EUROPEAN JOURNAL OF ECOLOGY

EJE 2015, 1(2): 12-27, doi: 10.1515/eje-2015-0013

Tree diversity in the tropical dry forest of Bannerghatta National Park in Eastern Ghats, Southern India

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ABSTRACT

Tree species inventories, particularly of poorly known dry deciduous forests, are needed to protect and restore forests in degraded landscapes. A study of forest stand structure, and species diversity and density of trees with girth at breast height (GBH) ≥10 cm was conducted in four management zones of Bannerghatta National Park (BNP) in the Eastern Ghats of Southern India. We identified 128 tree species belonging to 45 families in 7.9 hectares. However, 44 species were represented by ≤ 2 individuals. Mean diversity values per site for the dry forest of BNP were: tree composition (23.8 ±7.6), plant density (100.69 ± 40.02), species diversity (2.56 ± 0.44) and species richness (10.48 ± 4.05). Tree diversity was not significantly different (P>0.05) across the four management zones in the park. However, the number of tree species identified significantly (P<0.05) increased with increasing number of sampling sites, but majority of the species were captured. Similarly, there were significant variations (p<0.05) between tree diameter class distributions. Juveniles accounted for 87% of the tree population. The structure of the forest was not homogeneous, with sections ranging from poorly structured to highly stratified configurations. The study suggests that there was moderate tree diversity in the tropical dry thorn forest of Bannerghatta National Park, but the forest was relatively young.

KEYWORDS

Diameter at breast height – diameter class distribution – species composition – species richness – tree allometry – tree density

INTRODUCTION

Tropical forests, which cover less than 10% of the total land area, harbour 50-90% of the known terrestrial plant and animal species and forest biodiversity underpins most of the forest ecosystem services (MEA 2005; Seppala et al. 2009; FAO 2010). They also provide an estimated 1.6 billion people with livelihood systems and wood, while other forest goods are valued at US$122 billion (World Bank 2004; FAO 2010). In India, about 40% of the rural population, particularly the indigenous forest dwellers and the poor, depend on forest resources for energy, forest products and employment, with income from sale of commercial forest products contributing 40-60% to their total income (Kumar et al. 2012). Thus, protection and restoration of habitats, which enhance biodiversity and productivity, could directly benefit communities dependent on these forest resources (Heywood 1995; Reddy & Ugle 2008).

In the last quarter of the twentieth century, efforts of the international community to sustainably manage forests and increase biodiversity have resulted in net gains in forest area in Europe and Asia and in 13% of the total forest area being brought under formal protection (UNEP 2011). However, although the global rate of net forest cover loss has slowed, forest biodiversity loss has continued to occur disproportionately. The highest levels of deforestation and forest degradation are reported for natural forests in tropical countries, which account for the largest proportion of biodiversity and ecosystem services attributable to all of the world's forests (Moutinho & Schwartzman, 2005; FAO 2010; UNEP 2011; Ndah et al. 2013). The twentieth century witnessed the greatest loss of biodiversity due to habitat destruction, primarily through conversion of forests to agriculture (FAO 2010). Apart from reducing biodiversity, deforestation and forest degradation also increase greenhouse gas emissions, incidences of flooding, soil erosion and insecurity in the food, water and energy sectors (Angelsen & Kaimowitz 1999; FAO 2010).

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Within the mega-biodiverse Indian peninsula (Briggs 2003; Mittermeier et al. 2005), the dry forests of the Eastern Ghats have a very rich variety of biological diversity (Gopalakrishna et al. 2010). They harbour more than 2600 species of angiosperms, gymnosperms and pteridophytes, with 454 endemic species belonging to 243 genera and 78 families (Kanyana 2008). Tree diversity is fundamental to tropical forest diversity because trees provide resources and habitats for almost all other species (Cannon et al. 1998; Huang et al. 2003). As a dominant life form, trees are easy to locate precisely and to count (Condit et al. 1998) and are also better known taxonomically (Gentry 1992). However, trees are particularly vulnerable compared with other plant forms because they take a long time to reach reproductive age. They are also associated with low productivity, high mortality rates, ever-increasing demand for food and energy and declining land productivity (FAO 2009). Therefore, loss of tree species can undermine biodiversity and ecosystem services, economic development and livelihoods of resource-poor households that depend directly and/or indirectly on forest resources.

However, the primary forests of the Eastern Ghats of peninsular India are disappearing at an alarming rate due to anthropogenic activities and are replaced by either forests consisting of pioneer species or other land use systems such as agriculture (Varma et al. 2009). The region is experiencing rapid changes in demography, economy and society and hence, the Eastern Ghats, faces serious challenges of tropical deforestation and forest degradation. Sustaining tree diversity depends on reliable inventories that are used to determine the nature and distribution of tree species in the forest ecosystem being managed. Quantitative plant diversity inventories of tropical forests are available for various forests of the Western Ghats, but the Eastern Ghats is poorly studied (Pitchiramu et al. 2008; Varma et al. 2009).

The tropical dry forest of the Bannerghatta National Park (BNP), a part of the Eastern Ghats, offers an ideal habitat for several endangered plant species and is the world's largest remaining scrub forest for elephants among its range countries. Located only 24 km south of the expanding city of Bangalore, the pressure of human activities on the park is enormous. Apart from five communities within the park, 117 communities are within the 5 km buffer zone of the park boundary and they all depend on it for subsistence. Thus, the BNP is threatened by natural and anthropogenic activities including ever-increasing demand for food and energy, urbanisation, reduced productivity of agricultural land, low forest productivity, proliferation of invasive species, climate change and habitat degradation due to encroachment, cattle grazing, overharvesting of forest resources and increasing stocking rates of wildlife such as elephants (Pitchairamu et al. 2008; Varma et al. 2009). Disturbances created by these factors affect forest dynamics and tree diversity at local and regional level (Hubbell et al. 1999).

