Tropical Ecology
https://doi.org/10.1007/s42965-021-00169-y

International Society for Tropical Ecology

RESEARCH ARTICLE

# Patterns of woody species diversity and structure in Thalewood House permanent preservation plot in Bannerghatta National Park, Bangalore, India

Ritu Kakkar[1] · K. H. Vinaya Kumar[1] · O. K. Remadevi[1] · M. Manjunatha[1] · B. Saritha[1] · Balasubramanya Sharma[1] · M. Kiranraddi · H. S. Dattaraja[2] · H. S. Suresh[2]

Received: 23 September 2019 / Revised: 2 March 2021 / Accepted: 27 May 2021


**Abstract**
A permanent forest dynamics study plot was established in Bannerghatta National Park (BNP) to understand the impact of climatic variability on deciduous forest trees. A 1 ha (100 m × 100 m) Permanent Preservation Plot (PPP) was established following the Centre for Tropical Forest Science (CTFS) protocol. All the woody plants (trees, shrubs, climbers) greater than 1 cm diameter at breast height (dbh) were tagged and measured. A total of 1,586 individuals were identified, tagged and included trees, shrubs, and climbers belonging to 28 flowering plant families with *Olea dioica*, *Cipadessa baccifera* and *Ziziphus oenoplia* as the dominant species. The tagged 1,586 individuals included 68 species with the top 10 species accounting for 74% of total abundance. The most ubiquitous species were *Hiptage benghalensis* and *Ziziphus oenoplia* occupying 23 quadrats out of the total 25. *Terminalia arjuna* had the highest Importance Value Index (IVI) followed by *Olea dioica* and *Terminalia bellirica*. Combretaceae with three species had the highest Family Importance Value (FIV) followed by Euphorbiaceae, Oleaceae and Rhamnaceae. A large number of species showed random dispersion which is not significant. However, in species having aggregated dispersion, the dispersion pattern is significant ($P < 0.05$). The plot has a mild undulation with 40% of the quadrats occupied by the presence of stream that comes alive during the monsoon. Plot is being monitored for recruitment, mortality and growth to understand the effects of climate variability on trees.

**Keywords** Diversity · Floristics · Spatial distribution · Topography · Tropical deciduous forest

## Introduction

Tree diversity in tropical forests is fundamental to the biodiversity as they provide resources and habitats to several organisms in these forests (Cannon et al 1998). Trees are easy to count and their taxonomy is also fairly well known (Gentry 1992; Condit 1998). Understanding tree community in a forest is the first step in assessing the sustainability of the forest, designing conservation strategies and management of the forests. Globally 52% of the forests are in the tropical region and they harbour much of the biological diversity known to the humans (Miles et al 2006). The quantitative inventories of the forests would help managers of the natural resources to design appropriate strategies for management and conservation of the important biological resources. The central question even today in tropical forest ecology is about understanding the mechanisms that drive, maintain and structure the diversity (Condit et al. 1992; Ashton 1988; Bunyavejchewin 2003). Tropical dry ecosystems are one of the least studied in the world (Murphy and Lugo 1986). Dry ecosystems are characterized by dry seasons of various periods (Murphy and Lugo 1986), inter-annual variability in climate and regular or repeated annual dry season fires (Swaine 1992; Sukumar et al. 1992, 2005; Sathya and Jayakumar 2017). Dry forests are also subjected to modification by humans either for agriculture expansion or developmental activities (Murphy and Lugo 1995). Environmental stochasticity influences the maintenance of diversity in more stressed ecosystems such as dry

✉ O. K. Remadevi
okremadevi@gmail.com

1 Environmental Management and Policy Research Institute, "Hasiru Bhavana", Doresanipalya Forest Campus, Vinayaka Nagara Circle, J.P Nagar 5th Phase, Bangalore 560078, India

2 Center for Ecological Sciences, Indian Institute of Science, Divecha Centre for Climate Change, Bengalore 560012, India

Published online: 26 June 2021

forests (Sukumar et al. 1998; Chisholm et al. 2014). Hence it becomes imperative that systematic following up of plants in a defined area for a long-term is a must for a meaningful understanding of dry forests in the world.

Dry tropical forests are the most extensive vegetation types in tropics (Miles et al. 2006; Hayden and Greene 2008). Yet they are the least understood and researched communities in the world. However, efforts are being made to understand these communities (McShea et al. 2011). Dry forests form the largest vegetation type in India (Singh and Khushwaha 2005; Singh and Chaturvedi 2017). It is also suggested that the dry forests are affected by climate change (Chaturvedi et al. 2012). It is predicted that areas that have dry forests will undergo changes under each climatic scenario (Ravindranath et al. 2006). There is no long-term study on dry forests in India except by Sukumar et al. (1992). But there are attempts to describe the diversity of dry forests in India (e.g., Yadav and Yadav 2005; Kumar et al. 2010; Reddy et al. 2011; Mandal and Joshi 2014), and understand other aspects such as soil properties (Kumar et al. 2010), phenology (Prasad and Hegde 1986; Murali and Sukumar 1993; Nanda et al. 2010), mammalian assemblage (Karanth and Sunquist 1992) and prey-predator relationships (Venkatram et al. 1995). Of late there are initiatives to study dry forests on a long-term scale to look at the impacts and recovery of dry forests due to human activities and human-mediated climate change (Stan and Sanches-Azofeifa 2019).

In the earlier part of the nineteenth century Long Term Research Sites (LTRS) were established in India and these were named as Linear Tree Increment (LTI), Linear Increment Plot (LIP), Linear Sample Plots (LSP) and also as Permanent Preservation Plots (PPP) (Rai 1996). The main objective of the former three has been the species identification and girth measurements, whereas PPPs are research sites that were established to study the species diversity and dynamics in the plot.

Permanent Preservation Plots (PPPs) require a great deal of discipline and patience to analyse them yearly/bi-yearly over a period long enough to answer questions relevant to succession (Bakker 1996). They allow us not only to (a) understand and extrapolate available observations, (b) predict vegetation changes, and (c) test ecological models, but also help in conservation and environmental policy decisions. PPPs of 1-ha size have been established in Agumbe, Seethanadi, Talakaveri, Chakra (Udupa KES 2017) by the Karnataka Forest Department (KFD) in collaboration with Sri. Jagadguru Chandrashekara Bharathi Memorial (JCBM) College, the main long-term objective of the study being to quantify changes in forest biomass, relate current forest structure, ecophysiology, and dynamics to local climate and soil properties.

Bannerghatta National Park (BNP) forms part of the Eastern Ghats and is under immense pressure due to human-mediated activities. It is located 22 km south of the burgeoning city of Bangalore and forms a vital lung space of 260.51 km$^2$ that has diverse flora and fauna. BNP is contiguous to Cauvery wildlife sanctuary on the south and forms an important corridor for movement of elephants along this vast terrain. The current study forms a part of the Environmental Management and Policy Research Institute (EMPRI) climate study initiative. Broader objectives of the study have been stated in Kakkar et al. (2018). The objectives of the present study on dry forests of Bannerghatta National Park (BNP) are to address the following specific questions.

1. What is the diversity pattern of dry forest of BNP?
2. How do the local topographic factors influence the spatial distribution of diversity?
3. How do the patterns of diversity and structure observed in BNP correspond with other dry forest sites across the tropics?

## Study Area

This study was conducted in the dry forests of Bannerghatta National Park (BNP) (12° 34′ to 12° 50′ N Latitude and 77° 31′ to 77° 38′ E Longitude) situated in the outskirts of Bengaluru city, India (Fig. 1). BNP has an area of 260.51 km$^2$. Started as a wildlife sanctuary, BNP was elevated to a national park in 2004. Administratively BNP has four wildlife ranges namely Bannerghatta, Harohalli, Anekal, and Kodihalli. BNP is also identified as an important elephant corridor which is a part of Karadikkal – Mahadeswara elephant corridor. The terrain of the park is undulating with a mean elevation of 850 m (range 700–1035 m). The climate of the park is a monsoonal type. The BNP receives rainfall from both South-West and North-East monsoons. Heavy rainfall occurs during the month of September and October from North-east monsoon and torrential rains from June to August from South-west monsoon (Fig. 2). Annual rainfall (based on South-West monsoon, North-East monsoon and Pre-monsoon) for the Anekal range varies from 417 to 1494 mm with a mean of 869 ± 236 mm between the years 1960 to 2016 (Fig. 3); occasionally the area receives heavy cyclonic rains in October and November. The mean annual temperature of the park is around 24.7 °C with a maximum 39.4 °C and minimum of 10.2 °C (Fig. 4).

The geology of the park shows that the rocks are of the oldest formation revealing crypto crystalline to coarse granites and complex gneiss. The rocks are light to dark grey or whitish muscovite granite gneiss or biotitic granite gneiss which varies considerably from place to place in structure, texture, and appearance. According to the fineness or coarseness of the constituent grains and the relative abundance or scarcity and mode of deposition of the darker ferro minerals,

