Sanctuary was declared as a Protected Area.

The Sanctuary is unique in its ecosystem, with a rich diversity of animals and plants in a lush green and undulating landscape, having an elevation varying from 65 to 1600 meters above mean sea level. It acts as a lone corridor for the passage of animals between the Southern and Northern Western Ghats, particularly connecting the Rajiv Gandhi National Park, Bandipur National Park, Wayanad and Aralam sanctuary, Pushpagiri Wildlife Sanctuary, and other nearby parks. Numerous endangered and rare species, including the Lion-tailed macaque, Malabar civet, Nilgiri martin, Slender loris, and Clawless otter, call it home. The river Laxmanthirtha, a significant tributary of the river Cauvery, originates in the sanctuary, while the river Barpole obtains a river status as it passes through it. The landscape is primarily undulating, with a few steeply to extremely steeply sloping valleys and hillocks. The deep loamy soil varies in depth from place to place, while the underlying rock is gneiss in origin. Here, the cold, dry, and wet seasons are noteworthy. By the middle of February, the cold season ends and the hot season begins. Mid-November to mid-January is the coldest time of the year. The rainy season lasts from June to September, whereas the dry season lasts from March to May. The Southwest Monsoon is primarily responsible for the rains received in the sanctuary. It occasionally experiences rainfall brought by the northeast monsoon. The mean yearly rainfall ranges from 2500 mm to 6000 mm.[18]

Tropical wet evergreen forests, semi-evergreen forests, shola forests, moist deciduous forests and grasslands are the principal types of forests found in the sanctuary. The shola forest species are mostly evergreen and range in size from dwarf trees on the edges, which can endure strong winds blowing over the hillocks, to huge trees in the centre. At least one small, perennial watercourse serves as a mini-reservoir in each of these Sholas. These forests are crucial for the environment, and each year, they face the threat of getting shrunken due to the wildfires that occur in these high-altitude grasslands.

Methods

Twenty-five plots, of size 20 m × 20 m each, were randomly laid across the site to analyze the tree structure of the shola forests in the sanctuary. The individuals enumerated were identified and classified into three categories, which are saplings (<3 cm DBH), juveniles (DBH 3-<10cm) and adults (≥10cm DBH). Data are processed and various diversity indices (Simpson index, Shannon Weiner Index, Fisher's alpha index) were computed by using the Vegan package in R.

Results

Species Richness

Sixty-five tree species from 47 genera and 35 families were documented from the tropical evergreen shola forests (1 ha) of Brahmagiri Wildlife Sanctuary, Karnataka, Western Ghats (Table 1). The Shannon-Wiener Index, Simpson and Fisher's alpha diversity indices were 3.654, 0.960 and 15.471 respectively for the area studied. These values indicate that the area shows high species diversity. Out of the 65 species identified,17 species were found endemic (26%) to the Western Ghats. Among those 17, four were endemic to Southern Western Ghats only. *Cinnamomum malabatrum* showed highest density among the endemic species, whereas *Elaeocarpus munronii, Litsea floribunda* and *Ixora notoniana* were the least. On the basis of the Hill numbers (q=0,1,2), the rarefaction and extrapolation curves are presented in figure 1. The curves for species richness (q=0) to attain asymptote requires more number of individual enumerations whereas the curves for the Shannon and Simpson diversity (q=1 and 2) leveled off indicating that the sampling of the present study is adequate because even the extrapolation values do not exceed (asymptote occur within the sampling size).

Tree Density, Composition and Occurrence

The present study in the shola forest covering 1 hectare (25 plots of 0.04 ha) yielded a total of 1507 stems. The density of the study site showed an extensive variation among the species ranging from 1 (5 species (*Elaeocarpus munronii, Ficus amplissima, Gordonia obtusa, Litsea floribunda and Sterculia guttata*)) to 183 stems for *Symplocos cochinchinensis*. *Symplocos cochinchinensis* is the most dominant in terms of density, followed

by *Celtis philippensis*, *Elaeocarpus serratus*, *Ligustrum robustum* and *Cinnamomum malabatrum.* However, the importance value index was highest for *Elaeocarpus serratus* (20.36) followed by *Ligustrum robustum* (19.37) and *Symplocos cochinchinensis* (19.36). Twelve species were considered as rare (≤ 2 individuals in total 25 plots) for the present study. The basal area of tree species enumerated from the site was 31.19 m^2 ha^{-1}. In terms of basal area, *Elaeocarpus serratus* was the most dominant species followed by *Dillenia bracteata* and *Ligustrum robustum.*

Table 1: List of woody plant species with their quantitative characteristics in the shola forest of the Brahmagiri Wildlife Sanctuary, Karnataka, India.