Park management for biodiversity conservation and human welfare requires a good understanding of the ecological status, ethnobotany and biology of the area (Dalle et al. 2002). However, hard data on floristic inventories and vegetation analyses of the tropical dry forest of BNP required to understand tree diversity, ecological processes and human livelihoods are scarce. Knowledge about the dry forests and their structural dynamics and wood species diversity are inadequate (Hubbell & Foster 1992; Varma et al. 2009). Varma *et al*. (2009) have argued for an in-depth study of various aspects of landscape, vegetation and tree diversity in BNP to better understand the vegetation composition and diversity and the degree of disturbance.

While the BNP provides fully protected habitats, there is still limited hard data on tree species diversity and distribution and forest stand structure. The impact of human activities resulting from the growing city of Bangalore is a fast-growing population and increasing economic activities of local communities in and around the park. This study addressed three questions: (i) what are the quantitative differences in forest stand structure and tree species diversity and distributions across forest management zones in the park; (ii) do relative abundances of tree species in various diameter classes differ with management zone; and (iii) to what extent are differences in overall tree diversity among sites associated with distribution of trees with DBH ≥ 10 cm. Tree species inventories will contribute forest biodiversity information to the park's reference database on forest assessment to inform conservation planning, ecological research and conservation of ecosystems and species in the park.

1. METHODS AND MATERIALS

1.1. Study area characteristics

The BNP (Figure 1), which covered an area of 102.74 km^2, lies between latitudes 12° 34' and 12° 50' N and between 77° 31' and 77° 38' E longitudes. The park includes a contiguous forest in the south and the world's largest remaining scrub forest for elephants among its range countries (Gopalakrishna *et al*. 2010). It has a highly undulating terrain with a mean altitude of 865 m (700-1035 m) above sea level, mean temperature of 27°C (12-38°C), and mean annual rainfall of 1065 mm (682-1607 mm). The geology of the park is characterised by rocks of the oldest formation revealing cryptocrystalline to coarse granites and complex gneiss, while granite sheet rocks dominate the higher hills (Rajeev 2002). The park is a home to several species of mammals, amphibians, reptiles and birds apart from the endangered Asian elephant. The vegetation consists of mainly the dry deciduous scrub forest, southern tropical dry deciduous forest and southern moist mixed forest. The BNP is divided into three wildlife ranges (WR): Bannerghatta, Harohalli and Anekal wildlife range. The park has an identified elephant corridor, the Karadikkal-Madeshwara elephant corridor (Varma et al. 2005).

1.2. Assessment of tree species

Tree diversity and distribution assessments were conducted between June and August 2012 in BNP. The park was divided

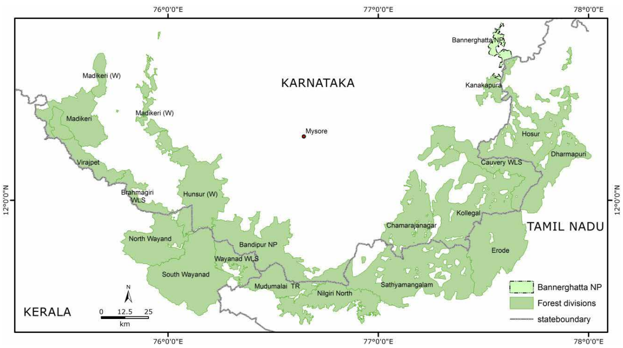

Figure 1. Map showing Bannerghatta National Park along with other adjoining forest divisions in Eastern Ghats

into 79 (1 km × 1 km) grid cells using ERDAS IMAGINE 9.1, an open source remote sensing and image processing software. This allows for processing satellite images and preparing maps used in geographical information system for geospatial applications. In each cell, a 250 m × 4 m belt transect with a north-east orientation was established (Figure 2). Transects were evenly distributed across the four management zones (Banngerghatta, Harohalli, Anekal and Karadikall-Madeshwala elephant corridor) covering all forests. Measurements of girth at breast height (GBH, 1.37 m) were taken for all trees with GBH ≥ 10 cm and converted to diameter and breast height (DBH) by dividing GBH values by Pi (3.14). All trees in 0.1 ha plots were enumerated, photographed and identified using the Champion and Seth's classification (1986) and the flora of Gurudeva (2001), Bhat (2000) and Mathew (2001) and voucher specimens of unidentified species were taken to the herbarium at the Indian Institute of Science. We used all tree species in plots to determine diameter class sizes for analysis. Data including geo-coordinates of the location, percentage canopy and percentage ground cover were collected at regular intervals using the ocular estimation method. This visual estimation technique is used to estimate the proportion of plot covered by tree canopy and the proportion of ground covered by vegetation.

1.3. Data analysis

Data were analysed to quantify tree species diversity, composition and density and forest structure across the four wildlife zones. Tree species abundance and relative abundance, density and relative density and species Importance Value Index (IVI) were analysed. The IVI value for a species, used to assess the distribution of species abundance, was computed as a sum of relative density, relative frequency and relative coverage (Rasavi et al. 2012). The diversity indices, including number of Taxa (S), Dominance (D), Shannon-Wiener's (H'), Simpson's index of diversity (1-D), Evenness (e^H/S), Equitability (J), Fisher's alpha index, were calculated using the software program PAST (PAleontological STatistics) (Hammer et al. 2001). The software is used for executing a range of standard numerical analysis and operations used in quantitative paleontology. The species accumulation curve was plotted using EstimateS, a free software application for computing a variety of biodiversity statistics, estimators and indices based on biotic data (Cowell 2013). A multivariate analysis of variance (MANOVA) test was carried out to assess the differences in tree diversity across the management zones.

