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Vegetation structure and floristic composition of a tropical dry deciduous forest in Bhadra Wildlife Sanctuary, Karnataka, India

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Abstract: A permanent 2 ha (200 m × 100 m) plot was established for long-term monitoring of plant diversity and dynamics in a tropical dry deciduous forest of Bhadra Wildlife Sanctuary, Karnataka, southern India. Enumeration of all woody plants ≥ 1 cm DBH (diameter at breast height) yielded a total of 1766 individuals that belonged to 46 species, 37 genera and 24 families. Combretaceae was the most abundant family in the forest with a family importance value of 68.3. Plant density varied from 20 - 90 individuals with an average 35 individuals/ quadrat (20 m × 20 m). *Randia dumetorum,* with 466 individuals (representing 26.7 % of the total density 2 ha^{-1}) with species importance value of 36.25, was the dominant species in the plot. The total basal area of the plot was 18.09 m^2 ha^{-1} with a mean of 0.72 m^2 $quadrat^{-1}$. The highest basal area of the plot was contributed by Combretaceae (12.93 m^2 2 ha^{-1}) at family level and *Terminalia tomentosa* (5.58 m^2 2 ha^{-1}) at species level. The lowest diameter class (1-10 cm) had the highest density (1054 individuals 2 ha^{-1}), but basal area was highest in the 80 - 90 cm diameter class (5.03m^2 2 ha^{-1}). Most of the species exhibited random or aggregated distribution over the plot. This study provides a baseline information on the dry forests of Bhadra Wildlife Sanctuary.

Resumen: Se estableció una parcela permanente de 2 ha (200 m × 100 m) para el monitoreo a largo plazo de la diversidad vegetal y la dinámica de un bosque tropical seco caducifolio del Sanctuary Bhadra para la Vida Silvestre, Karnataka, sur de la India. La enumeración de todas las plantas leñosas ≥ 1 cm DAP (diámetro a la altura del pecho) arrojó un total de 1766 individuos pertenecientes a 46 especies, 37 géneros y 24 familias. Combretaceae fue la familia más abundante en el bosque, con un valor de importancia de familia de 68.3. La densidad de plantas varió entre 20 y 90 individuos, con un promedio de 35 individuos por cuadro (20 m × 20 m). *Randia dumetorum*, con 466 individuos (representando 26.7 % de la densidad total en 2 ha^{-1}) y con un valor de importancia de especie de 36.25, fue la especie dominante en la parcela. El área basal total de la parcela fue de 18.09 m^2 ha^{-1}, con una media de 0.72 m^2 $quadrat^{-1}$. A nivel de familia Combretaceae hizo la contribución más grande al área basal de la parcela (12.93 m^2 2 ha^{-1}) y a nivel de especie lo hizo *Terminalia tomentosa* (5.58 m^2 2 ha^{-1}). La clase diamétrica menor (1-10 cm) tuvo la mayor densidad (1054 individuos 2 ha^{-1}), pero el área basal fue más grande en la clase diamétrica de 80 - 90 cm (5.03 m^2 2 ha^{-1}). La mayoría de las especies mostraron distribuciones aleatorias o agregadas en la parcela. Este estudio proporciona información de base sobre los bosques secos del Santuario Bhadra para la Vida Silvestre.

Resumo: Para acompanhamento a longo prazo da diversidade vegetal e da dinâmica de uma floresta tropical seca decídua, no santuário de vida selvagem em Bhadra, Karnataka, sul da Índia, foi estabelecida uma parcela permanente de 2 ha (200 m × 100 m). A enumeração de todas as plantas lenhosas ≥ 1 cm DAP (diâmetro à altura do peito) revelou um total de 1766

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indivíduos pertencentes a 46 espécies, 37 géneros e 24 famílias. As Combretaceae foram a família mais abundante na floresta com um valor de importância familiar de 68,3. A densidade de plantas variou entre os 20 e os 90 indivíduos, com uma média de 35 indivíduos/quadrado (20 × 20 m). A *Randia dumetorum*, com 466 indivíduos (representando 26,7 % da densidade total nos 2 ha^{-1}) e com um valor de importância específica de 36,25, foi a espécie dominante na parcela. A área basal total da parcela foi de 18.09 m^2 ha^{-1}, com uma média de 0.72 m^2 $quadrado^{-1}$. A maior área basal da parcela foi formada pelas Combretaceae (12.93 m^2 2 ha^{-1}), a nível familiar, e a *Terminalia tomentosa* (5.58 m^2 2 ha^{-1}), ao nível das espécies. A classe de menor diâmetro (1-10 cm) apresentou a maior densidade (1054 indivíduos 2 ha^{-1}), mas a área basal foi maior na classe de diâmetro de 80-90 cm (5.03 m^2 2 ha^{-1}). A maioria das espécies apresentou uma distribuição aleatória ou agregada no conjunto da parcela. Este estudo forneceu uma informação de base sobre as florestas secas do santuário de vida selvagem de Bhadra.

Key words: Dispersion pattern, diversity, dry deciduous forest, long-term monitoring, permanent plot, species richness.