Species Name	Density (No./ ha)	Frequency	Basal area (m2/ha)	IVI
Actinodaphne bourdillonii Gamble	20	6	0.27	4.21
Actinodaphne tadulingamii Gamble	18	6	0.25	3.99
Ardisia elliptica Thunb.	7	2	0.03	1.20
Callicarpa tomentosa (L.) Murr.	25	8	0.23	5.04
Calophyllum austroindicum Kosterm. ex P.F.Stevens	21	6	1.36	8.21
Careya arborea Roxb.	23	3	0.47	4.19
Casearia rubescens Dalz.	30	8	0.10	4.91
Celtis philippensis wightii (Planch.) E. Soepadmo	96	18	1.00	15.78
Cinnamomum malabatrum (Burm. f.) Presl	74	12	0.92	12.11
Cinnamomum perrottetii Meisn.	15	2	0.07	1.92
Daphniphyllum neilgherrense (Wight) K.Rosenthal	17	5	0.18	3.37
Dillenia bracteata Wight	49	9	3.02	17.02
Dysoxylum binectariferum (Roxb.) Hook.f. ex Bedd.	22	5	0.42	4.56
Elaeocarpus munronii (Wl.) Masters	1	1	0.03	0.49
Elaeocarpus serratus L.	84	15	3.24	22.06
Euonymus crenulatus Wall. ex Wight & Arn.	28	4	0.41	4.64
Euonymus dichotomus Heyne ex Wall.	5	2	0.07	1.21
Euonymus indicus Heyne ex Roxb.	8	5	0.11	2.49
Fagraea ceylanica Thunb.	4	1	0.04	0.72
Ficus amplissima Sm.	1	1	0.48	2.09
Flacourtia montana J.Graham	7	3	0.02	1.48
Garcinia indica (Thouars) Choisy	6	3	0.19	2.03
Glochidion malabaricum (Müll.Arg.) Bedd.	28	6	0.25	4.67
Gordonia obtusa Wall. ex Wight & Arn.	1	1	0.21	1.15
Hydnocarpus alpina Wight	26	5	0.45	4.94
Hypericum mysurense Wight & Arn.	2	1	0.00	0.46
Ixora notoniana Wall. ex G.Don	3	3	0.05	1.33
Lepisanthes decifiens	17	8	0.09	4.00
Ligustrum perottetti var. obovatum	24	4	0.21	3.64
Ligustrum robustum (Roxb.) Blume	75	16	3.02	20.97
Litsea deccanensis Gamble	3	1	0.06	0.73
Litsea floribunda (Bl.) Gamble	1	1	0.03	0.49
Litsea glabrata (Wall. ex Nees) Hook. fil.	10	3	0.08	1.91
Litsea insignis (Blume) Boerl.	9	3	0.10	1.92
Litsea wightiana (Nees) Benth. & Hook. fil.	6	3	0.36	2.66
Macaranga peltata (Roxb.) Müll.Arg.	33	10	1.07	9.23
Mallotus philippensis (Lam.) Müll.Arg.	4	2	0.08	1.19