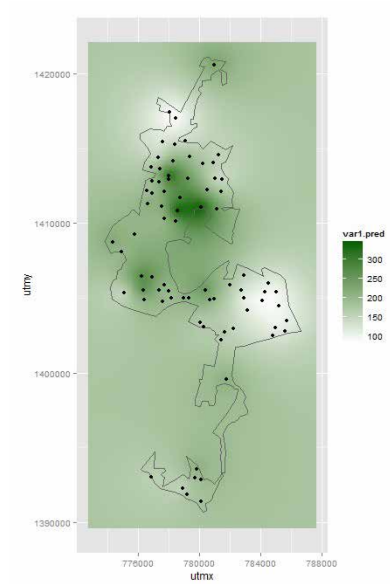

Figure 2. Map showing 79 (1 km × 1 km) grid cells used to establish belt transects for assessment of tree diversity in Bannerghatta National Park in Eastern Ghats

2. RESULTS

2.1. Species accumulation

Figure 3 shows a 'collector's curve' of woody species densities plotted as a function of number of sites enumerated. Cumulative densities of species for the first seven sites substantially increased with each additional site enumerated. However, the rate of increase diminished with increasing numbers of sites sampled after the seventh site. The 'collector's curve' flattened out as more woody species specimens were enumerated, but majority of the species were captured.

2.2. Tree diversity

A total of 7855 trees belonging to 128 species from 45 families were recorded within a sampled area of 7.9 ha. The five most abundant families were Combretaceae (n = 1103), Mimosaceae (546), Meliaceae (462), Rubiaceae (444) and Celastaceae (423) and their most dominant species in each family were *Anogeissus latifolia, Acacia chundra*, *Cedrela toona*, *Ixora arborea* and *Gymnosporia montana,* respectively. Fabaceae (13), Caesalpinioidaea (8), Rubiaceae (8), Mimosaceae (7) and Apocynaceae (7) were the most genetically diverse families (see Appendix 1). The IVI values for species ranged from 75 to 90%. Fifteen species were least abundant (represented by one individual), while seven trees could not be identified due to the non-availability of flower and/or fruit material.

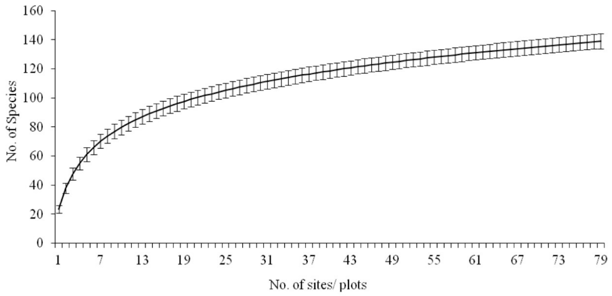

Figure 3. Tree species area curve for 7.9 ha of assessed forest in Bannerghatta National Park, Eastern Ghats

There were great variations in tree diversity indices across sites in the park (Table 1). Numbers of taxa per site (0.1 ha) ranged from 9 to 41 (mean 23.8 ± 7.6). Fifty three percent (53%) of the sites had more than 100 individual tree counts, but most of the site values were clustered in the middle of the range. The Shannon's evenness indices of diversity varied substantially between sites, ranging from 1.1 to 3.5 (mean, 2.6 ± 0.4 per site). The Simpson's index values for diversity varied from 0.4 to 1.0, but most of the indices were closer to 1.0 than 0. The Fisher's alpha index for species richness ranged from 3.2 to 25.2.

2.3. Tree diversity across zones

There were significant ($p < 0.05$) differences in tree diversity between the management zones. Bannerghatta management zone had the highest diversity, while Anekal zone had the lowest diversity. Tree diversity in the management zones decreased in the order: Bannerghatta > Harohalli > KM Corridor > Anekal wildlife zones. However, diversity values of Harohalli and KM Corridor were not statistically different from that of Bannerghatta and Anekal. Although the diversity index 'Individuals' showed significant differences ($p < 0.05$) in tree diversity across zones, six other diversity indices were not significantly different ($p > 0.05$) across the zones.

Table 1. Means of diversity indices of woody species at 79 sampling sites in the Bannerghatta National Park in Eastern Ghats, India

Variable	Mean ± SD	Range
Number of taxa	24 ± 8	9-41
Woody plant density (stems per site)	101 ± 40	16-182
Dominance index	0.1 ± 0.1	0-0.5
Shannon-Wiener's index	2.6 ± 0.4	1.1-3.5
Simpson index	0.9 ± 0.1	0.4-1.0
Evenness index	0.6 ± 0.1	0.5-0.9
Fisher's alpha index	3.2 ± 0.4	3.2-25.2

2.4. Forest structure

Mean tree density per site was 994 trees ha^{-1}, while the average number of individual trees in 0.1-ha plots was 101 ± 40 (16-182). Tree density consistently decreased with increasing diameter class of woody species from 0 to 5 cm to > 20 cm (Fig. 4). About 50% of the trees in sampled plots were in the 0-5 cm diameter class, while the 5-10 cm class accounted for 37%. The highest tree stand density and species richness were found in these two diameters, which accounted for 87% of enumerated trees. The > 15 cm DBH classes contributed < 4% to the total number of sampled trees (Table 2). However, there were no substantial ($p > 0.05$) variations in size class distribution of the individuals across the management zones. The mean basal area of sampled trees was 5.1 ± 3.6 m^2 ha^{-1}, with a larger proportion of trees in the smaller diameter classes.

2.5. Canopy cover and ground cover

Values of vegetation cover varied greatly from zero to full cover, with a mean overstory canopy cover of 38.42% (SE = 2.12, n = 76). The mean understory cover was 61.57% (SE = 2.12, n = 76), while the values varied from no ground cover to a full ground cover in some plots.