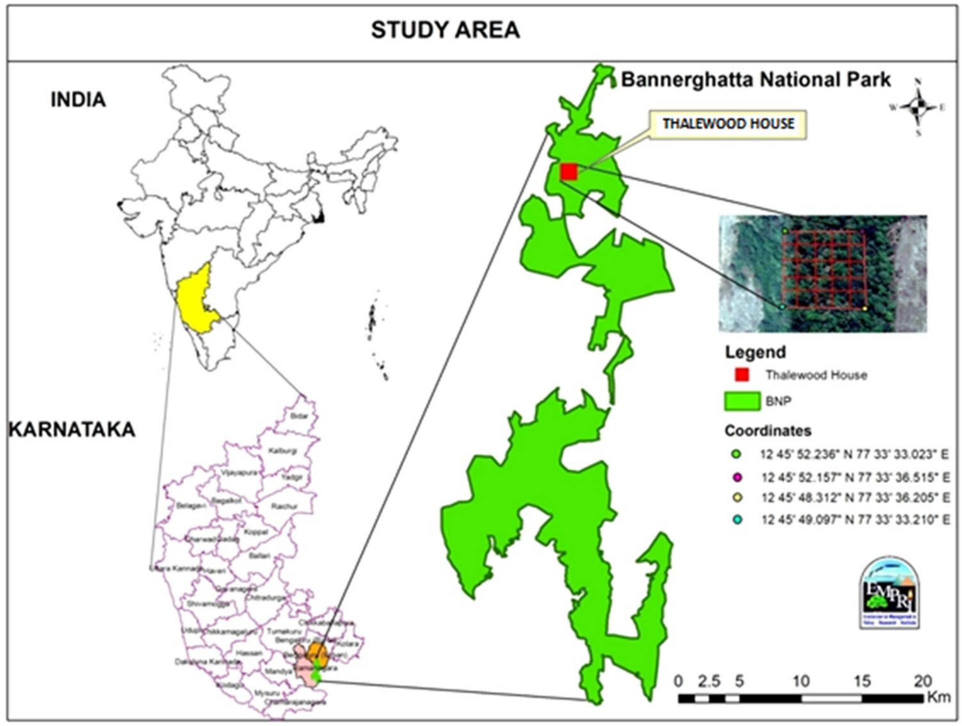


**Fig. 1** Location of Thalewood house permanent preservation plot in Bannerghatta National Park

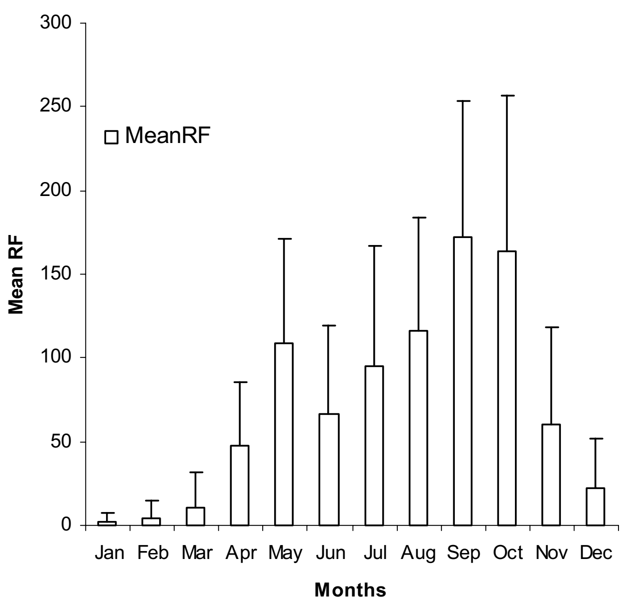


**Fig. 2** Mean rainfall (RF) during the months of January to December in Bannerghatta National Park

their complex gneiss masses have been styled "Peninsular Gneiss." The soil on the upper regions is red and gravely. The soil in the valleys is sandy loam and is formed with finer particles of the decomposed rocks washed down and deposited during rains. The soil is shallow on the hilltops and deep in the valleys and low-lying areas (Raju 2014).

## Vegetation

Bannerghatta National park has two major types of vegetation viz. scrub and deciduous vegetation. The scrub vegetation is seen mostly along the fringes of the park and experiences heavy biotic pressures by the local communities for reasons such as fuel wood collection and cattle grazing. The upper regions of the park are covered by mixed deciduous vegetation type whereas the valleys, watercourses and low lying areas are covered by moist deciduous vegetation which is relatively less disturbed and degraded as it is inaccessible due to the highly undulating terrain (Varma et al. 2009; Gopalakrishna et al. 2015).

## Methods

A permanent one-hectare (1 ha) forest dynamics preservation plot was established in BNP in accordance with CTFS protocols (Condit 1998). Plot establishment involved two stages, the first stage being gridding, and the second stage enumeration. Gridding involved dividing the entire plot into blocks (sub-plots) of 20 m × 20 m with the help of Theodolite after making corrections for the slope. Each 20 m × 20 m block (sub-plot) was further divided into blocks of 10 m × 10 m temporarily with ropes. In each 10 m × 10 m block, all woody individuals > 1 cm dbh (dbh refers to diameter at 1.37 m above the ground) were identified, marked with a unique tag number and measured for the size. Trees

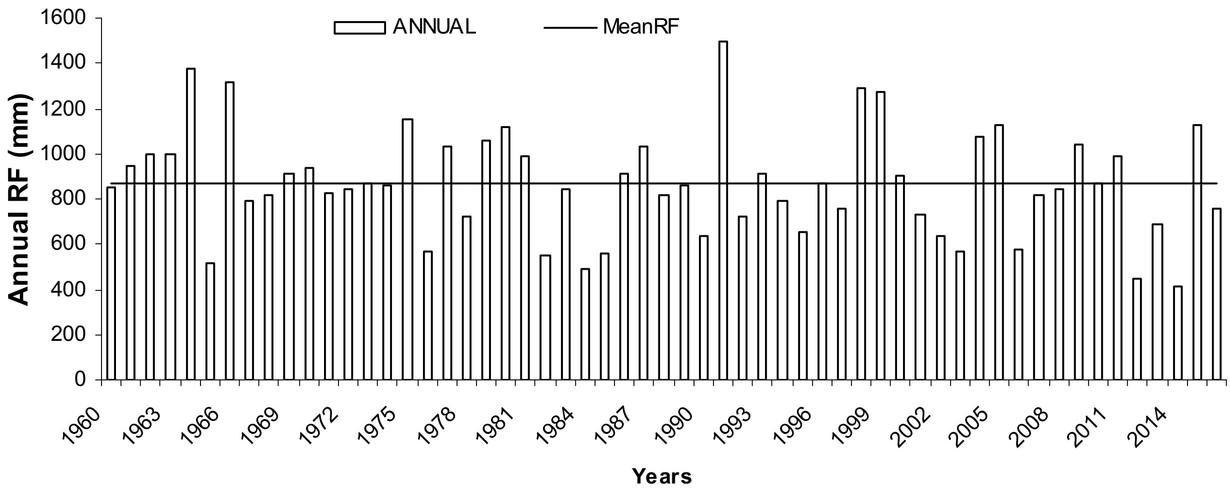


**Fig. 3** Annual rainfall (RF) between the years 1960 to 2016 in Bannerghatta National Park

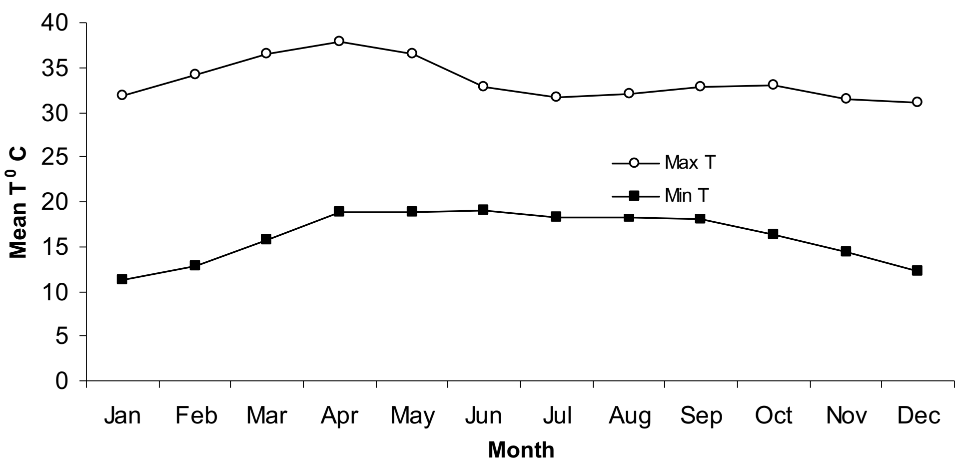


**Fig. 4** Mean maximum and minimum temperature in Bannerghatta National Park (2012-2015)

and shrubs with multiple stems branching out below breast height were measured. All the marked individuals were mapped for spatial location by measuring the *X* and *Y* coordinates to nearest 10 cm accuracy. The *X* and *Y* coordinates of each individual in a sub-plot was always measured from south-west corner of the plot considering it as the origin. The X and Y coordinates for multiple stemmed trees and shrubs were measured for the stem with largest size (dbh). Later X and Y coordinates of all individuals were converted to global X and Y values for spatial mapping.

The individuals in the plot were distributed into different size classes. Only the main stem was considered for size class distribution whereas all the stems of an individual were accounted for the basal area. The different size classes were 1–4.99 cm, 5–9.99 cm, 10–14.99 cm, 15–19.99 cm, 20–24.99 cm, 25–29.99 cm and > 30 cm.

## Analysis

The species abundance was expressed as relative abundance and cumulative abundance. The Importance Value Index (IVI) was calculated and defined as the sum of relative frequency, relative density and relative dominance (Cottam and Curtis 1956). Various estimates of diversity were calculated using the software PAleontological STatistics (PAST) (Hammer et al. 2001). A simple estimate of diversity is the species richness (number of species). Other estimates include

Simpson's index (probability of picking two different individuals belonging to two different species), Shannon–Wiener's index (a measure of heterogeneity). Basal area was estimated as an area of a circle ($\pi r^2$); the sum of the individual basal area was represented as a basal area of the plot and expressed as square meters.

Spatial distribution pattern of individuals in each species can be either random or non-random. We used Poisson distribution to generate the expected distribution and we compared the actual distribution of individuals with expected distribution with Chi-square test. Results were generated by using statistical software BioDiversity Pro (McAleece 1997). The levels of significance of the dispersion of each species were determined at $P < 0.05$.

Floristics of the community was characterized by Family Importance Value (FIV). Family Importance Value was calculated as the sum of a relative number of species in each family, the relative density of each family and relative dominance (sum of basal area) of each family.

## Results

A total of 1,586 individuals > 1 cm dbh belonging to 68 species and 28 different families of flowering plants were enumerated. Most dominant species was *Olea dioica* (Oleaceae) with 292 individuals accounting for 18.41% of the total abundance. Other dominant species were *Cipadessa baccifera* (Meliaceae) (154 individuals and 9.70% abundance) and *Ziziphus oenoplia* (Rhamnaceae) (139 individuals and 8.76% abundance). Top ten species account for 73.95% of total abundance. There were 19 species with one individual, and they included species such as *Dimocarpus longan* (Sapindaceae), *Memecylon umbellatum* (Melastomataceae) and *Premna tomentosa* (Verbenaceae). Relative Abundance and Cumulative abundance of top 10 species are given in the Table 1.

**Table 1** Relative and Cumulative abundances of top ten species in Thalewood house permanent preservation plot

| Name of species | Abundance (total individuals) | Relative abundance (%) | Cumulative abundance (%) |
|---|---|---|---|
| *Olea dioica* | 292 | 18.41 | 18.41 |
| *Cipadessa baccifera* | 154 | 9.71 | 28.12 |
| *Ziziphus oenoplia* | 139 | 8.76 | 36.89 |
| *Phyllanthus polyphyllus* | 134 | 8.45 | 45.33 |
| *Hiptage benghalensis* | 132 | 8.32 | 53.66 |
| *Ixora nigricans* | 106 | 6.68 | 60.34 |
| *Polyalthia cerasoides* | 74 | 4.67 | 65.01 |
| *Ardisia solanacea* | 57 | 3.59 | 68.60 |
| *Glochidion velutinum* | 45 | 2.84 | 71.44 |
| *Jasminum sp* | 40 | 2.52 | 73.96 |

**Table 2** Diversity parameters of the plot at hectare and 400 $m^2$ (20 × 20 m)

| Parameters | Community level (1 ha) | At quadrat (20 X 20 m), N = 25 | |
|---|---|---|---|
| | | Mean ± SD | Coefficient of Variation (CV) |
| Number of Species | 68 | 16.4 ± 6.16 | 37.58 |
| Dominance | 0.077 | 0.148 ± 0.067 | 45.18 |
| Simpson's Index | 0.922 | 0.851 ± 0.067 | 7.88 |
| Shannon's Index | 3.04 | 2.28 ± 0.363 | 15.90 |
| Evenness | 0.307 | 0.659 ± 0.120 | 18.33 |
| Fisher's Alpha | 14.44 | 7.89 ± 2.84 | 36.01 |
| Chao 1 | 82.25 | 23.52 ± 12.17 | 52.37 |

Species that had highest IVI was classified as a canopy species: *Terminalia arjuna* (Combretaceae) (35.11) followed by *Olea dioica* (Oleaceae) (30.67) and *Terminalia bellirica* (Combretaceae) (29.55). IVI of all species enumerated in the plot is given in Appendix 1.