Melicope lunu-ankenda (Gaertn.) T.G. Hartley	16	5	0.07	2.90
Meliosma simplicifolia (Roxb.) Walp. ssp. simplicifolia	9	1	0.47	2.61
Memecylon malabaricum Cogn.	12	5	0.28	3.40
Memecylon sp.	2	1	0.00	0.46
Microtropis wallichiana Wight ex Thwaites	12	5	0.11	2.79
Murraya paniculata (L.) Jack	13	3	0.11	2.22
Neolitsea cassia (L.) Kosterm.	32	6	0.50	5.88
Neolitsea zeylanica (Nees & T. Nees) Merr.	59	7	0.19	6.90
Nothapodytes nimmoniana (J.Graham) Mabb.	21	8	1.37	8.84
Phoenix humilis (L.) Cav.	6	2	0.05	1.20
Phyllanthus emblica L.	3	1	0.00	0.52
Psychotria dalzellii Hook.f.	32	5	0.08	4.04
Psydrax dicoccos Gaertn.	44	8	0.25	6.42
Schefflera wallichiana (Wight & Arn.) Harms	2	1	0.01	0.47
Sterculia guttata Roxb.	1	1	0.08	0.66
Symplocos cochinchinensis (Lour.) S.Moore	183	14	0.97	20.39
Symplocos macrocarpa macrocarpa	9	4	0.05	2.04
Symplocos macrophylla (Beddome) Nooteboom	33	9	2.05	12.44
Symplocos monantha Wight	27	10	0.22	5.76
Symplocos sp.	19	5	0.11	3.24
Syzygium montanum Gamble	5	3	0.44	2.85
Syzygium munronii (Wt.) Chandrab.	6	3	0.02	1.40
Toona ciliata M. Roem.	6	4	0.23	2.47
Tricalysia apiocarpa (Dalzell ex Hook.f.) Gamble	5	3	0.09	1.60
Tricalysia sphaerocarpa (Dalzell ex Hook.f.) Gamble	3	3	0.07	1.38
Vernonia arborea Buch.-Ham.	20	4	0.56	4.64
Viburnum cylindricum Buch.	2	2	0.00	0.77
Wendlandia thyrsoidea (Roth) Steud.	73	6	0.51	8.70

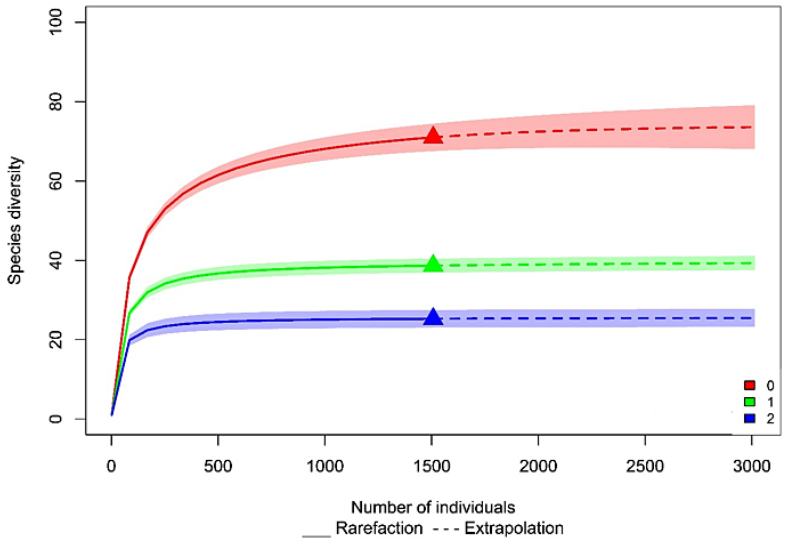

Fig. 1: The rarefaction-extrapolation curves of the tree community in the Brahmagiri Wildlife Sanctuary. The solid lines represent the rarefaction (interpolation) and the dashed lines represent the extrapolation curves (0 - species richness; 1- Shannon's index; 2- Simpson Index).

Distribution Pattern

The abundance to frequency analysis indicated that all the recorded species in the area showed contagious distribution patterns. Not one species was common among the 25 study plots. *Celtis philippensis* was distributed in more sampling units (18 study plots) followed by *Ligustrum robustum* (16 plots), *Elaeocarpus serratus* (15 plots), *Symplocos cochinchinensis* (14 plots), and *Cinnamomum malabatrum* (12 plots). However, 13 species were present in only one plot and 8 species occurred only in two plots.

Table 2: Family contribution in the shola forest ecosystems at Brahmagiri Wildlife Sanctuary, Karnataka, India.

Family	Genus	Species
Achariaceae	1	1
Araliaceae	1	1
Arecaceae	1	1
Asteraceae	1	1
Calophyllaceae	1	1
Cannabaceae	1	1
Celastraceae	2	4
Clusiaceae	1	1
Daphniphyllaceae	1	1
Dilleniaceae	1	1
Elaeocarpaceae	1	2
Euphorbiaceae	2	2
Flacourtiaceae	1	1
Gentianaceae	1	1
Hypericaceae	1	1
Icacinaceae	1	1
Lamiaceae	1	1
Lauraceae	4	11
Lecythidaceae	1	1
Malvaceae	1	1
Melastomataceae	1	2
Meliaceae	2	2
Moraceae	1	1
Myrtaceae	1	2
Oleaceae	1	2
Phyllanthaceae	2	2
Primulaceae	1	1
Rubiaceae	5	6
Rutaceae	2	2
Sabiaceae	1	1
Salicaceae	1	1
Sapindaceae	1	1
Symplocaceae	1	5
Theaceae	1	1
Viburnaceae	1	1