Table 2. Size class distribution of individuals in all sampled plots in the Bannerghatta National Park

Sl No.	Size class (DBH in cm)	Frequency of occurrence (%)
1	0-5	50.12
2	5-10	36.91
3	10-15	8.78
4	15-20	2.41
5	20-25	0.71
6	25-30	0.31
7	30-35	0.19
8	35-40	0.10
9	40-45	0.03
10	45-50	0.01

DBH: diameter and breast height

3. DISCUSSION

Tree density significantly contributes to the forest's functional diversity, ecological processes and ecosystem services. Mean tree density of 994 stems ha^{-1} in dry forests of the BNP in Eastern Ghats exceeded that of tropical deciduous forests of the northern Eastern Ghats (352, Panda et al. 2013), Kalrayan hills of Eastern Ghats (815, Kadavul & Parthasarathy 1999a);

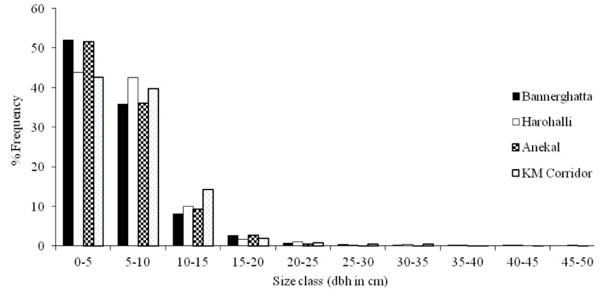

Figure 4. Tree girth class distributions across four management zones in Bannerghatta National Park, Eastern Ghats

tropical evergreen forests in Western Ghats (447, Ayyapan & Parthasarathy 2001); dry deciduous forest in Piranmalai forest in Tamil Nadu, Eastern Ghats (389, Pitchairamu et al. 2008); tropical deciduous forests of Eastern Ghats, southern Andhra Pradesh (735, Reddy & Ugle 2008). However, stem density in this forest study was lower than that of dry forests of West Bengal (1283, Krishnamurthy et al. 2010). The diffrences between current and published forest stem densities can be explained by anthropogenic activities in BNP, which have resulted in a forest dominated by juveniles. Tree density significantly differed across the sites, presumably due to factors related to seed dispersal, survival and establishment and also on resources extraction.

Tree species richness is fundamental to tropical forest biodiversity because trees provide resources and habitats for almost all other forest species (Huston 1994; Whitmore 1998). Tree species richness in Bannerghata forests, which ranged from 9 to 41 species per 0.1 ha site, was higher than the published range (4-13) for the same area (Varma et al. 2009). Similarly, species richness of 128 tree species over 7.9 ha was higher than the published count of 63 tree species in a 50-ha plot in Mudumalai Forest Reserve in India (Condit et al. 2000). However, the mean tree species richness of the forest in BNP (16 species with DBH > 10 cm) was significantly lower than the minimum values of published ranges of 56-283 species (> 10 cm DBH) ha^{-1} in mature tropical forests (Phillips & Gentry 1994) and 30-57 species ha^{-1} for various sites of the Western Ghats in Milodai and Courtallam Reserve Forest (Chandrashekara & Ramakrishna 1994; Parthasarathy & Karthikeyan 1997), and of 20-223 tree species ha^{-1} in tropical rainforests (Parthasarathy & Sethi 1997). Other studies have also reported 256 species over 222 ha in dry deciduous tropical forests of Eastern Ghats in India (Panda et al. 2013), 272 species in the 60 ha in southern Eastern Ghats (Pragasan & Parthasarathy 2010), and 996 species in a 52-ha plot in Lambir, Malaysia (Condit et al. 2000). Higher published species counts found in this study could be attributed to a combination of factors related to sampling size variations, species interaction (i.e. competition and niche diversification) and stand density (seed dispersal and survival and resource extraction). Within BNP, larger sampling area in this study gave a larger number of species than the smaller area previously sampled in the same park (Varma et al. 2009).

The five most abundant families in the BNP were Combretaceae, Mimosaceae, Meliaceae, Rubiaceae and Celastaceae, while Panda *et al*. (2013) found Euphorbiacea and Moraceae to be the most dominant families in the northern portion of Eastern Ghats. Padalia *et al*. (2004) also report that Euphorbitaceae and Rubiace are the most dominant families in all forest types, except mangrove. Disparities in family composition values could be attributed to anthropogenic activities and environmental activities. The dominance of a family could be attributed to habitat adaptation and favourable environmental conditions (soil and climatic conditions) that encourage pollination, dispersal and establishment of species (Coley & Barone 1996; Egbe et al. 2012; Panda et al. 2013). The family Fabaceae was the most genetically diverse, followed by Caesalpinioidaea, Rubiaceae, Mimosaceae and Apocynaceae. Dominance in the tropical forests of BNP, calculated as IVI, varied greatly in different stands. The forests were dominated by *A. latifolia* and *A. chundra*, with an IVI value of 90 each, followed by *I. arborea* (86) and *G. montana* (85), *C. toona* (75). About 44 species were least abundant, represented by one-two individuals, suggesting that they were rare species and needed to be protected. Seven trees could not be identified due to the non-availability of flower and/or fruit material and were labelled as unidentified trees.

A rich ecosystem has a large Shannon-Wiener index (H') value, while an ecosytem with a low value has low species diversity (Sobuy & Rahman 2011; Deka et al. 2012) and index values range from 0 to 5. A mean index of 2.56 suggests the dry forest of BNP had moderate tree species diversity. The measured index in this study was greater than the published value (1.57) for the same area (Varma et al. 2009). The H' values (1.07-3.45) in this study were within the range (0.83-4.1) reported for forests on the Indian subcontinent (Ayyapan & Parthasarathy 1999; Pandey 2000; Pitchairamu et al. 2008). The mean basal area of sampled trees (5.1 ± 3.6 m2 ha^{-1}) reveals a community with a limited number of trees with large girth presumably due to anthropogenic activities. However, the basal area was greater than the published value (3.28 m^2) for the same study site, but lower than that (6.59-48.49 m^2 ha^{-1}) of a tropical dry deciduous forest in Eastern Ghats, Tamil Nadu (Pitchairamu et al. 2008). A strong relationship between basal area, tree density and species diversity determines the ecosystem function of a dry forest and hence, recurring disturbance reduces the development of biomass and stems. Species diversity could, therefore, be enhanced by reducing the variability in tree basal area by regulating local disturbances (Pitchairamu et al. 2008). However, the effect of elephants on forest structure and tree diversity needs to be assessed.