Introduction

Tropical forests harbour the greatest wealth of biological and genetic diversity (Hubbell & Foster 1983). Covering only 7 % of the earth's land surface these forests have more than half of the worlds' species (May & Stumpf 2000). The tropical forests with a mean annual rainfall of 250 - 2000 mm and Potential Evapo-Transpiration (PET) >1 represent tropical dry forests (Holdridge 1967); these forests which once covered more than half the tropics have decreased considerably over the few decades due to various human interventions. Of the 86 % of the tropical forest area in India, 54 % are classified as dry deciduous, and 37 % as moist deciduous (Kaul & Sharma 1971; Singh & Kushwaha 2005). However, research on the population, ecosystems dynamics and conservation efforts on these forests is very rare (Mooney *et al.* 1995) even though these dry forests occupy more area than wet forests and have been of greater use to humans, their ecology is poorly known. The disappearance of tropical forests at an estimated rate of 1 - 2 % per year comes at a time when our knowledge of their structure, composition, dynamics, diversity and taxonomy has been not fully unraveled (Hubbell & Foster 1983). Kharkwal *et al.* (2005) opine that accelerated species loss could lead to collapse of the ecosystem. So far studies on forests conducted in the Western Ghats have been largely qualitative describing the forest type, dominant species and other physiognomic parameters (Kanade *et al.* 2008) and there were some studies such as Sukumar *et al.* (1992) and Ganesh *et al.* (1996) which describe the forests quantitatively. Further, Murphy and Lugo (1986) argued that the seasonally dry deciduous forests are the most disturbed and least protected ecosystems on earth. As about 42 % of the world forests are dry forests, successful conservation of these tropical forests will ultimately depend on understanding their ecosystems (Gentry 1990; Hartshorn 1983). A wide range of sampling methods have been employed in diversity inventories over the years (Ganesh *et al.* 1996; Mani & Parthasarathy 2006). But surely there is a lack of uniform methodology that has always been a concern for meaningful comparisons (Kanade *et al.* 2008). How high diversity in these tropical forests is maintained and how they change over time require long-term monitoring using permanent plots (Condit 1995; Hubbell & Foster 1983; Phillips & Gentry 1994).

Quantitative floristic inventories based on small sized permanent plots (1 - 2 ha) have been used in recent years to characterize the vegetation in different tropical forests by documenting their structure, composition and diversity (Parthasarathy 2001; Sagar *et al.* 2003; Smith & Killeen 1995; Strasberg 1996). There has been increasing interest even in documenting the long-term dynamics of tropical forests through the establishment of perm-anent plots. These forest inventories serve as an invaluable research base for diverse aspects of tropical ecology while providing information crucial for their conservation and management (Ayyappan & Parthasarathy 1999).

The objective of the present paper is to describe the vegetation structure, composition and

diversity of a 2 ha permanent plot in a moderately disturbed, tropical dry deciduous forest of Bhadra Wildlife Sanctuary, Karnataka, India.

Material and methods

Study area

Bhadra Wildlife Sanctuary is located in Karnataka State, south India, and extends between 13º 25' and 13º 50' N latitude to 75º 15' and 75º 50' E longitude. The elevation gradient (from 750 m to 2100 m above msl) has resulted in a variety of vegetation ranging from dry deciduous to semi-evergreen forests including the unique shola forest at Bababudan Giri at 1400 m above msl.

The study site is Choudikatte located near Umbalebailu about 30 km south of Shimoga town at 13º 45.3' N latitude and 75º 35.5' E longitude in the northern region of the sanctuary at 800 m above msl (Fig. 1). The study plot, with gentle slopes leading up to ridges, was aligned 100 m eastwards and 200 m northwards. The difference between the lowest and highest point in the plot was 23 m. The site receives a mean annual rainfall of 1044.3 mm (data recorded at the Irrigation Department of Bhadra River Project 12 km west of the study site) during the 13 year period 1992 - 2004. The temperature in the area varies little and has a monthly mean of 23.93 ºC (Fig. 2).

Choudikatte, just 10 km away from the backwaters of Bhadra River Project and surrounded by 3 - 4 villages, is classified as 'southern mixed dry deciduous forest' of type '5AC3' (Champion & Seth 1968). It is dominated by tree species *Xylia xylocarpa, Tectona grandis* and *Randia dumetorum* and its mammalian fauna include the tiger, panther, deer and primates. The area is subject to constant change due to anthropogenic activities like collection of fuel wood, honey, litter and bamboo, resulting in a few footpaths into and through the study site.