Family Composition

Out of 35 families, 23 families were represented by singletons and taxonomically, the most speciose family is Lauraceae with a total of 11 species, followed by Rubiaceae (6 species), Symplocaceae (5 species) and Celastraceae (4 species; Table 2). Symplocaceae was the most dominant family with regard to abundance followed by Cannabaceae, Elaeocarpaceae, Oleaceae and Lauraceae, while in terms of basal area, Elaeocarpaceae was dominated.

Stand Structure

The diameter class-wise distribution of trees exposed that 67% of the forest stand has the lower diameter class (0 cm -10 cm DBH) individuals and with an increase in the diameter class, the number of individuals declined (Fig 2). The stand structure of the tree population revealed that the juveniles (637) were comparatively higher in number than adults (500) and saplings (370). In addition, diameter class-wise analysis indicated that the highest level of species richness was exhibited by the adult tree population. The diameter class-wise distribution of the top five abundant species is presented in the figure 3. Among the top five species, *Symplocos cochinchinensis* and *Elaeocarpus serratus* have more juvenile population than that of saplings and adults whereas the adult population was highest in *Cinnamomum malabatrum* and *Ligustrum robustum*. *Symplocos cochinchinensis* positioned in first among the top five, whose adult population diameter did not exceed the 20 cm DBH. In contrast, among the 5 top species, *Elaeocarpus serratus* and *Ligustrum robustum* species alone represented the large diameter class (≥60 cm DBH) individuals. Among the adult population of all the top species, abundance decreases with an increase in the diameter class.

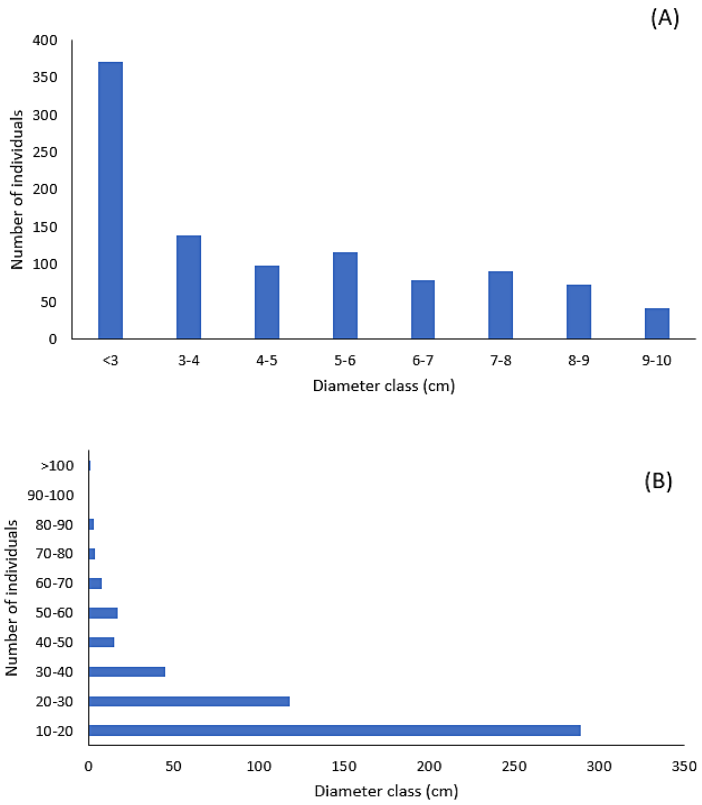

Fig. 2: Diameter class-wise distribution of tree species ((A) <10 cm DBH stems and (B) >10 cm DBH stems in Brahmagiri Wildlife Sanctuary, India.