Most ubiquitous species were *Hiptage benghalensis* and *Ziziphus oenoplia* which occurred in 23 quadrats. There were 17 species which were present in more than 10 quadrats. There were 21 species which occurred only in one quadrat.

There were 22 species (32.3% of the species complement) belonging to canopy layer, 20 species (29.4% of the species complement) belonging to understorey layer, 18 species (26.4% of the species complement) belonging to shrub layer and 8 species (11.7% of the species complement) classified as climbers. Among the canopy species, most ubiquitous species was *Olea dioica* (Oleaceae) (22 quadrats) followed by *Terminalia bellerica* (Combretaceae) (19 quadrats). Among the understorey *Phyllanthus polyphyllus* (20 quadrats) and *Ixora nigricans* (19 quadrats) were ubiquitous. Among the shrubs, *Cipadessa baccifera* (Meliaceae) and *Mimosa rubicaulis* (Fabaceae) were ubiquitous, while among climbers included *Hiptage benghalensis* (Malpighiaceae) (23 quadrats) and *Ziziphus oenoplia* (Rhamnaceae) (23 quadrats).

### Diversity patterns

At the community level 68 species had > 1 cm dbh. Simpson's index (probability of picking two different species) (0.922) and Shannon' index (index of heterogeneity) were high (3.04). Fisher's alpha, which is not sensitive to plot size, was 14.44 (Table 2). At quadrat level the measures of diversity were low (Table 2), whereas the Evenness (the distribution of individuals among species) was high compared to whole community level. The diversity parameters with

**Table 3** Diversity parameters with different size cut off at Thalewood house plot

| Parameter | Individuals > 1 cm dbh | Individuals > 3 cm dbh | Individuals > 10 cm dbh | Individuals > 30 cm dbh |
|---|---|---|---|---|
| Number of Species | 68 | 55 | 33 | 11 |
| Dominance | 0.077 | 0.072 | 0.088 | 0.240 |
| Simpson's Index | 0.922 | 0.928 | 0.911 | 0.759 |
| Shannon's Index | 3.04 | 3.07 | 2.832 | 1.702 |
| Evenness | 0.307 | 0.391 | 0.514 | 0.498 |
| Fisher's Alpha | 14.44 | 13.43 | 11.07 | 3.691 |
| Chao 1 | 82.25 | 80.5 | 37 | 26 |

**Table 4** Significance of diversity estimates with different size cut off (Values are T values as derived from PAST)

| Size cut off | > 1 cm dbh | > 3 cm dbh | > 10 cm dbh | > 30 cm dbh |
|---|---|---|---|---|
| Shannon's Index (Heterogeneity) | | | | |
| > 1 cm dbh | NA | – 0.245 NS | – 2.73 S | 10.91 S |
| > 3 cm dbh | – | NA | – 2.748 S | – 10.77 S |
| > 10 cm dbh | – | – | NA | 7.929 S |
| > 30 cm dbh | – | – | – | NA |
| Simpson's Index (Probability of picking two individuals belonging to different species) | | | | |
| > 1 cm dbh | NA | 1.084 NS | 1.274 NS | – 5.696 S |
| > 3 cm dbh | – | NA | 1.791 NS | 5.859 S |
| > 10 cm dbh | – | – | NA | – 5.094 S |
| > 30 cm dbh | – | – | – | NA |

different size cut-off showed that as the size cut-off increased there is a reduction in number of species and other diversity parameters (Table 3). But as the size cut-off increased there was an increase in the dominance suggesting monopoly of a single species (Table 3). Diversity parameters across different sizes were compared using "Diversity t-test" in PAST. It was found that both Shannon's index and Simpson's index were not different (Table 4), while Shannon's index was different at higher size classes (Table 4) and Simpson's index was different only with 30 cm dbh size cut-off (Table 4).

## Spatial analysis of the diversity parameters

The plot was divided into quadrats with stream and no stream based on stream occupancy in the quadrat. The quadrat was considered as "stream quadrat", if the stream occupies > 50% of the area of the quadrat. There were 10 quadrats with stream cover and 15 quadrats without stream. The differences in diversity (Table 5) were analysed between the quadrats as stream cover provides a unique habitat.

## Structural parameters

The plot had 1,586 individuals > 1 cm dbh. Mean number of individuals per quadrat was 63.4 ± 31.5 individuals (range = 10–109 individuals, N = 25). Mean density in the first half of the plot was significantly lower than the second half (T test, t = – 2.710, P < 0.006, S) suggesting considerable variation in stem packing across the plot (ANOVA, $F$ = 7.14, P < 0.01, S).

Total basal area of the plot was 31.57 $m^2$/ha for all the stems > 1 cm dbh. However, the basal area varied from 0.30 $m^2$ to 4.81 $m^2$ among the quadrats with a mean of 1.25 ± 0.91 $m^2$ (CV = 73.10). The density and basal area of the plots have no relationship among them. Maximum size of an individual in the plot was 126.6 cm, for a fig species (*Ficus microcarpa*).

Among the different life-forms, canopy species accounted for 29.1% of total abundance, while understorey species accounted for 31.9%, climbers for 21% species, and shrubs 17.7%. The canopy species accounted for 88.1% of the basal area followed by understorey (7.8%), shrubs (0.94%) and climbers (3.0%).

Density of the stems in stream plots was 46.3 ± 26.5 (12–85, N = 10) and in no-stream plot was 74.8 ± 29.89 (10–108, N = 15). No-stream plots had considerably higher stems than stream plots (t = – 2.49, P < 0.01, df = 21). The variability in density across plots was significant (ANOVA,

**Table 5** Diversity parameters for stream plots and non-stream plots

| Parameters | Stream plots mean ± SD (range) (CV) | Non-stream plots mean ± SD (range) (CV) | Differences (significance) |
|---|---|---|---|
| Number of species | 12.8 ± 5.41 (7–23) (42.28) | 19.8 ± 5.58 (6–29) (29.07) | T = – 2.86, P < 0.004, df = 20 |
| Dominance | 0.183 ± 0.089 (0.12–0.43) (48.95) | 0.124 ± 0.032(0.063–0.2) (25.76) | T = 1.99, P < 0.03, df = 11 |
| Simpson's Index | 0.816 ± 0.089 (0.566–0.872) (11.01) | 0.875 ± 0.032 (0.8–0.936)(3.66) | T = – 1.99, P < 0.03, df = 11 |
| Shannon's Index | 2.06 ± 0.353 (1.261–2.568) (17.1) | 2.44 ± 0.297 (1.696–3.01) (12.17) | T = – 2.808, P < 0.006, df = 17 |
| Evenness | 0.681 ± 0.156 (0.441–0.921) (23.01) | 0.640 ± 0.095 (0.512–0.908) (14.93) | T = 0.733, P < 0.238, df = 13 NS |
| Fisher's Alpha | 6.45 ± 1.99 (3.09–10.45) (30.92) | 915 ± 2.93 (6.08–14.79) (32.09) | T = – 2.736, P < 0.005, df = 23 |
| Chao 1 | 16.92 ± 8.25 (7.75–31.0) (49.04) | 28.61 ± 12.90(7.0–56.0) (45.10) | T = – 2.787, P < 0.005, df = 23 |

*F* = 5.94, P < 0.02). Basal area and biomass in stream and no-stream plots showed significant differences. Mean basal area in stream plots was (8554.5 ± 5487.5 $cm^2$) while in the no-stream plots it was (14,778.4 ± 10,769 $cm^2$). No-stream plots had significantly higher basal area (t = -1.92, P < 0.03, df = 22) and biomass (t = − 3.33, P < 0.001, df = 23) compared to stream plots.

### Size class distribution

The size class distribution of individuals showed an inverted "J" type suggesting majority of individuals in the lower size class (Fig. 5.). There were 793 individuals > 3 cm dbh, 220 trees > 10 cm dbh, and 69 trees > 30 cm dbh.

### Spatial distribution patterns

Many species (66.2%) in the plot showed non-significant random spatial dispersion pattern (Appendix 2). But species such as *Dendrocalamus strictus* (3 groups in 2 sub-plots) and *Ziziphus rugosa* (3 individuals in 2 subplots) showed significant random dispersion. However, canopy species such as *Terminalia bellerica* (34 individuals, 19 sub-plots), *Terminalia arjuna* (29 individuals, 15 sub-plots), and *Diospyros montana* (16 individuals, 14 sub-plots), though present in many sub-plots, had non-significant random dispersion at a hectare scale.

A total of 23 species (33.8%) in the plot had significant clumped or aggregate dispersion. This includes most abundant species *Olea dioica* and other canopy species such as *Syzygium cumini*, *Shorea roxburghii*, and *Schleichera oleosa* (Tables 6, 7). Species such as *Phyllanthus reticulatus*, *Mitragyna parvifolia*, and *Schleichera oleosa*, though they have 2, 4, 6 individuals respectively, represented in 1, 2, 3 subplots, showed significant clumped dispersion. Spatial distribution of all individuals in the community is given in the Fig. 6. Four abundant species with significant dispersion and four species with random dispersion are given in the respective Figs. 7(a-d) and 8(a-d). The dispersion pattern of all species with their density and frequency of occurrence is tabulated in the Appendix 2.