The Shannon diversity indices in this study suggest that the dry forest in the park was moderately species diverse. Tree diversity in BNP was probably influenced by variability in topography, edaphic and climatic conditions, animal populations and human activities. Although, girth diameter threshold in this study did not capture a large population of invasive species, Varma *et al*. (2009) reported that 30% of the park was infested with *Lantana camara* and *Chromolaena odorata*, which aggressively compete with native tree species, while 25% of the park is barren land or rock outcrops. These factors greatly affected the tree density and diversity.

The mean Shannon's evenness index for BNP was comparable to the published index for the same area (Varma et al. 2009). The index suggests that abundances of individual trees of identified species in sampled forest stands were fairly even and 75% of indices were within the range 0.50-0.79. *A. latifolia*, *A. chundra* and *C. toona* were the most abundant tree species in BNP, accounting for 21% of the individual trees recorded. In a separate study (Varma et al. 2009), *A. latifolia, A. chundra, Shorea robusta* acounted for 55% of the enumerated trees. The differences between the results obtained in this study and those mentioned in the above reference could be attributed to differences in sampling designs. Varma *et al*. (2009) recorded 309 individuals belonging to 37 species compared with 7855 individuals belonging to 128 species in this study. According to Condit *et al*. (1996), diversity studies may underestimate the species richness in tropical forests when stem counts are less than 1000. With increasing sample size, the number of species increases, diversity stabilises and evenness decreases (Oksanen 2004). The large proportion of species represented by ≤ 2 individuals (34%) in this study indicates that a large number of sampled tree species in the park were rare. Therefore, priority should be given to Eastern Ghats, which is facing a lot of pressure from increasing population and development activities.

The low mean Simpson's dominance index for sites in the park (0.13 ± 0.09) suggests that most of the species identified were equally present at various sampled sites. The range of dominance indices for BNP (0.00-0.55) varied greatly compared with 0.13-0.31 reported for various sites in the tropical dry deciduous forest in Piranmalai forest in Eastern Ghats in Tamil Nadu (Pitcharaimu et al. 2008), and Kolli hills (0.37-0.83, Lakshmi 1995). Species diversity across the management zones in the park was not significantly ($p > 0.05$) different. However, tree species abundance differed significantly ($p < 0.05$) between Bannerghatta and Anekal management zones. The Bannerghatta wildlife zone had the highest species abundance and the Anekal wildlife zone lowest species diversity.

The 'collector's curve' of the numbers of trees plotted as a function of numbers of sites did not reach asymptote completely indicating that the region could potentially add some more species to the list with increased sampling effort. Increasing the sample size could increase the likelihood of finding new species because larger areas are more environmentally heterogeneous than smaller ones. The number of individuals significantly decreased with increasing tree diameter classes, with largest proportions (87%) of individuals captured in the 0-5 and 5-10 cm diameter classes. Tree diameter frequency showed a J-type population structure at all study sites, which conforms with other forest stands in Eastern Ghats (Kadavul & Parthasarathy 1999a, b). The higher contribution of smaller diameter classes suggests that the forest stand is dominated by juveniles. The presence of high numbers of juveniles was presumably due to the severe disturbance in terms of wood cutting, logging for timber and grazing.

The proportion of canopy cover (38%) in the dry forest of Bannerghatta was greater than the published value (25.7%) for the same site (Varma et al. 2009). Current canopy cover values suggest that the BNP had an open type of forest presumably because of anthropogenic activities. Adhikari and Southworth (2012) reported that although BNP was formally declared as a national park in 1974, forest cover declined until 1992 due to felling trees for commercial and industrial purposes, following normal 30-year production forest rotation cycle. Local communities in and outside the park are also exerting pressure on the park through resource harvesting, agriculture and livestock grazing. Rajeev (2002) also suggested that stunted tree growth due to poor soil and nutrient conditions could result in an open canopy.

4. CONCLUSION

Floristic inventories and vegetation analysis of the tropical dry deciduous forest of the BNP showed that although tree density was high, basal area and alpha diversity were relatively low probably because of historical disturbances, biomass harvesting, clearance of forest for agriculture, infrastructural development and tourism. The large population of juveniles (saplings) in BNP is typical of a growing forest. With agricultural communities located in the park coupled with a fast-growing Indian economy, the pressure on forest resources in BNP is increasing. However, the impact of elephants on forest structure and tree diversity needs to be assessed. Diversity indices indicate that plant communities in the park were less complex than in a mature dry forest and may have lower energy transfers, predation, competition and niche availability. These features are typical of a growing forest. Therefore, conservation activities must focus on protecting and restoring the forest and enhancing alternative livelihoods for communities in and around the park to reduce pressure on forest structure and tree diversity in BNP.

Acknowledgement: The study was financially supported by A Rocha International under the 'Vegetation Dynamics and Carbon Sequestration Research Program', with implementation support from A Rocha India, the Karnataka Forest Department and Park Service. We are grateful to the Karnataka Forest Department for authorising ARI and A Rocha India to conduct research in BNP. We are particularly indebted to Dr. Swaminathan, Retired Principal Chief Conservator of Forests (Wildlife), Kumar Pushkar, Chief Conservator of Forests, Devaraj N., Deputy Conservator of Forests, who facilitated the studies in the park. Fieldwork would have been unbearable without forest guards and watchers of BNP, who assisted in cutting transects and identification of trees. Finally, we greatly appreciate the comments from Dr. Jeremy Lindsell and several other peers, who looked at the manuscript.