Regeneration Status of Tree Species

Among the identified species, 41 species showed all three stages of development, i.e., sapling stage, juveniles and adults (Table 3). In total, 500 adult (≥10 cm DBH) stems were enumerated from the present study followed by 637 juveniles (≥3 cm - <10 cm DBH) and 370 saplings (<3 cm DBH). Five species have no adult population (*Hypericum mysurense*, *Memecylon* sp., *Phyllanthus emblica*, *Schefflera wallichiana* and *Viburnum cylindricum*) whereas their sapling and juvenile population was found. On contrary, for nine species, the adult population was only obtained without juveniles or saplings which indicates that those species have poor regeneration potential in the study area. Only one species (*Phyllanthus emblica*) had only saplings recorded without any juvenile or adult population. However, the *Phyllanthus emblica* was documented from the plot which is located towards the periphery region of the study area. Two species had no juvenile population but the sapling stage and adults were there.

Table 3: Diameter classwise distribution of the woody plant species community in the Brahmagiri wildlife Sanctuary, Karnataka, India.

Species Name	Saplings	Juveniles	Adults
Actinodaphne bourdillonii Gamble	6	7	7
Actinodaphne tadulingamii Gamble	9	6	3
Ardisia elliptica Thunb.	4	2	1
Callicarpa tomentosa (L.) Murr.	7	13	5
Calophyllum austroindicum Kosterm. ex P.F.Stevens	1	7	13
Careya arborea Roxb.	4	10	9
Casearia rubescens Dalz.	12	14	4
Celtis philippensis wightii (Planch.) E. Soepadmo	33	33	30
Cinnamomum malabatrum (Burm. f.) Presl	19	25	30
Cinnamomum perrottetii Meisn.	-	14	1
Daphniphyllum neilgherrense (Wight) K.Rosenthal	6	6	5
Dillenia bracteata Wight	13	11	25
Dysoxylum binectariferum (Roxb.) Hook.f. ex Bedd.	5	10	7
Elaeocarpus munronii (Wl.) Masters	-	-	1
Elaeocarpus serratus L.	17	34	33
Euonymus crenulatus Wall. ex Wight & Arn.	4	15	9
Euonymus dichotomus Heyne ex Wall.	1	1	3
Euonymus indicus Heyne ex Roxb.	1	2	5
Fagraea ceylanica Thunb.	-	3	1
Ficus amplissima Sm.	-	-	1
Flacourtia montana J.Graham	6	-	1
Garcinia indica (Thouars) Choisy	-	1	5
Glochidion malabaricum (Müll.Arg.) Bedd.	11	10	7
Gordonia obtusa Wall. ex Wight & Arn.	-	-	1
Hydnocarpus alpina Wight	11	3	12
Hypericum mysurense Wight & Arn.	-	2	-
Ixora notoniana Wall. ex G.Don	-	1	2
Lepisanthes decifiens (Wight & Arn.) Radlk.	1	12	4
Ligustrum perottetti var. obovatum (C.B.Clarke) Gamble	14	3	7
Ligustrum robustum (Roxb.) Blume	9	23	43
Litsea deccanensis Gamble	-	1	2
Litsea floribunda (Bl.) Gamble	-	-	1
Litsea glabrata (Wall. ex Nees) Hook. fil.	-	6	4

Litsea insignis (Blume) Boerl.	2	2	5
Litsea wightiana (Nees) Benth. & Hook. fil.	-	4	2
Macaranga peltata (Roxb.) Müll.Arg.	10	3	20
Mallotus philippensis (Lam.) Müll.Arg.	-	-	4
Melicope lunu-ankenda (Gaertn.) T.G. Hartley	1	13	2
Meliosma simplicifolia (Roxb.) Walp. ssp. simplicifolia	3	1	5
Memecylon malabaricum Cogn.	2	6	4
Memecylon sp.	1	1	-
Microtropis wallichiana Wight ex Thwaites	3	6	3
Murraya paniculata (L.) Jack	1	8	4
Neolitsea cassia (L.) Kosterm.	10	10	12
Neolitsea zeylanica (Nees & T. Nees) Merr.	35	18	6
Nothapodytes nimmoniana (J.Graham) Mabb.	3	8	10
Phoenix humilis (L.) Cav.	-	3	3
Phyllanthus emblica L.	3	-	-
Psychotria dalzellii Hook.f.	19	11	2
Psydrax dicoccos Gaertn.	1	39	4
Schefflera wallichiana (Wight & Arn.) Harms	-	2	-
Sterculia guttata Roxb.	-	-	1
Symplocos cochinchinensis (Lour.) S.Moore	41	112	30
Symplocos macrocarpa macrocarpa	1	5	3
Symplocos macrophylla (Beddome) Nooteboom	-	5	28
Symplocos monantha Wight	5	17	5
Symplocos sp.	3	14	2
Syzygium montanum Gamble	-	-	5
Syzygium munronii (Wt.) Chandrab.	3	2	1
Toona ciliata M. Roem.	1	2	3
Tricalysia apiocarpa (Dalzell ex Hook.f.) Gamble	-	3	2
Tricalysia sphaerocarpa (Dalzell ex Hook.f.) Gamble	-	1	2
Vernonia arborea Buch.-Ham.	4	8	8
Viburnum cylindricum Buch.	1	1	-
Wendlandia thyrsoidea (Roth) Steud.	18	47	8