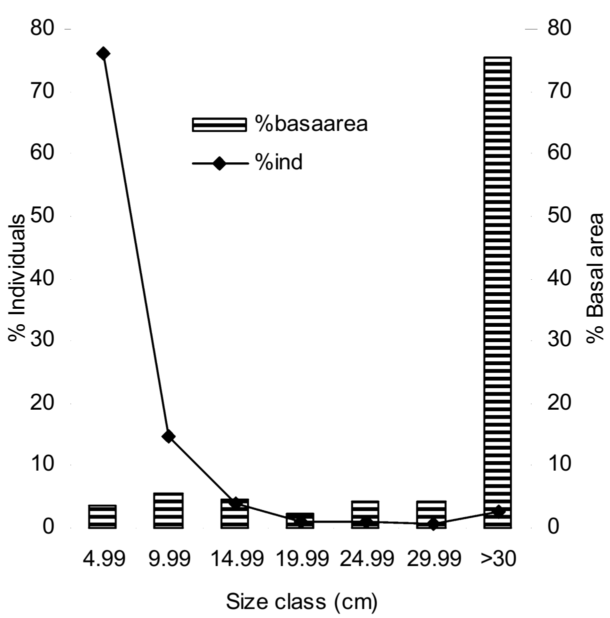


**Fig. 5** Size class distribution of individuals in Thalewood house permanent preservation plot

### Floristics

There were 28 flowering families in the dry forest floristics of BNP. Most speciose families were Euphorbiaceae and Leguminosae (Fabaceae) with 9 species each followed by Rubiaceae (6 species). There were 15 families such as Dipterocarpaceae, Moraceae, and Meliaceae with one species. Family Oleaceae was the most abundant with 332 individuals followed by Euphorbiaceae (225 individuals) and Rubiaceae (169 individuals). Families such as Burseraceae, Moraceae and Melastomataceae were represented by one individual. Family Combretaceae had highest FIV (60.84) followed by Euphorbiaceae (31.14), Oleaceae (30.83) and Rhamnaceae (26.77). List of families with their FIV is given in the Table 8.

## Discussion

In the current article we described patterns of diversity, structure and floristics of the Thalewood house plot. Thalewood house plot in BNP is interesting both structurally and floristically. Recently Coleman (2019) posed 100 questions towards conserving biodiversity of Southeast Asia. Thalewood house plot in a way would provide answers to the questions raised. Many respondents said that they have gaps in the "fundamental functioning of ecosystem" especially in south and Southeast Asian countries (Coleman et al 2019). Long-term monitoring of the Thalewood house plot would

**Table 6** Density and basal area across different size class in the plot

| Size class (cm) | Density (Number of stems) (%) | Basal area $m^2$/ha (%) |
|---|---|---|
| 1–4.99 cm | 1125 (70.93) | 1.175 (3.77) |
| 5- 9.99 | 254 (16.02) | 1.749 (5.54) |
| 10 – 19.99 | 102 (6.43) | 2.134 (6.76) |
| 20 – 29.99 | 36 (2.27) | 2.667 (8.45) |
| > 30 | 69 (4.35) | 23.849 (75.53) |
| Total | 1586 (100) | 31.574 (100) |

**Table 7** Percent size class of major Canopy and understorey species

| Size class(cm) | *Olea dioica* (Canopy) | *Phyllanthus polyphyllus* (understorey) | *Polyalthia cerasoides* (understorey) | *Syzygium cumini* (Canopy) | *Terminalia arjuna* (Canopy) | *Terminalia bellerica* (Canopy) |
|---|---|---|---|---|---|---|
| 4.99 | 70.349 | 86.214 | 88.889 | 42.857 | 0.000 | 0.000 |
| 9.99 | 18.798 | 12.757 | 8.889 | 10.204 | 12.195 | 2.222 |
| 14.99 | 6.202 | 1.029 | 1.111 | 6.122 | 4.878 | 4.444 |
| 19.99 | 1.744 | 0.000 | 0.000 | 4.082 | 4.878 | 4.444 |
| 24.99 | 0.969 | 0.000 | 0.000 | 0.000 | 4.878 | 20.000 |
| 29.99 | 1.163 | 0.000 | 1.111 | 4.082 | 9.756 | 13.333 |
| 34.99 | 0.388 | 0.000 | 0.000 | 4.082 | 4.878 | 6.667 |
| 39.99 | 0.000 | 0.000 | 0.000 | 12.245 | 4.878 | 15.556 |
| 44.99 | 0.194 | 0.000 | 0.000 | 0.000 | 4.878 | 2.222 |
| 49.99 | 0.194 | 0.000 | 0.000 | 2.041 | 7.317 | 2.222 |
| > 50 | 0.000 | 0.000 | 0.000 | 14.286 | 41.463 | 28.889 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |

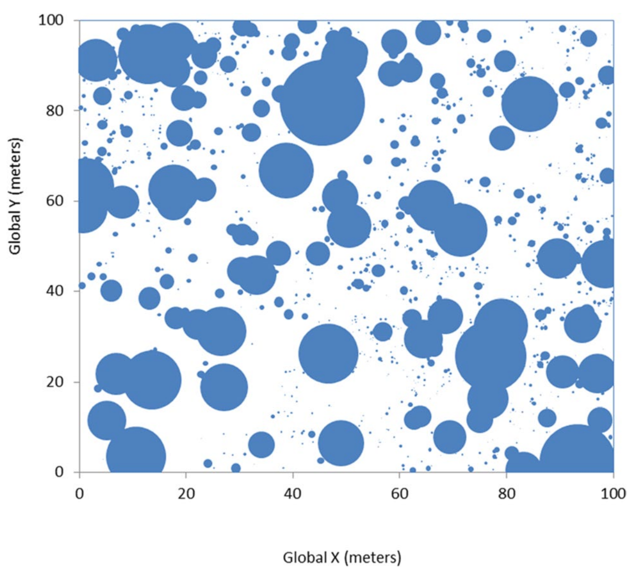


**Fig. 6** Spatial distribution of all individuals in Thalewood house plot (Size of the bubble indicate size of the stem)

help to bridge the gaps. Climate variability, dry season fire and mega-herbivores are some of the important factors that maintain and shape the deciduous forests (Sukumar et al. 2005). This plot has shown similarities and differences with other dry forest sites in India and elsewhere in tropics. Thalewood house plot has mild undulation and with a stream in the middle. The topographical feature of the plot has given scope for micro-habitat variation which would necessitate many species to co-exist.

## Diversity

Thalewood house plot has 68 species of flowering plants in a hectare which is in the range of number of species reported from dry forests of India and elsewhere. In Africa, there is a wide range of species numbers reported from various forest sites. Kacholi (2014) reported 93 species in a hectare forest at Morogoro, Tanzania and species numbers ranging from 8–122 species a hectare (Kacholi 2014). The dry forests of neo-tropics are reported to have on an average 64.9 species (Gentry 1995). Gentry (1988) also reported that lowland dry forests have 50–70 species in 1000 $m^2$ area. Coelho et al. (2012) reported that dry forests in Brazil have a range of 23 – 50 species. Dokrak et al. (1999) reported 93 species from mixed deciduous forests from Thailand. In the secondary dry forest of Myanmar 30 species have been reported (Sann et al. 2016). A total of 204 species and morphospecies were reported from seven neotropical dry deciduous plots in Central America (Gillespie et al. 2000). Reddy et al (2011) reported species richness in the range 52 – 110 species in a hectare from northern Andhra Pradesh. Sathya and Jayakumar (2017) reported 62 species from Satyamangalam, the Tamilnadu area. The Thalewood house plot seems to be in the range of species numbers encountered in different dry forest sites. However, lower species numbers have also been recorded in dry forests. For example, Kumar et al. (2010) reported range of 16–38 species in Western India. Kushwaha and Nandy (2012) enumerated 35 species in dry Sal forests and 134 species from moist Sal forests. Shankar (2001) enumerated 87 species > 3 cm dbh in the lowland dry Sal forests of Mahananda Wildlife Sanctuary. Sahu et al. (2012b) enumerated a total of 46 species (range = 22 – 29) in three different regions in Niyamgiri hills, Odisha. Dutta and Devi (2013) reported 34 species of trees > 10 cm dbh

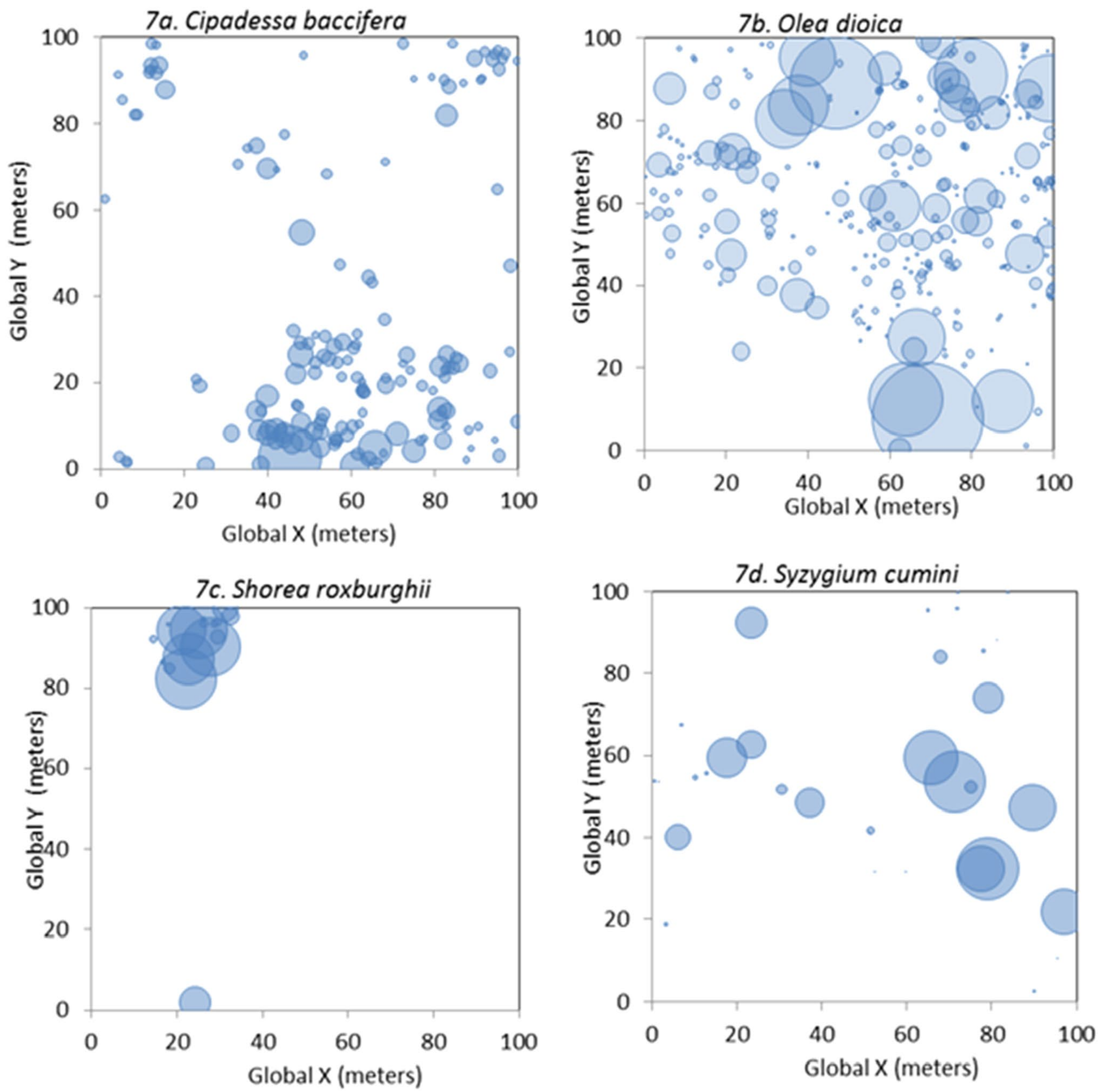


**Fig. 7** Spatial distribution of different species having significant aggregate (clumped) distribution (Size of the bubble indicate size of the stem) (**a–d**)

from moist sal forests of Doboka reserve in Assam from a 0.5 ha area. There is a considerable variation in species composition and number of species enumerated in different deciduous forest plots. It has been observed that there is also considerable variation in area sampled across different geographical locations.