A permanent rectangular plot of 2 ha (200 × 100 m²) was established in the study site. The fieldwork was conducted from January to August 2004 with a theodolite-surveying instrument. The whole plot was sub demarcated into 20 m x 20 m quadrats with appropriate corrections made for slope. The corners of the quadrats were marked

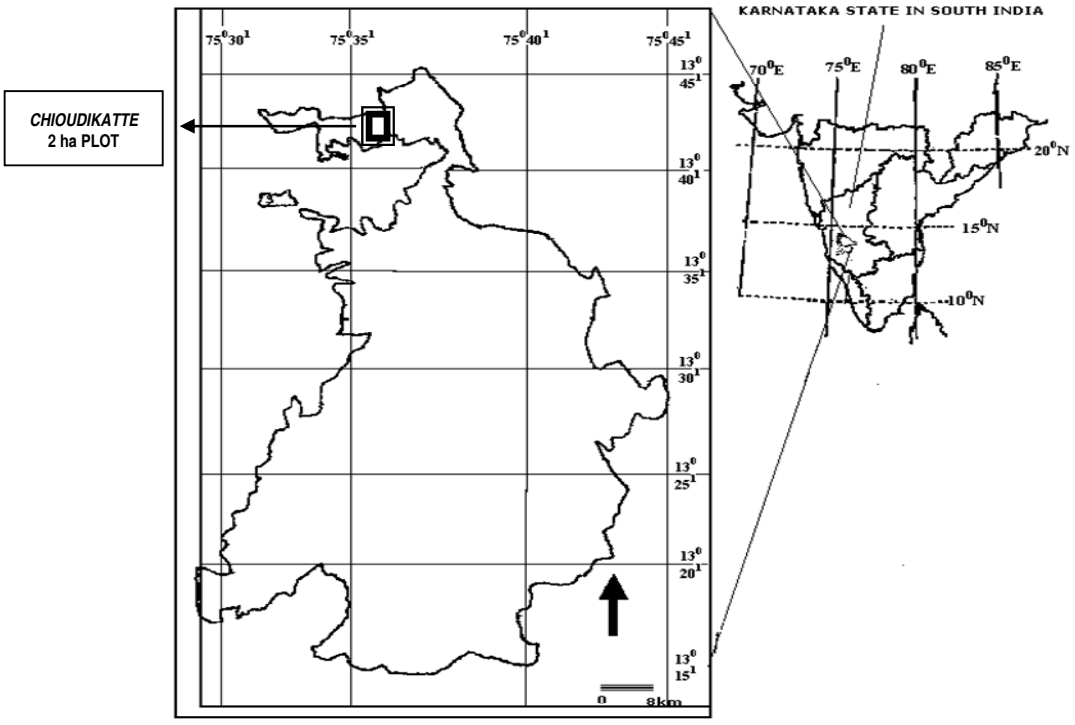


Fig. 1. Location of Choudikatte study area in Bhadra Wildlife sanctuary, Karnataka, southern India.

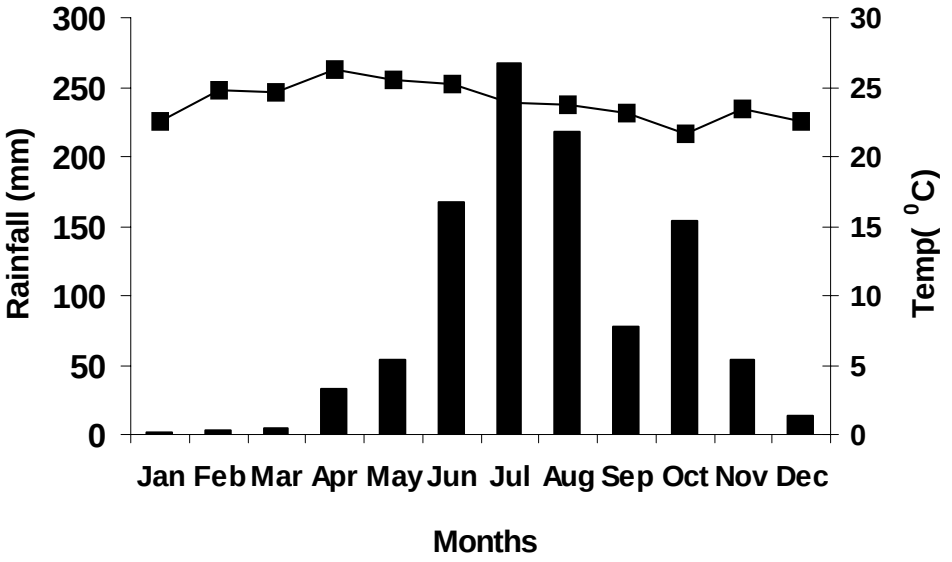


Fig. 2. Average monthly rainfall (mm) and temperature in °C from 1992 to 2004 recorded at the Irrigation Department, Bhadra River Project, the nearest monitoring station to study site of Choudikatte.

with stone pillars. All living woody plants ≥ 1 cm diameter at breast height (i.e., 1.3 m from the ground) were enumerated using sequentially numbered aluminium tags. Spatial locations of the enumerated plants were mapped to the nearest meter by measuring the X and Y co-ordinates along two adjacent sides of the plot. Individuals with multiple stems arising below or above ground branches were given single number but measured for their circumference separately (Sukumar *et al.* 1992). Voucher specimens of species were collected; their identities confirmed by referring to various regional floras (Gamble & Fischer 1998; Ramaswamy *et al.* 2001; Saldanha 1996; Yoganarasimhan *et al.* 1982) and are deposited in the herbarium of Department of Applied Botany, Kuvempu University. During the survey and enumeration utmost care was taken to avoid disturbance to the flora and fauna.