In the case of 17 endemic species, 10 species showed all three stages of development (adults, juveniles and saplings) while six species have no sapling population which indicates its poor regeneration potential in the study area. However, *Elaeocarpus munronii* and *Litsea floribunda* had an adult population alone in the study area which had no sapling and juvenile populations.

Discussion

The present woody plant diversity study in the tropical evergreen shola forest patches of Brahmagiri Wildlife Sanctuary, Karnataka was carried out to understand the structure and floristic composition of that forest. These forests belong to the category of montane evergreen shola forests. The study has recorded a total of 65 tree species (≤1cm DBH) from 1 ha, showing greater species richness compared to 61 species in 63.17 ha[15] and 54 species in 11.34 ha.[10] Similarly, the values obtained from the study are comparatively greater than that of those studies done in 1 ha areas of the upper montane ecosystem in Southern Brazil[19] (26 species ha^{-1}), secondary tropical evergreen forest in Cachar district of Assam[20] (52 species ha^{-1}), tropical wet evergreen forest in Nelliampathy hills, Kerala[21] (30 species ha^{-1}) and tropical wet evergreen forest in Karnataka[22] (28 -38 species ha^{-1}). The values (63 species ha^{-1}) obtained from the Thaishola of Nilgiri mountains[23] (2000 - 2200 masl) are close to the diversity values obtained from the present study. At the same time, the value is lower than that of the species diversity recorded from the montane shola forests of Kukkal, Palni hills[9] (83 species ha^{-1})

and Nilgiri Mountains, southern India[14] (97 species ha^{-1}). The variations in species diversity can be altered due to the differences in elevation[24] climatic, edaphic characteristics, rainfall patterns[25] and other environmental conditions.[26] Human interference and cattle grazing is almost nil in the present study site. The sanctuary area is well preserved, undisturbed and no encroachment reported in the vicinity of the sanctuary even though the area around is mostly utilized for coffee plantations. These could be the reasons for greater species richness in this area.