Diversity estimates for the Thalewood house plot are in the range of diversity estimates for several dry forest sites (Shankar 2001; Dutta and Devi 2013). However, the comparison and interpretation are difficult as these estimates are not calculated in a uniform way or many a times methods of estimation are unclear. It is clear from our analysis that diversity estimates vary with different size cut-off within the same plot.

## Spatial distribution

Many species in the plot have shown random distribution at the scale of 1 ha. Thirty three percent of the species have shown clumped dispersion. Dispersion pattern of species is a

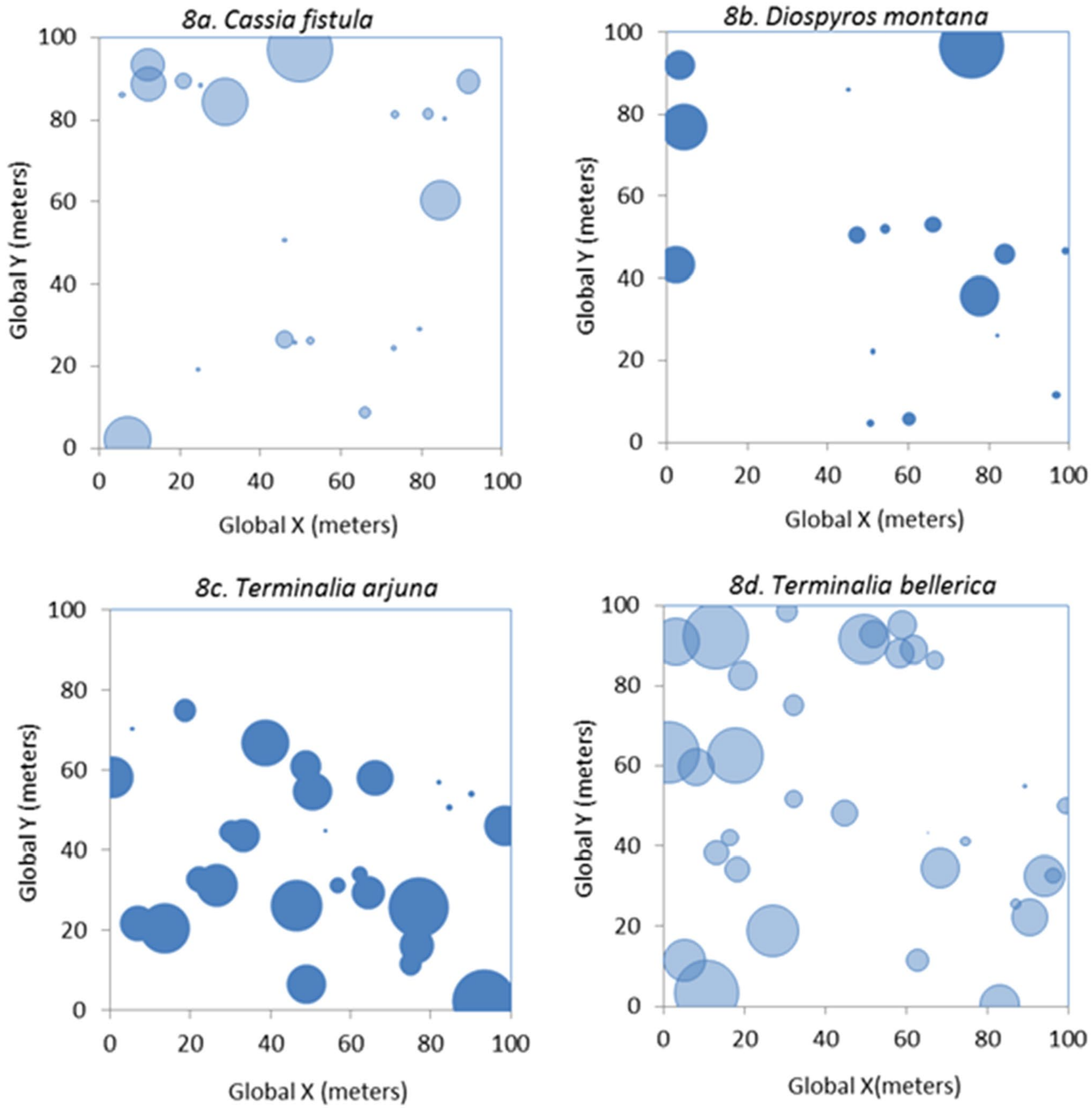


**Fig. 8** Spatial distribution of different species with random (non-significant aggregate) distribution (Size of the bubble indicate size of the stem) (**a**–**d**)

function of its dispersal mechanism and habitat requirements (habitat differentiation). Constraints in dispersal capabilities are one of the factors that results in dispersion pattern of a species. Clumped dispersion is observed in species with passive mode of dispersal. Most of the species that show clumped dispersion in the plot have passive dispersal mechanisms.

Tropical dry forests are subjected to moisture stress during the dry season. Moisture availability and length of dry season determine the species composition and performance of a species (Chaturvedi et al 2011). We proposed a hypothesis that species density and basal area in stream plots should be more than non-stream plots and species found in stream plots should do better compared to non-stream plots. We used density and basal area (Table 9) as proxy to reject

**Table 8** Family Importance Values (FIV) of all families present in the plot. Families are arranged in descending order of FIV

| Family | Relative number of species (%) | Relative density (%) | Relative dominance (%) | Family importance value (FIV) |
|---|---|---|---|---|
| Combretaceae | 4.35 | 4.04 | 52.46 | 60.85 |
| Euphorbiaceae | 13.04 | 14.19 | 3.91 | 31.14 |
| Oleaceae | 2.90 | 20.93 | 7.00 | 30.84 |
| Rhamnaceae | 7.25 | 16.77 | 2.76 | 26.77 |
| Rubiaceae | 8.70 | 10.66 | 1.81 | 21.16 |
| Leguminosae | 13.04 | 3.66 | 3.88 | 20.58 |
| Myrtaceae | 1.45 | 2.08 | 11.47 | 15.00 |
| Moraceae | 1.45 | 0.06 | 11.39 | 12.90 |
| Annonaceae | 5.80 | 5.42 | 0.76 | 11.98 |
| Meliaceae | 1.45 | 9.71 | 0.42 | 11.58 |
| Apocynaceae | 5.80 | 1.32 | 0.09 | 7.21 |
| Myrsinaceae | 2.90 | 3.72 | 0.34 | 6.96 |
| Verbenaceae | 4.35 | 0.76 | 0.96 | 6.06 |
| Sapindaceae | 4.35 | 1.01 | 0.46 | 5.82 |
| Ebenaceae | 2.90 | 1.13 | 0.33 | 4.37 |
| Boraginaceae | 1.45 | 1.64 | 0.82 | 3.91 |
| Dipterocarpaceae | 1.45 | 1.07 | 0.91 | 3.43 |
| Celastraceae | 2.90 | 0.13 | 0.00 | 3.03 |
| Malpighiaceae | 1.45 | 0.69 | 0.06 | 2.20 |
| Lecythidaceae | 1.45 | 0.13 | 0.13 | 1.71 |
| Poaceae | 1.45 | 0.19 | 0.01 | 1.64 |
| Erythroxylaceae | 1.45 | 0.19 | 0.00 | 1.64 |
| Sterculiaceae | 1.45 | 0.13 | 0.01 | 1.58 |
| Rutaceae | 1.45 | 0.13 | 0.00 | 1.58 |
| Melastomataceae | 1.45 | 0.06 | 0.01 | 1.52 |
| Convolvulaceae | 1.45 | 0.06 | 0.00 | 1.51 |
| Burseraceae | 1.45 | 0.06 | 0.00 | 1.51 |
| Vivianiaceae | 1.45 | 0.06 | 0.00 | 1.51 |
| Grand Total | 100 | 100 | 100 | 300 |

or accept our hypothesis. We used species with clumped dispersion and different densities. Dispersal limitation was the main reason for aggregate dispersion of species. This is also true for many species in the tropics that show aggregate dispersion (Mahanand and Behera 2019).

## Structure

Density of individuals is expressed with different size cut-off. Most forest plots usually have the size cut-off as 10 cm gbh (girth at breast height) (3.0 cm dbh) or 10 cm dbh (30 cm gbh). Thalewood house plot has 1586 individuals > 1 cm dbh, 793 individuals (> 3 cm dbh), 207 individuals (> 10 cm dbh), 69 individuals (> 30 cm dbh) and basal area of 31.7 $m^2$ in a hectare. Deciduous forests across India have varied density and basal area. Mudumalai forests has 525 individuals/ha over 1 cm dbh and had a basal area of 24.5 $m^2$ (Sukumar et al. 1992). Manna and Mishra (2017) reported a density of 1336 stems/ha and basal area of 30.5 $m^2$/ha from Sal (*Shorea robusta*) forests of Lalgarh, West Bengal. The density values varied from 702 individuals/ha to 1671 individuals/ha and the basal area from 15.43 to 71.76 $m^2$/ha in the dry deciduous forests of Madhya Pradesh, India (Joshi and Dhyani 2019). Sahu et al. (2012a, b) reported a density of 443 trees/ha and a basal area of 13.73 $m^2$/ha. Stem density was in the range of 280 stems/ha to 1,130 stems/ha and the basal area was 11.1 $m^2$/ha to 36.9 $m^2$/ha in tropical dry evergreen forests around coast of Pondicherry (Visalakshi 1995). Reddy et al. (2007) reported stem density of 568 stems/ha over 10 cm dbh and basal area of 43.1 $m^2$/ha from Similipal Tiger Reserve, Odisha. Pandey (2001) from the teak dominated forests from Satpura in central India reported the mean density of 1090 individuals/ha and basal area of 13.33 $m^2$/ha. Dry deciduous Sal forest in West Bengal had 1006 stems/ha with 19.62 $m^2$/ha while the moist deciduous Sal forest in West Bengal had 438 stems/ha and basal area of