Data analysis

Density, abundance, frequency, basal area (as πr^2) and their relative measures for each species have been calculated. A single summary statistic or Importance Value was calculated by summing the relative values for species (Species Importance Value- SIV), and for families (Family Importance Value- FIV) according to Ganesh *et al.* (1996). The equations used are given below:

SIV = relative frequency + relative density + relative dominance, where,

Relative frequency = (number of plots containing a species × 100)/ sum of frequencies of all species.

Relative density = (number of individuals of a species x 100)/ total number of individuals of all species.

Relative dominance = (basal area of a species × 100)/ total basal area of all species.

The Family Importance Value (FIV) was calculated as follows,

FIV = relative density + relative diversity + relative dominance where,

Relative density = (number of individuals of the species × 100)/ total number of individuals in the sample.

Relative diversity = (number of species in the family × 100)/ total number of species in the sample.

Relative dominance = (basal area of the family × 100)/ total basal area in the sample.

A species-area curve was plotted using the new species encountered in each of the subsequent fifty 20 m × 20 m quadrats measured in terms of ha.

Shannon-Weiner and Simpson diversity indices were calculated as follows (Magurran 1998).

Shanon-Weiner Index $H^1 = -\sum pi \ln pi$

Where pi = ni/N, i.e. the proportion of individuals

of 'i' the species (ni) and total number of individuals of all the species (N)

Simpson's Index $D = \sum \frac{ni(ni-1)}{N(N-1)}$

Where, N = total number of individuals in the sample

ni = number of individuals of species 'i'

Pattern of dispersion of species was studied by variance -to- mean ratio (v/m) of the densities of the species in each quadrat. A ratio of 1.0 or nearer to 1.0 indicates a random dispersion, less than 1.0 a uniform dispersion and greater than 1.0 an increasingly clumped or aggregated dispersion (Joshi *et al.* 1997).

Results

Vegetation structure: Stand density

A total of 1766 woody individuals ≥ 1 cm were enumerated in the 2 ha area. Canopy trees included *Terminalia paniculata* (179 individuals), *T. tomentosa* (98 individuals) and *Pterocarpus marsupium* (32 individuals), while the middle storey was comprised of *Xylia xylocarpa*, *Tectona grandis* and *Dalbergia latifolia* with 211, 151 and 66 individuals. In the understorey, *Randia dumetorum* (466 individuals) and *Holarrhena antidysenterica* (112 individuals) were the dominant species along with saplings of the former two strata (Table 1). Dense patches of cosmopolitan weed *Chromalaena odorata* are probably affecting the understorey species. Even then patches of *Barleria involucrata*, *B. courtallica*, *Blepharis asperrima* (Acanthaceae), *Desmodium pulchellum, D. gangeiticum* (Papilionaceae), *Costus speciosus* (Costaceae) and some of the grasses like *Brachiaria setigera, Themeda triandra* and *Eragostis nigra* occur in the forest.

Basal Area

The basal area of the 2 ha sampled plot was 36.75 m^2. Quadrat-wise, the basal area varied from a low of 0.29 m^2 to 1.23 m^2 with a mean of 0.72 m^2; basal area exceeded the mean stand basal area in 25 quadrats. *Terminalia tomentosa* had the largest basal area in the plot with about 15.4 % (5.58 m^2 $2ha^{-1}$) of the total basal area followed by *Anogeissus latifolia* with 3.56 m^2 $2ha^{-1}$ (10.1 %) and *Terminalia paniculata* with 3.28 m^2 $2ha^{-1}$ (8.9 %) of the total area. These three species along with *Tectona grandis, Dalbergia latifolia* and *Xylia xylocarpa* contributed about 55.8 % (22.6 m^2 $2ha^{-1}$) of the total basal area. The dominant families based on basal area were Combretaceae with 12.93 m^2 $2ha^{-1}$ (35.18 %) followed by Papilionaceae with 5.57 m^2 $2ha^{-1}$ (15.1 %) and Mimosaceae with 54 m^2 $2ha^{-1}$ (12.35 %).

Patterns of dispersion

The stand density of each quadrat varied from 20 to 91 stems (not trees) with a mean of 39 stems per quadrat. In 21 of the 50 quadrats sampled, the stem density exceeded the mean stand density. None of the 46 species studied exhibited uniform dispersion patterns but about 30 species exhibited random dispersion, particularly *Diospyros montana* and *Zizhiphus oenoplea*. Among the remaining 16 aggregated species, 13 species including the most dominant *Randia dumetorum*, *Terminalia paniculata* and *Xylia xylocarpa* displayed clumped dispersion.

Floristic structure: Species richness and density

The census of individuals ≥ 1 cm in the 2 ha permanent plot resulted in 44 identified and 2 unidentified plant species which represented 37 genera and 24 families. Species richness varied from 6 to 17 species per quadrat with a mean of 11 species per quadrat. The densities of the 46 species enumerated in the 2 ha plot showed a wide variation, ranging from 1 individual each for four species to 466 individuals for *Randia dumetorum*. Based on their density in the 2 ha plot, species were grouped in to the five following categories:

(a) Predominant species (species with ≥ 200 individuals): *Randia dumetorum* (466 individuals) and *Xylia xylocarpa* (211 individuals) belonged to this category representing 4.3 % of the plot's species and 38.3 % of the plot's density (Table 1).