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Appendix 1. Tree species diversity in tropical dry forests in Bannerghatta National Park, Eastern Ghats, India

Sl. No.	Species	Family	Abundance	Relative Abundance	Cumulative Abundance	IVI
1	*Anogeissus latifolia*	Combretaceae	1103	14.04	14.04	90.08
2	*Acacia chundra*	Mimosaceae	546	6.95	20.99	90.15
3	*Cedrela toona*	Meliaceae	462	5.88	26.87	75.54
4	*Ioxora arborea*	Rubiaceae	444	5.65	32.53	85.62
5	*Gymnosporia montana*	Celastraceae	423	5.39	37.91	85.22
6	*Ochna squarrosa*	Ochnaceae	326	4.15	42.06	44.85
7	*Fagraea ceilanica*	Potaliaceae	315	4.01	46.07	53.31
8	*Shorea roxburghii*	Dipterocarpacae	265	3.37	49.45	26.81
9	*Lantana camara*	Verbenaceae	206	2.62	52.07	63.97
10	*Ziziphus nummularia*	Rhamnaceae	180	2.29	54.36	65.10
11	*Cassia alata*	Caesalpiniaceae	168	2.14	56.50	36.48
12	*Diospyros melanoxylon*	Ebenaceae	159	2.02	58.52	69.73
13	*Flagellaria indica*	Flagellariaceae	134	1.71	60.23	40.30
14	*Pavetta indica*	Rubiaceae	130	1.65	61.88	52.72
15	*Catunaregam spinosa*	Rubiaceae	126	1.60	63.49	53.99
16	*Dalbergia paniculata*	Fabaceae	122	1.55	65.04	67.36
17	*Stereospermum xylocarpum*	Bignoniaceae	117	1.49	66.53	49.29
18	*Pterolobium indicum*	Fabaceae	116	1.48	68.01	45.15
19	*Chloroxylon swietenia*	Rutaceae	110	1.40	69.41	25.28
20	*Polyalthia cerasoides*	Annonaceae	104	1.32	70.73	44.44
21	*Cassia fistula*	Caesalpiniaceae	103	1.31	72.04	62.74
22	*Randia uliginosa*	Rubiaceae	99	1.26	73.30	44.82
23	*Ziziphus xylopyrus*	Rhamnaceae	77	0.98	74.28	36.44
24	*Lagerstroemia parviflora*	Lythraceae	77	0.98	75.26	43.04
25	*Santalum album*	Santalaceae	76	0.97	76.23	31.65
26	*Grewia villosa*	Tiliaceae	74	0.94	77.17	31.55
27	*Terminalia chebula*	Combretaceae	72	0.92	78.09	38.80
28	*Strychnos potatorum*	Loganiaceae	68	0.87	78.96	37.93
29	*Wrightia tinctoria*	Apocynaceae	66	0.84	79.80	27.46

Sl. No.	Species	Family	Abundance	Relative Abundance	Cumulative Abundance	IVI
30	*Acacia caesia*	Mimosaceae	66	0.84	80.64	41.68
31	*Diaspora montane*	Ebenaceae	64	0.81	81.45	44.41
32	*Eucalyptus globulus*	Myrtaceae	62	0.79	82.24	13.49
33	*Wrightia sps*	Apocynaceae	58	0.74	82.98	29.55
34	*Melia dubia*	Meliaceae	58	0.74	83.72	32.57
35	*Limonia acidissima*	Rutaceae	56	0.71	84.43	32.09
36	*Manilkara kauki*	Sapotaceae	53	0.67	85.11	27.90
37	*Rhodomyrtus parviflora*	Myrtaceae	50	0.64	85.74	27.44
38	*Pterocarpus marsupium*	Fabaceae	48	0.61	86.35	21.28
39	*Psydrax dicoccos*	Rubiaceae	46	0.59	86.94	28.48
40	*Dendrocalamus strictus*	Poaceae	44	0.56	87.50	15.92
41	*Hardwickia binata*	Caesalpiniaceae	43	0.55	88.05	40.57
42	*Jasminum angustifolium*	Olacaceae	42	0.53	88.58	24.71
43	*Albizia amara*	Caesalpiniaceae	40	0.51	89.09	20.59
44	*Vitex altissima*	Verbenaceae	38	0.48	89.57	23.91
45	*Ximenia americana*	Olacaceae	37	0.47	90.04	15.92
46	*Holarrhena antidysenterica*	Apocynaceae	35	0.45	90.49	17.51
47	*Scolopia crenata*	Flacourtiaceae	30	0.38	90.87	21.08
48	*Premna tomentosa*	Verbenaceae	30	0.38	91.25	28.69
49	*Gliricidia sepium*	Fabaceae	29	0.37	91.62	1.69
50	*Ziziphus mauritiana*	Rhamnaceae	28	0.36	91.98	13.39
51	*Capparis sepiaria*	Capparidaceae	25	0.32	92.30	18.19
52	*Acacia senegal*	Fabaceae	24	0.31	92.60	13.12
53	Unidentified tree*		24	0.31	92.91	15.72
54	*Hiptage benghalensis*	Malphigiaceae	24	0.31	93.21	16.87
55	*Dodonaea viscosa*	Sapindaceae	22	0.28	93.49	16.74
56	*Semecarpus anacardium*	Anacardiaceae	20	0.25	93.75	17.99
57	*Albizia odoratissima*	Caesalpiniaceae	19	0.24	93.99	11.70
58	*Cipadessa baccifera*	Meliaceae	19	0.24	94.23	12.61