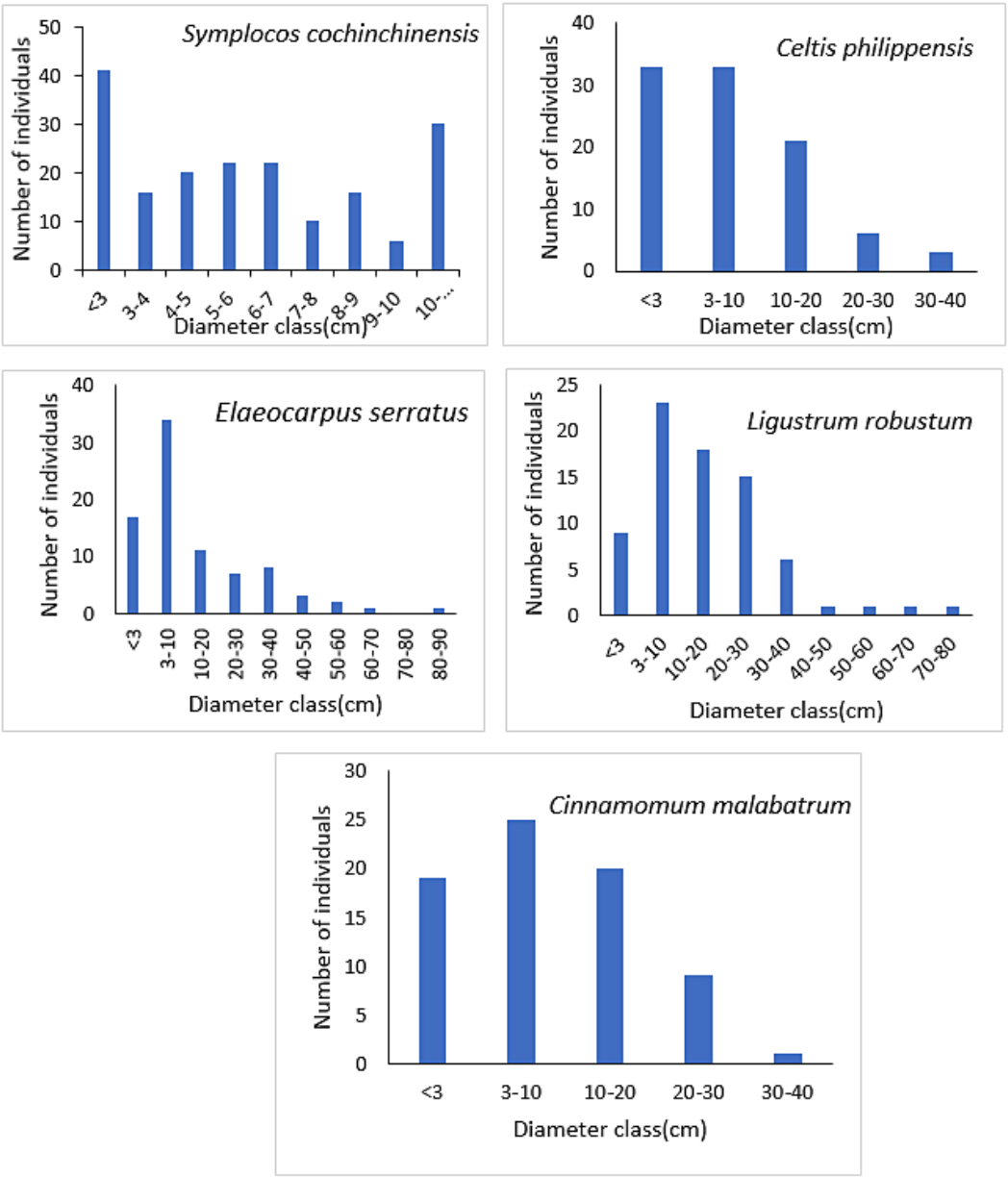

Fig. 3: Diameter class wise distribution of the dominant species in the Brahmagiri Wildlife Sanctuary, Karnataka, India.

The adult tree density (≥10 cm DBH) in the current study is lower compared to the values recorded from Southeast Belize[27] (937 individuals ha^{-1}), Southern Brazil[19] (1208 individuals ha^{-1})Brazilian Amazon[28] (1482 individuals ha^{-1}), Bolivian Amazon[29] (649 individuals ha^{-1}), Ecuadorian Amazon[30] (693 individuals ha^{-1}), Mare, Central Amazonia[31] (645 individuals ha^{-1}), Brazilian Amazon[32] (618-654 individuals ha^{-1}), East Usambara Mountains, Tanzania[33] (880 individuals ha^{-1}), Borneo[34] (602 individuals ha^{-1}), Cachar district, Assam[20] (2152 individuals ha^{-1}) Nagaland[35] (613 individuals ha^{-1}) and Nilgiri Mountains, southern India[14] (1224 individuals ha^{-1}). At the same time, the values are comparable with Monteverde Cloud Forest Reserve, Costa Rica[36] (555 individuals ha^{-1}), Venezuela[37] (355-563 individuals ha^{-1}), Central Africa[38] (425 individuals ha^{-1}) and Kukkal Forest, Palni hills[9] (451 individuals ha^{-1}). However, the current study showed greater density values when compared with Namdapha Tiger Reserve, Arunachal Pradesh[39] (328 individuals ha^{-1}). These variations in stem density might be attributed to elevation, composition of species and micro climatic conditions.[40]