(b) Dominant species (species with 100 to 199 individuals): *Terminalia paniculata, Tectona grandis, Holararrhena antidysenterica and Anogeissus latifolia* together accounting for 8.7 % of the plot's species and 31.03 % of the stand density (548 individuals) represented this group.

(c) Common species (species with 25 to 99 individuals): Five species, *Terminalia tomentosa, Dalbergia latifolia, Ziziphus oenoplea, Spondias pinnata* and *Bauhinia malabarica,* accounting for 10.8 % of total species richness and 15.68 % of stand density represented this group and collectively they had 319 stems.

(d) Rare species (species with 3 to 24 individuals): Twenty-five species making up 54.3 % of the total plot's species and 255 individuals (14.4 % of the stand density) formed this group. Examples are *Adina cordifolia Dillenia pentagyna, Butea monosperma,* etc.

Table 1. Abundance, density, frequency, basal area and Species Importance Values (SIV) of the vegetation in Choudikatte 2 ha permanent plot.

S. No.	Species	Family	No. of Ind. 2 ha^{-1}	Density (no. $quad.^{-1}$)	Frequency	Basal area (m^2 $2ha^{-1}$)	SIV
1	*Randia dumetorum*	Rubiaceae	466	9.32	1.0	0.220	35.26
2	*Terminalia paniculata*	Combretaceae	179	3.58	0.90	3.289	26.53
3	*Terminalia tomentosa*	Combretaceae	98	1.96	0.78	5.580	24.08
4	*Xylia xylocarpa*	Mimosaceae	211	4.22	0.94	2.110	25.46
5	*Tectona grandis*	Verbenaceae	151	3.02	0.80	2.930	23.09
6	*Anogeissus latifolia*	Combretaceae	106	2.12	0.82	3.560	22.55
7	*Dalbergia latifolia*	Papilionaceae	66	1.32	0.70	2.620	16.65
8	*Holarrhena antidysenterica*	Apocynaceae	112	2.24	0.80	0.090	13.20
9	*Spondias pinnata*	Anacardiaceae	38	0.76	0.48	2.270	12.29
10	*Bauhinia malabarica*	Caesalpiniaceae	31	0.62	0.40	1.180	8.27
11	*Pterocarpus marsupium*	Papilionaceae	22	0.44	0.32	1.700	8.50
12	*Butea monosperma*	Papilionaceae	21	0.42	0.26	0.990	6.03
13	*Dillenia pentagyna*	Dillenaceae	22	0.44	0.30	0.990	6.42
14	*Ziziphus oenoplea*	Rhamnaceae	45	0.88	0.38	0.500	5.698
15	*Albizia odoratissima*	Mimosaceae	11	0.22	0.22	1.370	6.16
16	*Careya arborea*	Lecythidaceae	20	0.40	0.30	0.614	5.28
17	*Phyllanthus emblica*	Euphorbiaceae	21	0.42	0.30	0.577	4.23
18	*Bombax malabarica*	Bombacaceae	10	0.20	0.18	0.950	5.30
19	*Adina cordifolia*	Rubiaceae	21	0.44	0.26	0.345	3.50
20	*Albizia lebbeck*	Mimosaceae	11	0.24	0.16	0.745	4.36
21	*Terminalia bellirica*	Combretaceae	12	0.24	0.20	0.505	3.04
22	*Hymenodictyon excelsum*	Rubiaceae	7	0.14	0.12	0.670	2.72
23	*Schleichera oleosa*	Sapindacee	5	0.10	0.06	0.840	4.05
24	*Lagerstroemia microcarpa*	Lythraceae	13	0.28	0.18	0.086	2.01
25	*Dalbergia lanceolaria*	Papilionaceae	6	0.14	0.12	0.265	2.28
26	*Diospyros montana*	Ebenaceae	7	0.14	0.14	0.002	1.565
27	*Ficus sp.*	Moraceae	2	0.04	0.04	0.370	1.44
28	*Mitragyna parviflora*	Rubiaceae	4	0.08	0.08	0.147	1.28
29	*Semecarpus anacardium*	Anacardiaceae	4	0.08	0.08	0.127	1.23
30	*Radermachera xylocarpa*	Bignoniaceae	3	0.06	0.06	0.216	1.25
31	*Acacia sp.*	Mimosaceae	5	0.10	0.06	0.101	1.05
32	*Diospyros melanoxylon*	Ebenaceae	5	0.10	0.10	0.006	1.126
33	UI-1*	UI-1	2	0.04	0.04	0.270	1.17
34	*Grewia tilaefolia*	Teliaceae	4	0.08	0.08	0.090	1.13
35	*Cammiphora caudata*	Burseraceae	4	0.08	0.08	0.080	1.10
36	*Dendrocalamus strictus*	Poaceae	4	0.08	0.08	0	0.89
37	*Acacia sp.*	Mimosaceae	1	0.02	0.02	0.220	0.82
38	*Cassia fistula*	Caesalpiniaceae	3	0.06	0.06	0.020	0.72

Contd...