**Table 9** Species density and basal area in stream plots and non-stream plots

| Species (dispersal type) | Mean ± SD (Stream plots) | Mean ± SD (No stream plots) | T value | P value (df) |
|---|---|---|---|---|
| Density of stems > 1 cm dbh | | | | |
| *Olea dioica* | 7.63 ± 8.34 | 13.86 ± 8.39 | – 1.87627393 | 0.03697 (22) |
| *Cipadessa baccifera* | 5.81 ± 9.00 | 6.00 ± 5.63 | – 0.05901198 | 0.47683 (16) |
| *Phllanthus polyphllus* | 2.18 ± 1.99 | 7.33 ± 7.97 | – 2.40066065 | 0.01444 (16) |
| *Ixora nigricans* | 1.18 ± 1.40 | 6.2 ± 5.45 | – 3.41335831 | 0.00177 (16) |
| *Syzygium cumini* | 1.00 ± 1.84 | 1.46 ± 1.30 | – 0.71828305 | 0.24116 (17) |
| *Terminalia arjuna* | 1.18 ± 0.98 | 1.46 ± 1.43 | 0.242555388 | 0.40520 (24) |
| *Terminalia bellerica* | 0.63 ± 0.80 | 1.8 ± 1.14 | – 3.03372865 | 0.00286 (24) |
| Basal area ($cm^2$) | | | | |
| *Olea dioica* | 623.33 ± 963.93 | 1003.25 ± 1046.52 | – 0.95733 | 0.17417 (23) |
| *Cipadessa baccifera* | 65.02 ± 136.85 | 40.75 ± 52.77 | 0.558406 | 0.29341 (12) |
| *Phllanthus polyphllus* | 43.34 ± 46.00 | 292.15 ± 313.66 | – 3.02806 | 0.00423 (15) |
| *Ixora nigricans* | 7.07 ± 9.90 | 77.26 ± 73.68 | – 3.64447 | 0.00119 (15) |
| *Syzygium cumini* | 921.65 ± 1746.76 | 1738.30 ± 2894.40 | – 0.89323 | 0.19049 (23) |
| *Terminalia arjuna* | 4845.47 ± 4571.35 | 2688.74 ± 4242.36 | 1.225019 | 0.11706 (21) |
| *Terminalia bellerica* | 832.38 ± 1138.86 | 4191.64 ± 3868.54 | – 3.18042 | 0.00273 (17) |

56.52 $m^2$/ha (Kushwaha and Nandy 2012). Shankar (2001) reported a stand density of 484 individuals/ha with > 3 cm dbh and basal area of 26.3 $m^2$/ha. He also provided a comprehensive comparative list of different dry forest plots in India and their structural attributes. Dutta and Devi (2013) reported exceptionally high basal area of 88.87 $m^2$/ha for Doboka Reserve forest with 422 individuals/ha with > 10 cm dbh. The stem density in the deciduous forests of India showed a varied number of stems per hectare so as the basal area. This variation can be attributed to protection given to a patch, intensity of usage, current degree of disturbance and previous history of land management.

Dry forests in Mexico with different land–use history had densities of individuals varying from 2575 ± 55 to 4745 ± 985 while basal area was in the range of 12.5 ± 2.6 to 14.6 ± 0.3 $m^2$/ha. Low basal area in this forest is attributed to a lack of individuals in higher size class (Romero-Duque et al. 2007). However, in Thalewood house plot though there is a considerable number of individuals in lower size class (71% of the stand was < 5 cm dbh), they contribute less to the basal area (3.7%) while individuals > 30 cm (4.3% of the stand) contribute 75.5% to the basal area.

## Floristics

There were 28 families reported from Thalewood house plot. This conforms to Gentry (1995) that the equatorial dry forests have 28 families per sample. Kumar et al. (2010) reported a range of 16–23 families from different dry forests from Western India. Most speciose family is Euphorbiaceae and Leguminosae (Fabaceae). Similar familial composition is also reported from Satyamangalam, Tamilnadu(Sathya and Jayakumar 2017). However, family Combretaceae dominates with highest FIV value. Our results agree with earlier results in terms of familial composition. Gopalakishna et al. (2015) reported that the most abundant families in BNP are Combretaceae, Fabaceae, Meliaceae, Rubiaceae and Celastraceae. However, the differences are families such as Meliaceae, Rubiaceae and Celastraceae which are not dominant families in the plot. This difference could be attributed to sampling protocol as it provides different microhabitats (Gopalakrishna et al. 2015). Family Combretaceae is dominant in the dry forests of Mudumalai, dry forests of Western India and forests in the Eastern Ghats (Sukumar et al. 1992; Kumar et al. 2010; Naidu and Kumar 2016). Families Euphorbiaceae and Fabaceae dominate the floristics of dry forests in many localities (Shankar 2001; Reddy et al 2011; Joshi and Dhyani 2019) but in Similipal Tiger Reserve Rubiaceae dominates the floristics along with Euphorbiaceae (Reddy et al. 2007). In Doboka reserve forest (moist Sal forests) Fabaceae and Combretaceae were the dominant families (Dutta and Devi 2013).

In several dry forest sites in neo-tropics Bignoniaceae and Leguminosae are the most dominant families (Gentry 1995; Gillespie et al. 2000; Romero-Duque et al. 2007). Other families that dominate the floristics of dry forests in neotropics include Rubiaceae, Sapindaceae, Euphorbiaceae, Flacourtiaceae, Capparidaceae and Myrtaceae (Gentry 1995). Fabaceae, Apocyanaceae and Malvaceae dominated floristics of Brazilian dry forests (Coelho et al. 2012) while the Fabaceae is the most dominant family in Peruvian dry forests (Muenchow et al. 2013). Thalewood house plot differs from neotropics dry forests by not having Bignoniaceae in the floristics but have other families mentioned above. The dry forests in Southeast Asia, forest in Himalayan foothills and plains of India and Myanmar are characterized by presence of “Dry Dipeterocarps” (mostly with genus Shorea) which is absent in both Africa and neotropics (Dokrak et al. 1999). The dry forests of Tanzania are similar in floristics with BNP by having Fabaceae as the dominant family but differs from BNP by having Moraceae, Sterculiaceae and Bignoniaceae as dominant families (Kacholi 2014). The dry forests of Eastern Ghats had similar familial composition compared to BNP (Reddy et al. 2008). Family Fabaceae is dominant in dry forests across the globe (Gentry 1995).

## Conclusions

The dry forests of BNP are species rich and the range of species is comparable to other dry forests in India. The density is on higher side compared to other dry forest sites in India. But this conclusion is subjective as it depends on several considerations. This plot has stream inside and resulted in moisture difference though this study does not have data to characterize the difference. Except for some parameters such as number of species between stream and non-stream plots, Fisher’s alpha and Chao 1, there was no difference in the habitats. The number of species and other diversity estimates are comparable to other dry forest sites. However, the word of caution is the estimates could be estimated in several ways. Until and unless the method of estimation is uniform, it is just not right to draw conclusions. The basal area of the plot is relatively on the higher side as the forest is protected. This long-term project will provide more interesting results as the monitoring progresses further. This study is relevant in the present context as there are “gaps in the fundamental functioning of ecosystem” especially in south and Southeast Asian countries (Coleman et al. 2019).

## Appendix 1

See Table 10.

**Table 10** Importance Value Index (IVI) of all species in Thalewood house plot

| Name of Species | Total Individuals | No. of quadrats species occur | Basal area (cm$^2$) | Important Value Index (IVI) |
|---|---|---|---|---|
| *Acacia concina* | 4 | 4 | 317.92 | 1.32 |
| *Albizia odoratissima* | 1 | 1 | 1126.90 | 0.66 |
| *Allophylus cobbe* | 9 | 5 | 58.29 | 1.8 |
| *Ardisia solanacea* | 57 | 11 | 1048.48 | 6.59 |
| *Bauhinia racemosa* | 2 | 2 | 14.53 | 0.61 |
| *Breynia retusa* | 3 | 3 | 61.53 | 0.94 |
| *Breynia vitis-idaea* | 1 | 1 | 3.46 | 0.31 |
| *Butea frondosa* | 2 | 2 | 338.20 | 0.72 |
| *Caesarea sp.* | 1 | 1 | 2.01 | 0.31 |
| *Canthium dicoccum* | 1 | 1 | 5.34 | 0.31 |
| *Canthium parviflorum* | 8 | 6 | 54.51 | 1.97 |
| *Careya arborea* | 2 | 2 | 422.26 | 0.74 |
| *Cassia fistula* | 21 | 12 | 1388.46 | 4.67 |
| *Cassia spectabilis* | 1 | 1 | 31.51 | 0.32 |
| *Celastrus paniculatus* | 1 | 1 | 0.95 | 0.31 |
| *Cipadessa baccifera* | 154 | 21 | 1326.55 | 15.21 |
| *Cordia wallichii* | 26 | 8 | 2598.88 | 4.4 |
| *Dalbergia lanceolaria* | 7 | 3 | 4941.09 | 2.73 |
| *Dendrocalamus strictus* | 3 | 2 | 17.25 | 0.68 |
| *Dimocarpus longan* | 1 | 1 | 1.77 | 0.31 |
| *Diospyros melanoxylon* | 2 | 2 | 48.84 | 0.63 |
| *Diospyros montana* | 16 | 14 | 1007.63 | 4.72 |
| *Embelia tsjeriam-cottam* | 2 | 2 | 28.85 | 0.62 |
| *Ervatamia heyneana* | 3 | 3 | 29.28 | 0.92 |
| *Erythroxylum monogynum* | 3 | 3 | 13.71 | 0.92 |