The basal area of a species indicates how dominant it is in a stand.[41] The current study showed a basal area of 31.19 m^2 ha^{-1} which is much closer to the pantropical average[42] (32 m2 ha^{-1}). The basal area values from the Nilgiri Mountains, southern India[14] (53.33 m^2 ha^{-1}), Kukkal, Palni hills[9] (62 m^2 ha^{-1}), Kalakad, Western Ghats[43] (55 -94 m^2 ha^{-1}), Nelliampathy hills, Kerala[21] (61.9 m^2 ha^{-1}), Hollongapar Gibbon wildlife sanctuary, Assam[44] (58 m^2 ha^{-1}) and Southern Brazil, South America[17] (47.3 m^2 ha^{-1}) are all higher than the values obtained from the present study, as here the adult population (≤10 cm DBH) was lower than the juveniles which could be the reason for the lower basal area. Whereas, our values are comparable with several reports (31 m^2 ha^{-1})[31], (30.03 m^2 ha^{-1})[45], (29.6 m^2 ha^{-1})[38], (29 - 42 m^2 ha^{-1})[22]. However, some studies[28,29,19&46] reported lower values than the present study. Wide variations in the basal area across different regions would be attributed to structural variations in the forest. Only 16 large diameter (≥60 cm DBH) individuals were present which belongs to 8 species (*Ficus amplissima Sm*., *Dillenia bracteata*, *Ligustrum robustum*, *Symplocos macrophylla rosea*, *Elaeocarpus serratus* L., *Litsea wightiana*, *Calophyllum austroindicum*, *Nothapodytes nimmoniana*). Sholas would have a larger proportion of adult trees with high basal area but the present study area have fewer large diameter trees recorded, at the same time, a large number (1007) of small-diameter (≤10 cm DBH) trees are present in the study site. This variation in the abundance of different diameter classes could be the reason for the lower basal area compared to other shola forests.

The study resulted in a total density of 1507 individuals (≤1 cm DBH) in 1 ha area of which the lower diameter class (≤10cm) individuals are having higher proportion (67% (1007 individuals)) than that of the adult class (≥10 cm DBH) (500 individuals). Similarly, it is observed more juvenile population than adult population and stated that the presence of more lower diameter class individuals than the high diameter class can be perceived as an indication of a regenerating forest.[47] In the study,[41] out of 65 species (63%) showed all three growth phases (saplings, juveniles and adults). The difference in the population structure can be due to microclimatic variations, topographic and edaphic peculiarities[48] etc. Along with that, dominant adult trees species have also exhibited an adequate sapling and juvenile population too, thereby indicating that those species have a good regeneration potential.[49] Symplocacae family shows dominance in the juvenile population as they have exhibited a high regeneration potential in the present study area. The species that showed profuse regeneration (≤10 cm DBH) in the study site were *Symplocos cochinchinensis*, *Celtis philippensis*, Neolitsea zeylanica, Wendlandia thyrsoidea, *Elaeocarpus serratus* and *Cinnamomum malabatrum*. However,[8] species occur as adult stage only with no sapling or juvenile stage of development, of which 2 species (*Elaeocarpus munronii* and *Litsea floribunda*) are endemic to Western Ghats. These results indicate that attention is required in order to sustain the population of those species for the future. Understanding the regeneration potential of each species is needed for proper forest management and species conservation measures.[50] In particular, studies are required to recognize the reasons for the poor regeneration potential of those endemic species in the study area for conservation in the future. The poor regeneration capacity of those species can be attributed to their inability to tolerate extreme weather conditions, less seed supply, germination potential, light inavailability, soil nutrients and other

properties and the landscape nature.[40] In several species, the younger stage population was way higher than the adults, which is likely that the species composition and structure of these forests can be altered over time. Out of 18000 species of flowering plants documented from India, 30% belong to the Western Ghats.[51,52] The total number of endemic plant species in the Western Ghats was estimated as 1600[1] and 56% of the evergreen tree species are endemic. There were 17 species in this study that are endemic to the Western Ghats which identifies 26% of the total species (65) collected. The endemism level of the current study is comparable to the study of Davidar *et al*., 2007(30%). Among the identified species, three species were identified as those which grow in disturbed evergreen forests (*Callicarpa tomentosa, Ficus amplissima, Garcinia indica*) though there weren't any signs of disturbance noted from the sites of the sample collection, and these three species show poor regeneration potential as well (*only Callicarpa tomentosa* displays all three stages of development). Eleven species have been identified as those that are found along the margins of the hills and forests.

Conclusion

The present study exposes that the vegetation structure of the Brahmagiri wildlife sanctuary retains tree diversity comparable to the pantropical average. All the dominant species in this study site have better regeneration potential. However, few species including two endemic species have poor regeneration status. This enlighten that thorough understanding of the regeneration potential of those species is warranted in order to carry out proper management plans and conservation.

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Conflict of Interest

There is no conflict of interest.

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