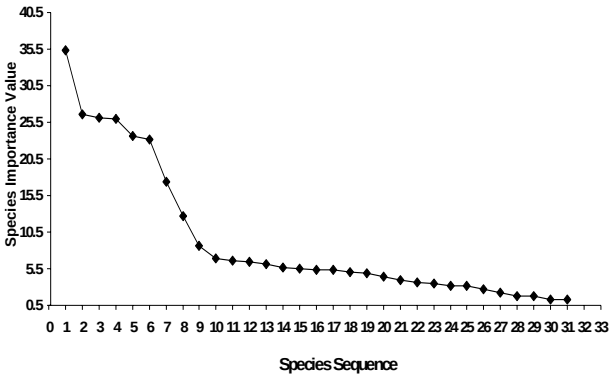
Table 1. Continued.

S. No.	Species	Family	No. of Ind. 2 ha^{-1}	Density (no. quad.$^{-1}$)	Frequency	Basal area (m^2 2ha^{-1})	SIV
39	*Canthium dicoccum*	Rubiaceae	3	0.06	0.06	0.0008	0.672
40	*Dolichondrone falcata*	Bignoniaceae	2	0.04	0.04	0.057	0.59
41	*Ziziphus xylopyrus*	Rhamnaceae	2	0.06	0.04	0.002	0.505
42	*Hardwickia binata*	Caesalpiniaceae	2	0.04	0.04	0.02	0.49
43	*Lagerstroemia parviflora*	Lythraceae	1	0.02	0.02	0.025	0.29
44	*Lagerstroemia lanceolata*	Lythraceae	1	0.02	0.02	0.0006	0.231
45	*Santalum album*	Santalaceae	1	0.02	0.02	0.0013	0.233
46	UI-2*	UI-2	1	0.02	0.02	0.0013	0.233
Total	46 Species		1766			36.75	300

* UI-Unidentified.

(e) Very rare species (species with ≤ 3 individuals): Four species with 2 individuals each and five species with 1 individual each contributed to this group. *Santalum album, Lagerstroemia lanceolata*, *Albizia chinensis* belong to this category along with the two unidentified species.

The most speciose genera were *Terminalia* and *Lagerstroemia,* each with three species. However, species of *Lagerstroemia* had only 1 - 14 individuals per species in the plot, whereas the species of *Terminalia* had 12 - 179 individuals per species and was the most abundant genus in the plot. *Terminalia panicuata* (179 individuals) and *T. tomentosa* (98 individuals) were co-dominant species in the plot based on SIV (Fig. 3). Initially the Species Importance Value showed a gradual decrease up to the species *Holarhhena antidy senterica* and then it sharply declined. *Randia dumetorum,* with a SIV of 35.26, figured on the top of SIV hierarchy. *Terminalia paniculata* and *Xylia xylocarpa* followed *Randia dumetorum* with SIV of 26.53 and 25.46, respectively. Species such as *Santalum album* and *Lagerstroemia lanceolata* had the lowest SIV with 0.23 each. The species-area curve showed an increase in species until it attained an asymptote around 1.6 ha (Fig. 4).



1. *R. dumetorum*, 2. *T. tomentosa*, 3. *T. paniculata*, 4. *X. xylocarpa*, 5. *A. latifolia*, 6. *T. grandis*, 7. *D. latifolia*, 8. *H. antidysenterica*, 9. *B. malabarica*, 10. *D. pentagyna*, 11. *L. coromandelica*, 12. *A. odoratissima*, 13. *B. monosperma*, 14. *Z. oenoplea*, 15. *Bo. malabarica*, 16. *P. emblica*, 17. *P. marsupium*, 19. *S. pinnata*, 20. *A. coridfolia*, 21. *T. bellirica*, 22. *M. parvifolia*, 23. *S. oleosa*, 24. UI (1), 25. *D. lanceolaria*, 26. *H. excelsum*, 27. *H. excelsum*, 28. *R. xylocarpa*, 29. *D. montana*, 30. *Ficus* sp., 31. *S. anacardium*, 32. *G. tilaefolia*, 33. *L. parviflora.*

Fig. 3. Species Importance Values for Choudikatte 2 ha permanent plot.

Family composition

Of the 24 families recorded (two unidentified), Mimosaceae and Rubiaceae are dominant based on species richness with five species each. Based on density plot^{-1} the top order of families were Rubiaceae (502 individuals), Combretaceae (395 individuals) and Papilionaceae (116 individuals), each of the latter two with four species. Thirteen families including two unidentified, were represented by just one species. Based on FIV, Combretaceae (68.3) ranked highest among families followed by Rubiaceae (40.8), Mimosaceae (36.4) and Papilionaceae (31.3) (Table 2).