**Table 10** (continued)

| Name of Species | Total Individuals | No. of quadrats species occur | Basal area ($cm^2$) | Important Value Index (IVI) |
|---|---|---|---|---|
| *Ficus microcarpa* | 1 | 1 | 35,957.51 | 11.69 |
| *Flueggea leucopyrus* | 1 | 1 | 2.01 | 0.31 |
| *Garuga pinnata* | 1 | 1 | 2.01 | 0.31 |
| *Glochidion velutinum* | 45 | 14 | 5183.64 | 7.87 |
| *Glochidion zeylanicum* | 18 | 2 | 683.67 | 1.84 |
| *Gmelina arborea* | 2 | 2 | 562.02 | 0.79 |
| *Helicteres isora* | 2 | 2 | 16.26 | 0.62 |
| *Hiptage benghalensis* | 132 | 23 | 6276.85 | 15.88 |
| *Holarrhena antidysenterica* | 1 | 1 | 27.24 | 0.31 |
| *Ichnocarpus frutescens* | 15 | 4 | 185.24 | 1.97 |
| *Ipomoea illustris* | 1 | 1 | 2.54 | 0.31 |
| *Ixora nigricans* | 106 | 19 | 1236.89 | 11.68 |
| *Jasminum sp.* | 40 | 13 | 209.28 | 5.74 |
| *Mallotus philippensis* | 14 | 4 | 953.01 | 2.15 |
| *Maytenus emarginata* | 1 | 1 | 7.74 | 0.31 |
| *Meiogyne sp.* | 1 | 1 | 398.62 | 0.43 |
| *Memecylon umbellatum* | 1 | 1 | 35.49 | 0.32 |
| *Mimosa rubicaulis* | 17 | 12 | 207.55 | 4.04 |
| *Mitragyna parvifolia* | 4 | 2 | 1757.59 | 1.29 |
| *Olea dioica* | 292 | 22 | 21,905.51 | 30.67 |
| *Pavetta indica* | 12 | 5 | 56.60 | 1.99 |
| *Phyllanthus emblica* | 7 | 7 | 558.12 | 2.31 |
| *Phyllanthus polyphyllus* | 134 | 20 | 4859.14 | 14.83 |
| *Phyllanthus reticulatus* | 2 | 1 | 44.34 | 0.38 |
| *Polyalthia cerasoides* | 74 | 17 | 1342.31 | 9.21 |
| *Polyalthia coffeoides* | 10 | 7 | 668.66 | 2.54 |
| *Premna tomentosa* | 1 | 1 | 1821.89 | 0.88 |
| *Pterocarpus marsupium* | 3 | 3 | 3893.13 | 2.15 |
| *Randia dumetorum* | 38 | 13 | 2597.60 | 6.37 |
| *Schleichera oleosa* | 6 | 3 | 1394.81 | 1.55 |
| *Scutia myrtina* | 1 | 1 | 18.84 | 0.31 |
| *Shorea roxburghii* | 17 | 3 | 2860.35 | 2.7 |
| *Syzygium cumini* | 33 | 16 | 36,212.74 | 17.42 |
| *Terminalia arjuna* | 29 | 15 | 93,631.40 | 35.11 |
| *Terminalia bellirica* | 34 | 19 | 72,030.85 | 29.55 |
| *Terminalia chebula* | 1 | 1 | 6.59 | 0.31 |
| *Toddalia asiatica* | 2 | 2 | 12.83 | 0.61 |
| *Uvaria narum* | 1 | 1 | 5.73 | 0.31 |
| *Ventilago madraspatana* | 2 | 1 | 48.12 | 1.11 |
| *Vitex altissima* | 9 | 8 | 635.56 | 2.71 |
| *Wrightia tinctoria* | 2 | 2 | 31.39 | 0.62 |
| *Ziziphus oenoplia* | 139 | 23 | 2531.71 | 15.13 |
| *Ziziphus rugosa* | 3 | 2 | 15.41 | 0.68 |
| Grand Total | 1586 | 25 | 315,777 | 300 |

## Appendix 2

See Table 11.

**Table 11** The dispersion pattern of all species with their density and frequency of occurrence

| Species | Aggregation | Frequency of occurrence | Density |
|---|---|---|---|
| *Allophylus cobbe* | Aggregated | 5 | 9 |
| *Ardisia solanacea* | Aggregated | 11 | 57 |
| *Cipadessa baccifera* | Aggregated | 21 | 154 |
| *Cordia wallichii* | Aggregated | 8 | 26 |
| *Dalbergia lanceolaria* | Aggregated | 3 | 7 |
| *Glochidion velutinum* | Aggregated | 14 | 45 |
| *Glochidion zeylanicum* | Aggregated | 2 | 18 |
| *Ichnocarpus frutescens* | Aggregated | 4 | 15 |
| *Ixora nigricans* | Aggregated | 19 | 106 |
| *Jasminum sp.* | Aggregated | 13 | 40 |
| *Mallotus philippensis* | Aggregated | 4 | 14 |
| *Mitragyna parvifolia* | Aggregated | 2 | 4 |
| *Olea dioica* | Aggregated | 22 | 292 |
| *Pavetta indica* | Aggregated | 5 | 12 |
| *Phyllanthus polyphyllus* | Aggregated | 20 | 134 |
| *Phyllanthus reticulatus* | Aggregated | 1 | 2 |
| *Polyalthia cerasoides* | Aggregated | 17 | 74 |
| *Randia dumetorum* | Aggregated | 13 | 38 |
| *Schleichera oleosa* | Aggregated | 3 | 6 |
| *Shorea roxburghii* | Aggregated | 3 | 17 |
| *Syzygium cumini* | Aggregated | 16 | 33 |
| *Ventilago madraspatana* | Aggregated | 23 | 123 |
| *Ziziphus oenoplia* | Aggregated | 23 | 139 |
| Species | Aggregation | Frequency of occurrence | Density |
| *Acacia concina* | Random | 4 | 4 |
| *Albizia odoratissima* | Random | 1 | 1 |
| *Bauhinia racemosa* | Random | 2 | 2 |
| *Breynia retusa* | Random | 3 | 3 |
| *Breynia vitis-idaea* | Random | 1 | 1 |
| *Butea frondosa* | Random | 2 | 2 |
| *Caesarea sp.* | Random | 1 | 1 |
| *Canthium dicoccum* | Random | 1 | 1 |
| *Canthium parviflorum* | Random | 6 | 8 |
| *Careya arborea* | Random | 2 | 2 |
| *Cassia fistula* | Random | 12 | 21 |
| *Cassia spectabilis* | Random | 1 | 1 |
| *Celastrus paniculatus* | Random | 1 | 1 |
| *Dendrocalamus strictus* | Random | 2 | 3 |
| *Dimocarpus longan* | Random | 1 | 1 |
| *Diospyros melanoxylon* | Random | 2 | 2 |
| *Diospyros montana* | Random | 14 | 16 |
| *Embelia tsjeriam-cottam* | Random | 2 | 2 |
| *Ervatamia heyneana* | Random | 3 | 3 |
| *Erythroxylum monogynum* | Random | 3 | 3 |
| *Ficus microcarpa* | Random | 1 | 1 |
| *Flueggea leucopyrus* | Random | 1 | 1 |

**Table 11** (continued)

| Species | Aggregation | Frequency of occurrence | Density |
|---|---|---|---|
| *Garuga pinnata* | Random | 1 | 1 |
| *Gmelina arborea* | Random | 2 | 2 |
| *Helicteres isora* | Random | 2 | 2 |
| *Hiptage benghalensis* | Random | 8 | 11 |
| *Holarrhena antidysenterica* | Random | 1 | 1 |
| *Ipomoea illustris* | Random | 1 | 1 |
| *Maytenus emarginata* | Random | 1 | 1 |
| *Meiogyne sp.* | Random | 1 | 1 |
| *Memecylon umbellatum* | Random | 1 | 1 |
| *Mimosa rubicaulis* | Random | 12 | 17 |
| *Phyllanthus emblica* | Random | 7 | 7 |
| *Polyalthia coffeoides* | Random | 7 | 10 |
| *Premna tomentosa* | Random | 1 | 1 |
| *Pterocarpus marsupium* | Random | 3 | 3 |
| *Scutia myrtina* | Random | 1 | 1 |
| *Terminalia arjuna* | Random | 15 | 29 |
| *Terminalia bellirica* | Random | 19 | 34 |
| *Terminalia chebula* | Random | 1 | 1 |
| *Toddalia asiatica* | Random | 2 | 2 |
| *Uvaria narum* | Random | 1 | 1 |
| *Vitex altissima* | Random | 8 | 9 |
| *Wrightia tinctoria* | Random | 2 | 2 |
| *Ziziphus rugosa* | Random | 2 | 3 |

**Acknowledgements** Environmental Management and Policy Research Institute (EMPRI) would like to thank the Karnataka Forest Department (KFD) for giving permission to establish the plot (PPP) in BNP and also providing us help and manpower during our studies in this elephant prone area. EMPRI is indebted to BNP forest watchers for helping us in identifying species using the local language and to A.N. Sringeswara, Curator (Assistant Professor), Botanical Garden, University of Agricultural Sciences, Bangalore for identifying and validating some of the Thalewood house species. The financial support provided by the Department of Science and Technology under the SPLICE project is gratefully acknowledged.

## References

Ashton PS (1988) Dipterocarp biology as a window to the understanding of tropical forest structure. Annu Rev Ecol Syst 19:347–370

Bakker JP, Olff H, Willems JH, Zobel M (1996) Why do we need permanent plots in the study of long-term vegetation dynamics? J Veg Sci 7:147–156

Bunyavejchewin S, JLaFrankie, PJ Baker and M Kanzaki, (2003) Spatial distribution patterns of the dominant canopy dipterocarp species in a seasonal dry evergreen forest in western Thailand. For Ecol Manag 175:87–101

Cannon CH, Peart DR, Leighton M (1998) Tree species diversity in commercially logged Bornean rainforest. Science 28:1366–1368

Chaturvedi RK, Raghubanshi AS, Singh JS (2011) Effect of small-scale variations in environmental factors on the distribution of woody species in tropical deciduous forests of Vindhyan highlands, India. J Bot. https://doi.org/10.1155/2011/297097

Chaturvedi RK, Joshi J, Jayaraman M, Bala G, Ravindranath NH (2012) Multi-model climate change projections for India under representative concentration pathways. Curr Sci 103:791–802

Chisholm RA, Condit R, Abd. Rahman K, Baker PJ, Bunyavejchewin S, Chen YY, Chuyong G, Dattaraja HS, Davies S, Ewango CEN, Gunatilleke CVS, Gunatilleke IAUN, Hubbell S, Kenfack D, Kiratiprayoon S, Lin Y, Makana JR, Pongpattananurak N, Pulla S, Punchi-Manage R, Sukumar R, Su SH, Sun IF, Suresh HS, Tan S, Thomas D, Yap S (2014) Temporal variability of forest communities: empirical estimates of population change in 4000 tree species. Ecol Lett 17:855–865

Coelho MS, Almada ED, Quintino AV, Fernandes GW, Santos RMS, Sanchez-Azofeifa GA, Espírito-Santo MMD (2012) Floristic composition and structure of a seasonally dry tropical forest at different successional stages in the Espinhaco Mountains, southeastern Brazil. Interciencia 37:190–196

Coleman et al (2019) Top 100 research questions for biodiversity conservation in Southeast Asia. Biol Consev 234:211–220

Condit R et al (1998) Assessing forest diversity on small plots: calibration using species-individual curves from 50-ha plots. In: Dallmeir F, Comiskey JA (eds) Forest biodiversity research, Monitoring and modeling conceptual background-old world case studies. Paris, pp 247–268