Sl. No.	Species	Family	Abundance	Relative Abundance	Cumulative Abundance	IVI
59	*Securinega virosa*	Euphorbiaceae	19	0.24	94.47	12.90
60	*Azadirachta indica*	Meliaceae	19	0.24	94.72	17.20
61	*Phyllanthus virgatus*	Euphorbiaceae	19	0.24	94.96	16.92
62	*Acacia torta*	Mimosaceae	18	0.23	95.19	9.60
63	*Gmelina arborea* Roxb.	Verbenaceae	18	0.23	95.42	10.36
64	*Phyllanthus emblica*	Euphorbiaceae	17	0.22	95.63	10.72
65	*Syzygium cumini*	Myrtaceae	15	0.19	95.82	8.47
66	*Soymida febrifuga*	Meliaceae	15	0.19	96.02	8.06
67	*Butea frondosa*	Fabaceae	14	0.18	96.19	5.67
68	*Pongamia pinnata*	Fabaceae	13	0.17	96.36	7.47
69	*Sterculia villosa*	Sterculiaceae	12	0.15	96.51	10.31
70	*Ichnocarpus frutescens*	Apocynaceae	11	0.14	96.65	6.53
71	*Dalbergia sps.*	Fabaceae	11	0.14	96.79	9.21
72	*Butea monosperma*	Fabaceae	11	0.14	96.93	14.02
73	*Grewia tiliifolia*	Tiliaceae	10	0.13	97.06	4.11
74	*Flacourtia indica*	Flacourtiaceae	10	0.13	97.19	9.05
75	*Diospyros malabarica*	Ebenaceae	9	0.11	97.30	7.99
76	*Cassine glauca*	Celastraceae	9	0.11	97.42	10.36
77	*Acacia auriculiformis*	Mimosaceae	8	0.10	97.52	4.19
78	*Mucuna pruriens*	Fabaceae	8	0.10	97.62	3.94
79	*Albizia lebbeck*	Caesalpiniaceae	8	0.10	97.72	5.78
80	*Dalbergia latifolia*	Fabaceae	8	0.10	97.82	6.44
81	*Scleropyrum pentandrum*	Santalaceae	8	0.10	97.92	5.37
82	*Acacia leucophloea*	Mimosaceae	8	0.10	98.03	8.93
83	*Dichrostachys cinerea*	Mimosaceae	8	0.10	98.13	6.54
84	*Careya arborea*	Lecythidaceae	8	0.10	98.23	9.02
85	*Oxalis corniculata*	Oxalidaceae	7	0.09	98.32	1.42
86	*Xylia xylocarpa*	Fabaceae	7	0.09	98.41	1.47
87	*Balanites roxburghii*	Balanitaceae	7	0.09	98.50	3.00

Sl. No.	Species	Family	Abundance	Relative Abundance	Cumulative Abundance	IVI
88	*Gardenia gummifera*	Rubiaceae	7	0.09	98.59	5.44
89	*Toddalia aculeata*	Rutaceae	6	0.08	98.66	6.42
90	*Buchanania latifolia*	Anacardiaceae	5	0.06	98.73	3.98
91	*Ficus benghalensis*	Moraceae	5	0.06	98.79	11.40
92	*Nicandra sps.*	Solanaceae	5	0.06	98.85	5.16
93	*Terminalia bellerica*	Combretaceae	5	0.06	98.92	5.37
94	*Secamone emetica*	Asclepiadaceae	4	0.05	98.97	5.17
95	Unidentified tree 3*			0.05	99.02	5.40
96	*Stereospermum suaveolens*	Bignoniaceae	3	0.04	99.06	1.33
97	Unidentified tree 4*		3	0.04	99.10	1.35
98	*Terminalia crenulata*	Combretaceae	3	0.04	99.13	2.88
99	*Rubus niveus*	Rosaceae	3	0.04	99.17	2.60
100	*Mangifera indica*	Anacardiaceae	3	0.04	99.21	2.75
101	*Cordia dichotoma*	Boraginaceae	3	0.04	99.25	2.58
102	*Tamarindus indica*	Caesalpiniaceae	3	0.04	99.29	6.63
103	*Ficus sps.*	Moraceae	3	0.04	99.33	4.17
104	*Morinda tinctoria*	Rubiaceae	3	0.04	99.36	3.89
105	*Alangium salvifolium*	Alangiaceae	2	0.03	99.39	1.31
106	*Givotia moluccana*	Euphorbiaceae	2	0.03	99.41	1.31
107	*Decalepis hamiltonii*	Asclepiadaceae	2	0.03	99.44	4.45
108	*Sterculia urens* Roxb.	Sterculiaceae	2	0.03	99.47	1.31
109	*Commiphora caudata*	Burseraceae	2	0.03	99.49	1.33
110	*Delonix elata*	Caesalpiniaceae	2	0.03	99.52	1.30
111	Unidentified tree 2*		2	0.03	99.54	1.30
112	*Feronia elephantum*	Rutaceae	2	0.03	99.57	2.71
113	*Ailanthus excelsa*	Simaroubaceae	2	0.03	99.59	3.82
114	*Ficus microcarpa*	Moraceae	2	0.03	99.62	2.57
115	*Ficus rumphii*	Moraceae	2	0.03	99.64	2.56
116	*Atalantia monophylla*	Rutaceae	2	0.03	99.67	2.56

Sl. No.	Species	Family	Abundance	Relative Abundance	Cumulative Abundance	IVI
117	*Michelia sps.*	Magnoliaceae	2	0.03	99.69	2.66
118	*Mitragyna parvifolia*	Rubiaceae	2	0.03	99.72	2.73
119	*Gardenia sps.*	Rubiaceae	2	0.03	99.75	2.59
120	*Terminalia arjuna*	Combretaceae	2	0.03	99.77	2.98
121	*Nicandra physalodes*	Solanaceae	1	0.01	99.78	1.40
122	*Ficus virens*	Moraceae	1	0.01	99.80	1.36
123	*Pavetta montana*	Rubiaceae	1	0.01	99.81	1.36
124	*Boswellia serrata*	Burseraceae	1	0.01	99.82	2.20
125	*Haldina cordifolia*	Rubiaceae	1	0.01	99.83	1.35
126	*Celastrus paniculatus*	Celastraceae	1	0.01	99.85	4.53
127	*Acacia nilotica*	Mimosaceae	1	0.01	99.86	7.04
128	*Jatropha curcas*	Euphorbiaceae	1	0.01	99.87	1.28
129	*Derris scandens*	Fabaceae	1	0.01	99.89	1.29
130	*Miliusa tomentosa*	Annonaceae	1	0.01	99.90	1.28
131	*Careya sps.*	Lecythidaceae	1	0.01	99.91	1.29
132	*Terminalia paniculata*	Combretaceae	1	0.01	99.92	1.29
133	*Tectona grandis*	Verbenaceae	1	0.01	99.94	1.28
134	*Capparis zeylanica*	Capparidaceae	1	0.01	99.95	1.29
135	*Datura stramonium*	Solanaceae	1	0.01	99.96	1.31
136	Unidentified tree 1*		1	0.01	99.97	1.30
137	Unidentified tree 6*		1	0.01	99.99	1.28
138	Unidentified tree 5*		1	0.01	100.00	1.28