The floristic structure of the study site exhibited a typical reverse 'J' shaped curve (Fig. 5). The smallest DBH class 1 - 10 cm was the richest in terms of number of species (31 species) and stand density (1034 stems), but had a basal area of

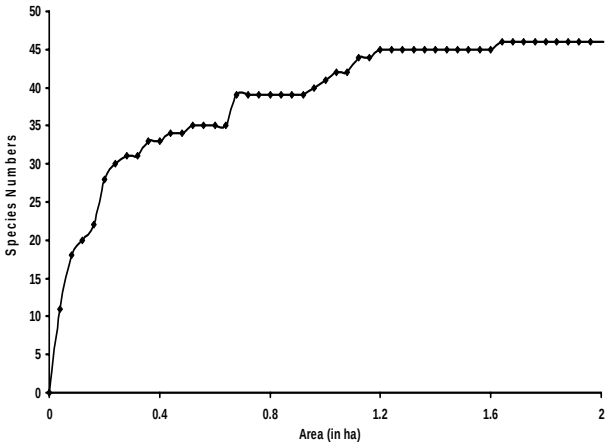


Fig. 4. Species-area curve for Choudikatte 2 ha permanent plot .

only 0.24 m^2. The 80 - 60 cm class had the highest basal area of 5.03 m^2 (13.9 %) which was contributed by 18 species and 89 stems (Table 3). The Shannon-Wiener and Simpson's indices were 3.30 and 7.94, respectively for the whole 2 ha plot.

Discussion

Structurally and floristically the tropical dry forests are less complex than the wet forests, comprising about half or less of the tree species of wet forests (Murphy & Lugo 1986). In this regard the present study carried out in the dry forest of Bhadra Wildlife Sanctuary, Karnataka is similar to many other dry forests in diversity and species composition. Species richness of the present study (46 species in 2 ha for individuals ≥ 1 cm) is closer to the species richness of the dry forests in Puerto Rico (50 species, Murphy & Lugo 1986), lower when compared to the 71 species of larger (50 ha) permanent plot of the Mudumalai Wildlife Sanctuary (Sukumar *et al.* 1992), but far less to the 133 species of Savanadurga State Forests of Karnataka (Murali *et al.* 2003). A stem density of 980 stems ha^{-1} (≥ 1 cm) for the dry forest of Bhadra is comparably higher than that of the dry tropical forests of Mudumalai, southern India, which recor-ded about 540 stems ha^{-1} (Sukumar *et al.* 1992). This is consistent with many of the other dry forests, which are characterized by the presence of large number of lower diameter class individuals. This observation is evident from the diameter class distribution in the plot that exhibited a typical reverse 'J' trend with maximum individuals occupying lower girth classes, indicating a good regeneration status of the forest. Such a higher density of small-sized individuals can be attributed to the open canopy and lower densities of the larger individuals (Manokaran & Lafrankie 1990). The acquisition of saturation by the species-area curve indicates that the 2 ha plot was a sufficient sample to determine the diversity of the forest. Thus, the minimal area to record the complete species diversity of the studied forest would be about 1.6 ha. A mean basal area of 18.2 m^2 ha^{-1} recorded in the study is almost equal to the 15 m^2 ha^{-1} basal area of the dry forests of St. Lucia (Gonzalez & Zak 1996) and lower than that of the Puerto Rico dry forests which measured 21 m^2 ha^{-1} (Murphy & Lugo 1986). The lower basal area in the forest likely results from smaller numbers of larger individuals (Gonzalez & Zak 1996).

The Importance Value Index revealed that this forest is dominated by relatively few species. The first seven species listed in Table 1 comprise about 62 % of the importance values. The dry forests in Puerto Rico (Murphy & Lugo 1986) and St. Lucia (Gonzalez & Zak 1996) also recorded the same observation with the seven most common species dominating the forests by comprising about 55 % and 67 % of the total importance values, respectively.

Among the 30 species analyzed for dispersion patterns, most of the species displayed either random or aggregated dispersions. None has shown uniform dispersion pattern that occurs as result of competition among species for water or other resources, and which enables higher species diversity in tropical forests (Connell 1971; MacMahon & Schimp 1981). Clumping or aggregation of individuals in the tropical forests is common and may be due to the inefficient mode of seed dispersal or due to the large gap formation in the forest that occurs on account of either natural or anthropogenic disturbances (Goparaju & Jha 2009; Odum 1971; Richards 1986). The random dispersion pattern exhibited by some species in the plot could be associated with frequent and large-scale disturbance such as fire (Armesto *et al.* 1986).

In contrast to the large-scale plots, small-scale permanent plots are efficient in terms of saving time and labour while providing useful data about the structure and diversity of forests. However, smaller plots with small scale sampling may fail to describe the actual distribution patterns of all the species as well as the beta diversity of a given area. Nevertheless, these plots provide useful data

Table 2. Family composition and Family Importance Value in Choudikatte 2 ha permanent plot.