Condit R (1998) Tropical Forest Census Plots: Methods and results from Barro Colorado Island, Panama and a comparison with other plots. Springer, Berlin

Condit R, Hubbell SP, Foster RB (1992) Stability and Change of a Neotropical Moist Forest over a Decade. Bioscience 42:822–828

Cottam G, Curtis JT (1956) The use of distance measures in phytosociological sampling. Ecologyvol 37:451–460

Dutta G, Devi A (2013) Plant diversity and community structure in tropical moist deciduous sal (*Shorea robusta* Gaertn.) forest of Assam, northeast India. J Environ Appl Biores 1:1–4
Gentry AH (1988) Changes in plant community diversity and floristic composition on environmental and geographical gradients. Ann Mo Bot Gard 75(1):1–34
Gentry AH (1992) Tropical forest biodiversity: Distribution patterns and their conservational significance. Oikos 63:19–28
Gentry, (1995) Diversity and floristic composition of neotropical dry forests. In: Bullock SH, Mooney HA, Medina E (eds) Seasonally dry tropical forests. Cambridge University Press, Cambridge, pp 149–194
Gillespie TW, Grijalva A, Farris CN (2000) Diversity, Composition and Structure of tropial dry forests in Central America. Plant Ecol 147:37–47
Gopalakrishna SP, Kaonga ML, Somashekar RK, Suresh HS, Suresh R (2015) Tree diversity in the tropical dry forest of Bannerghatta National Park in Eastern Ghats, southern India. Eur J Ecol 1:12–27
Hammer Ø, David ATH, Paul DR (2001) PAST: paleontological statistics software package for education and data analysis. Palaeontol Electron 4 (1), art. 4: 9pp., 178kb. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.
Hayden B, Greene DF (2008) The ecology of tropical dry forests. A chapter in the Encyclopedia of Tropical Ecology and Conservation (UNESCO)
Jannes M, von Wehrden H, Rodríguez EF, Arisméndiz RR, Bayer F, Richter M (2013) Woody vegetation of a Peruvian tropical dry forest along a climatic gradient depends more on soil than annual precipitation. Erdkundevol 67(3):241–248
Joshi RK, Dhyani S (2019) Biomass, Carbon density and diversity of tree species in tropical deciduous forests in Central India. Acta Ecol Sin 39:289–299
Kacholi DS (2014) Analysis of structure and diversity of the Kilengwe forest in the Morogoro region, Tanzania. Int J Biodivers 2014:1–8
Kakkar R, Vinaya Kumar KH, Remadevi OK, Manjunatha M, Saritha B, Sharma B, Kiranraddi M, Dattaraja HS, Suresh HS (2018) Establishing permanent preservation plots in Bannerghatta National Park for long-term ecological studies to monitor climate change. My Forest 54:19–34
Karanth KU, Sunquist ME (1992) Population structure, density and biomass of large herbivores in the tropical forests of Nagerhole, India. J Trop Ecol 8:21–35
Kumar JIN, Kumar RN, Bhoi RK, Sajish PR (2010) Tree species diversity and soil nutrient status of tropical dry deciduous forest of western India. Trop Ecol 51:273–279
Kushwaha SPS, Nandy S (2012) Species diversity and community structure in sal (*Shorea robusta*) forests of two different rainfall regimes in West Bengal, India. Biodivers Conserv 21:1215–1228
Mahanand S, Behera MD (2019) Understanding the Indian mainland-island biogeography through plant dispersal mechanism. Biodivers Conserv 28(8–9):2063–2084
Mandal G, Joshi SP (2014) Analysis of vegetation dynamics and phytodiversity from three dry deciduous forests of Doon Valley, Western Himalaya, India. J Asia-Pac Biodivers 7:292–304
Manna SS, Mishra SP (2017) Diversity, population structure and regeneration of tree species in Lalgarh forest range of West Bengal, India. Int J Bot Stud 2:191–195
Marod D, Kutintara U, Yarwudhi C, Tanaka H, Nakashisuka T (1999) Structural dynamics of a natural mixed deciduous forest in western Thailand. J Veg Sci 10:777–786
McAleece N, Gage JDG, Lambshead PJD, Paterson GLJ (1997) BioDiversity Professional statistics analysis software. Jointly developed by the Scottish Association for Marine Science and the Natural History Museum London.
McShea WJ, Davies SJ, Naris B (eds) (2011) The ecology and conservation of seasonally dry forests in Asia. Smithsonian Institution Scholarly Press, Washington, DC, pp 164–178
Miles LACN, DeFries RS, Ravilious C, IMay, S Blyth, V Kapos and JE Gordon, (2006) A global overview of the conservation status of tropical dry forests. J Biogeogr 33:491–505
Murali KS, Sukumar R (1993) Leaf flushing phenology and herbivory in a tropical dry deciduous forest, southern India. Oecologia 94:114–120
Murphy PG, Lugo AE (1986) Ecology of tropical dry forest. Annu Rev Ecol Syst 17:67–88
Murphy PG, Lugo AE (1995) Dry forests of Central America and the Caribbean. In: Bullock SH, Mooney HA, Medina E (eds) Seasonally dry tropical forests. Cambridge University Press, Cambridge, pp 9–34
Naidu MT, Kumar OA (2016) Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India. J Asia-Pac Biodivers 9:328–334
Nanda A, Prakasha HM, Krishnamurthy YL, Suresh HS (2010) Phenology of a tropical dry forest: study from Bhadra Wildlife Sanctuary, Karnataka, Peninsular India. Indian J For 33(2):167–172
Pande PK (2001) Structures of the tropical dry deciduous teak (*Tectona grandis*) forests of Satpura plateau (India) with special emphasis on regeneration and disturbance. J Trop Sci 13:329–343
Prasad SN, Hegde M (1986) Phenology and seasonality in the tropical deciduous forest of Bandipur. South India Proc Indian Acad Sci (plant Sci) 96:121–133
Rai SN (1996) Long term research sites in tropical forests in India. UNESCO Report
Raju R (2014) Master Plan of Bannerghatta Biological Park, Bangalore, 2014–15 to 2033–34, Karnataka Forest Department
Ravindranath NH, Joshi NV, Sukumar R, Saxena A (2006) Impact of climate change on forests in India. Curr Sci 90:354–361
Reddy CS, Pattanaik C, Mohapatra A, Biswal AK (2007) Phytosociological observations on tree diversity of tropical forest of Similipal Biosphere Reserve, Orissa, India. Taiwania 52:352–359
Reddy CS, Babar S, Giriraj A, Reddy KN, Thulsi Rao K (2008) Structure and floristic composition of tree diversity in tropical dry deciduous forest of eastern ghats, Southern Andhra Pradesh. India Asian J Sci Res 1(1):57–64
Reddy CS, Babar S, Giriraj A, Pattanaik C (2011) Structure and floristic composition of tree stand in tropical forest in the Eastern Ghats of northern Andhra Pradesh, India. J For Res 22(4):491–500
Romero-Duque LP, Jaramillo VJ, Perez Jimenez A (2007) Structure and diversity of secondary tropical dry forests in Mexico, differing in their prior land-use history. For Ecol Manag 253:38–47
Sahu SC, Dhal NK, Mohanty RC (2012a) Tree species diversity, distribution and population structure in a tropical dry deciduous forest of Malyagiri hill ranges, Eastern Ghats, India. Trop Ecol 53:163–168
Sahu SC, Dhal NK, Lal B, Mohanty RC (2012b) Differences in tree species diversity and soil nutrient status in a tropical sacred forest ecosystem on Niyamgiri hill range, Eastern Ghats, India. J Mt Sci 9:492–500
Sann B, Kanzaki M, Aung M, Htay KM (2016) Assessment of the recovery of a secondary tropical dry forest after human disturbance in Central Myanmar. J Trop For Sci 28(4):479–489
Sathya M, Jayakumar S (2017) Post-fire regeneration status of tree species in a tropical dry deciduous forest of southern India. J Trop For Sci 29:305–317
Shankar U (2001) A case of high tree diversity in a sal (*Shorea robusta*) dominated lowland forest of Eastern Himalaya: floristic composition, regeneration and conservation. Curr Sci 81:776–786
Singh JS, Chaturvedi RK (2017) Diversity of ecosystem types in India: a review. Proc Indian Natl Sci Acad 83:569–594

Singh KP, Kushwaha CP (2005) Emerging Paradigms of tree phenology in dry tropics. Curr Sci 89:964–975

Stan K, Sanchez-Azofeifa A (2019) Tropical dry forest diversity, climatic response, and resilience in a changing climate. Forests 10:443. https://doi.org/10.3390/f10050443

Sukumar R, Dattaraja HS, Suresh HS, Radhakrishnan J, Vasudeva R, Nirmala S, Joshi NV (1992) Long term monitoring of vegetation in a tropical deciduous forest in Mudumalai, southern India. Curr Sci 62:608–616

Sukumar R, Suresh HS, Dattaraja HS, Joshi NV (1998) Dynamics of a tropical deciduous forest: population changes (1988 through 1993) in a 50-hectare plot at Mudumalai, southern India. In: Dallmeier F, Comiskey JA (eds) Forest biodiversity research, monitoring and modelling: conceptual background and old world case studies, vol 20, Chapter 28. UNESCO, Paris and The Parthenon Publishing Group, Man and The Biosphere Series, pp 495–506

Sukumar R, Suresh HS, Dattaraja HS, Srinidhi S, Nath C (2005) The dynamics of a tropical dry forest in India: Climate, fire, elephants and the evolution of life-history strategies. In: Burslem D (ed) Biotic interactions in the tropics. Cambridge University Press, U.K., pp 510–529

Swaine MD (1992) Characteristic of dry forest in West Africa and the influence of fire. J Veg Sci 3:365–374

Udupa KES (2017) New steps in ecological studies. My Forest 53(1–2):1–7

Varma S, Anand VD, Gopakrishna SP, Avinash KG, Nishant MS (Eds) (2009) Ecology, conservation and management of the Asian Elephant in Bannerghatta National Park, Southern India. A Rocha India/ANCF: Asian Ecology and Conservation Reference Series No. 1. A Rocha India and Asian Nature Conservation Foundation, Bangalore

Venkatraman AB, Arumugam R, Sukumar R (1995) The foraging ecology of Dhole (*Coun alpinus*) in Mudumalai Sanctuary, southern India. J Zool 237:543–561

Visalakshi N (1995) Vegetation analysis of two tropical dry evergreen forests in southern India. Trop Ecol 36:117–127

Yadav AS, Yadav RK (2005) Plant community structure of the Bala–fort forest in Alwar, Rajasthan. Int J Ecol Environ Sci 31:109–117