* Unidentified trees listed in the table are not considered as a different species
IVI: Importance Value Index

Appendix 2. Species diversity indices for 79 sampled sites in the Bannerghatta National Park, India

Site No.	Taxa	Individuals	Dominance	Shannon	Simpson	Evenness	Equitability
1	10	43	0.43	1.34	0.57	0.38	0.58
2	14	154	0.38	1.50	0.62	0.32	0.57
3	17	60	0.10	2.50	0.90	0.72	0.88
4	13	42	0.12	2.31	0.88	0.77	0.90
5	29	161	0.17	2.47	0.83	0.41	0.73
6	32	148	0.08	2.95	0.92	0.59	0.85
7	23	92	0.08	2.74	0.92	0.67	0.87
8	10	16	0.13	2.19	0.88	0.89	0.95
9	24	162	0.08	2.79	0.92	0.68	0.88
10	21	125	0.10	2.58	0.90	0.63	0.85
11	31	101	0.08	2.99	0.92	0.64	0.87
12	35	131	0.10	2.93	0.90	0.53	0.82
13	41	103	0.04	3.45	0.96	0.77	0.93
14	30	115	0.06	3.03	0.94	0.69	0.89
15	25	144	0.14	2.44	0.86	0.46	0.76
16	30	134	0.08	2.89	0.92	0.60	0.85
17	25	161	0.14	2.44	0.86	0.46	0.76
18	35	157	0.08	2.97	0.92	0.56	0.84
19	20	57	0.12	2.53	0.88	0.63	0.84
20	32	102	0.06	3.04	0.94	0.65	0.88
21	19	79	0.20	2.16	0.80	0.46	0.73
22	27	127	0.07	2.89	0.93	0.66	0.88
23	35	132	0.07	3.04	0.93	0.60	0.86
24	20	71	0.11	2.54	0.89	0.64	0.85
25	29	132	0.09	2.82	0.91	0.58	0.84
26	25	129	0.09	2.76	0.91	0.63	0.86
27	40	160	0.05	3.24	0.95	0.64	0.88
28	32	118	0.06	3.07	0.94	0.67	0.89
29	30	167	0.13	2.71	0.87	0.50	0.80

Site No.	Taxa	Individuals	Dominance	Shannon	Simpson	Evenness	Equitability
30	29	113	0.07	2.93	0.93	0.65	0.87
31	16	86	0.21	2.02	0.79	0.47	0.73
32	25	130	0.09	2.76	0.91	0.63	0.86
33	26	100	0.09	2.81	0.91	0.64	0.86
34	26	100	0.11	2.69	0.89	0.57	0.83
35	21	78	0.08	2.73	0.92	0.73	0.90
36	27	85	0.08	2.85	0.92	0.64	0.87
37	18	78	0.18	2.25	0.82	0.53	0.78
38	31	84	0.09	2.93	0.91	0.60	0.85
39	21	182	0.17	2.27	0.84	0.46	0.75
40	30	123	0.11	2.75	0.89	0.52	0.81
41	41	115	0.05	3.39	0.95	0.72	0.91
42	1	1	1.00	0.00	0.00	1.00	0.00
43	28	95	0.08	2.91	0.92	0.66	0.87
44	27	124	0.13	2.63	0.87	0.52	0.80
45	25	95	0.13	2.57	0.87	0.52	0.80
46	27	73	0.09	2.82	0.91	0.62	0.86
47	22	96	0.34	1.86	0.66	0.29	0.60
48	26	78	0.10	2.84	0.90	0.66	0.87
49	20	102	0.12	2.48	0.88	0.60	0.83
50	27	82	0.09	2.87	0.91	0.65	0.87
51	27	106	0.09	2.78	0.91	0.60	0.84
52	18	70	0.17	2.22	0.83	0.51	0.77
53	9	49	0.55	1.08	0.45	0.33	0.49
54	16	40	0.10	2.52	0.90	0.78	0.91
55	26	105	0.10	2.76	0.90	0.61	0.85
56	19	56	0.11	2.53	0.89	0.66	0.86
57	18	62	0.17	2.25	0.83	0.53	0.78
58	34	168	0.10	2.86	0.90	0.51	0.81
59	34	104	0.07	3.09	0.93	0.65	0.88

Site No.	Taxa	Individuals	Dominance	Shannon	Simpson	Evenness	Equitability
60	27	172	0.15	2.49	0.85	0.45	0.76
61	9	29	0.15	2.04	0.85	0.86	0.93
62	15	50	0.17	2.16	0.83	0.58	0.80
63	21	97	0.12	2.53	0.88	0.60	0.83
64	19	68	0.15	2.39	0.85	0.58	0.81
65	15	67	0.37	1.62	0.63	0.34	0.60
66	20	72	0.09	2.68	0.91	0.73	0.90
67	15	40	0.21	2.13	0.79	0.56	0.78
68	18	65	0.16	2.31	0.84	0.56	0.80
69	16	58	0.13	2.37	0.87	0.67	0.86
70	31	130	0.10	2.93	0.90	0.60	0.85
71	17	53	0.16	2.27	0.84	0.57	0.80
72	23	113	0.17	2.38	0.83	0.47	0.76
73	17	152	0.31	1.76	0.69	0.34	0.62
74	17	91	0.15	2.31	0.85	0.59	0.81
75	14	51	0.12	2.29	0.88	0.71	0.87
76	30	108	0.06	3.07	0.94	0.72	0.90
77	21	174	0.19	2.14	0.81	0.40	0.70
78	11	38	0.13	2.17	0.87	0.80	0.91
79	31	124	0.08	2.90	0.92	0.59	0.84