Family	No. of Species	No. of trees	Basal Area (m^2 2 ha^{-1})	Relative density	Relative diversity	Relative dominance	FIV
Combretaceae	4	395	12.93	22.34	8.7	37.2	68.24
Rubiaceae	5	502	1.38	28.39	8.7	3.7	40.79
Mimosaceae	5	241	4.54	13.63	10.9	11.9	36.43
Papilionaceae	4	116	5.57	6.56	8.7	15.9	31.16
Verbenaceae	1	151	2.93	8.54	2.2	7.9	18.64
Anacardiaceae	2	42	2.39	2.38	4.5	5.99	12.87
Caesalpiniaceae	3	35	1.22	2.04	6.6	3.75	12.39
Apocynaceae	1	112	0.09	6.33	2.3	0.25	8.88
Lythraceae	3	16	0.00	0.9	6.6	0.29	7.79
Rhamnaceae	2	46	0.52	2.66	4.4	0.1	7.16
Dilleniaceae	1	22	0.99	1.24	2.2	2.5	5.94
Bombacaceae	1	10	0.95	0.57	2.2	2.63	5.40
Bignoniaceae	2	5	0.27	0.28	4.4	0.68	5.36
Lecythidaceae	1	20	0.61	1.13	2.3	1.95	5.38
Euphorbiaceae	1	21	0.57	1.19	2.3	1.8	5.29
Ebenaceae	2	12	0.008	0.68	4.4	0.02	5.10
Sapindaceae	1	5	0.84	0.28	2.2	2.1	4.58
Moraceae	1	2	0.37	0.11	2.2	0.92	3.23
UI-1*	1	1	0.27	0.06	2.2	0.68	2.94
Burseraceae	1	4	0.08	0.23	2.2	0.22	2.65
Teliaceae	1	2	0.09	0.11	2.2	0.22	2.53
Poaceae	1	4	0	0.23	2.2	0	2.43
Santalaceae	1	1	0.001	0.06	2.2	0	2.26
UI-2*	1	1	0.001	0.06	2.2	0	2.26
Total		1766	36.75	100	100	100	300

* UI-Unidentified.

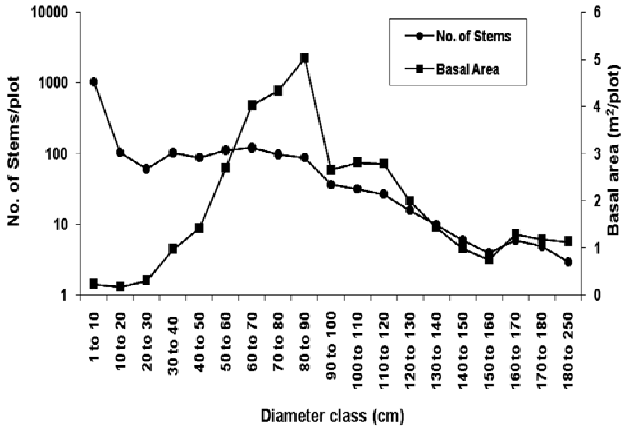


Fig. 5. Diameter class contribution towards number of stems and basal area (m^2) in Choudikatte plot.

when lack of resources, availability of manpower and all other logistical issues restrict the sample sizes to a minimum.

Conclusion

The 2 ha permanent plot established in the dry deciduous forest of Bhadra Wildlife Sanctuary exhibited greater species richness (46 species), basal area (36.75 m^2) and stand density (1766 individuals, 1961 stems) when compared to certain other dry deciduous forests. Further, this forest exhibits good regeneration status compared to other forests, and the permanently tagged individuals offer opportunities to investigate forest dynamics and changes in species relative abundances in the future. Even though the study site in Bhadra forest is protected,

Table 3. The proportion of species, stems and basal area in different size classes of Choudikatte 2 ha permanent plot.

S. No.	DBH Class (in cm)	No. of species $2ha^{-1}$	No. of stems $2ha^{-1}$	% of stems $2ha^{-1}$	Basal Area (m^2 $2ha^{-1}$)	% Basal Area
1	1 - 10	31	1034	52.84	0.24	0.66
2	10 - 20	15	105	5.30	0.18	0.50
3	20 - 30	17	61	3.11	0.31	0.85
4	30 - 40	15	104	5.30	0.98	2.70
5	40 - 50	19	89	4.50	1.42	3.91
6	50 - 60	18	113	5.80	2.70	7.43
7	60 - 70	24	122	6.22	4.03	11.09
8	70 - 80	21	98	5	4.34	11.94
9	80 - 90	18	89	4.53	5.03	13.84
10	90 - 100	13	37	1.89	2.66	7.32
11	100 - 110	14	32	1.63	2.82	7.76
12	110 - 120	15	27	1.37	2.80	7.70
13	120 - 130	11	16	0.81	2	5.50
14	130 - 140	7	10	0.50	1.44	3.96
15	140 - 150	6	6	0.30	1	2.75
16	150 - 160	3	4	0.20	0.76	2.09
17	160 - 170	6	6	0.30	1.30	3.58
18	170 - 180	4	5	0.25	1.19	3.27
19	180 - 250	3	3	0.15	1.14	3.14
	Total	46	1961	100	36.75 m^2	100

and despite the Government's constant efforts to provide alternate arrangements like social forestry and forest development corpora-tions, this forest is experiencing destruction because of the frequent visits of people from near by villages for their daily requirement of fuel, grass, fodder, fruits, bamboo and other non-timber forest produce. This has resulted in the fragmentation of the forest, thereby causing damage to both plant and animal diversity. Further, educating the local people and alerting the officials towards effective implementation of the rules would be helpful in decreasing the depletion of natural forest produce, which will in turn decrease the damage caused to this fragile ecosystem due to the various human disturbances. The present study in the Bhadra forest is very preliminary, and subsequent re census and monitoring will provide additional data on forest composition and diversity changes due to various disturbance regimes, which will be useful in forest management and conservation efforts.

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