

Tree diversity and natural regeneration in Tropical Dry Deciduous Forest of Panna Tiger Reserve, India

Talat Parveen (✉ talatparveen09@gmail.com)

Aligarh Muslim University <https://orcid.org/0000-0001-8271-6237>

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Aligarh Muslim University

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Abstract

The disturbance is a major factor driving the decline of tropical forests and their associated fauna. Henceforth, basic information on species diversity would be useful for assessing the success of management in the fragmented and human-disturbed landscape. We accounted for tree species diversity and their regeneration pattern from the tropical dry deciduous forest of Panna Tiger Reserve (PTR), India. Considering this, random vegetation sampling along with transects was carried out in different ranges of PTR. It is spread over in an area of 2998.98 km² that situated in the northern part of Madhya Pradesh and distributed in Panna and Chhatarpur district. The tropical dry deciduous forest inventory in the 10.6132-ha area yielded a total of 46 woody species of > 10 cm GBH, belonged to 23 Families and 40 genera. The regeneration represented 27 species of < 30 cm height (seedling) under 16 families and 24 genera while sapling, which ranges from > 30cm to 1.3m, showed 24 species of 13 families and 32 genera. The Shannon diversity of Trees, seedlings, and saplings was 2.684, 2.525, and 2.401 respectively. A total stand density and basal area of 2391 stems of trees were estimated as 225.285 stand ha⁻¹ and 90.016 m²ha⁻¹ respectively. *Tectona grandis* scored the highest IVI value of 59.44 (19.81% of total IVI for all species) among the dominated tree species, followed by *Acacia catechu* (24.94), *Abrus precatorius* (23.25), *Zizyphus xylopyra* (22.94), *Anogeissus latifolia* (22.16) and *Lagerstroemia parviflora* (22.18). Nearly 23.913% of the total number of species was recorded as rare species. The highest seedling density was obtained for *Diospyros melanoxylon* followed by *Zizyphus xylopyra*, *Aegle marmelos*, *Wrightia tintoria*, and *Tectona grandis*, which declined in the subsequent sapling stage and showed a reverse pattern. Hence, the highest sapling density was recorded for *Tectona grandis* then *Aegle marmelos*, *Wrightia tintoria*, *Diospyros melanoxylon*, and *Zizyphus xylopyra*. A total of 36.956% of tree species were found to fail to establish in the community because species were represented by only adult or tree stage that listed as Not-regenerating. In terms of the most diverse family among the plant categories; viz. Tree, Seedling, Sapling, Fabaceae had the highest species richness. The highest tree stand density (127.576 stand ha⁻¹) was recorded in the girth class of 31-60cm (48.687% of the total tree stand density) followed by 10-30cm and 61-90cm. Likewise, a total basal area of 20.824 m²ha⁻¹ was occupied by 31-60cm that contributed 23.051% of the total basal area, so our data on the population structure of forest shows a similar trend wherein the distribution curve exponentially decreases with increasing girth classes that indicates not only a mid-successional forest but also a human-disturbed.

1 Introduction

Tropical forests are the most biologically rich and genetically diverse ecosystem on earth (Hubbell & Foster 1983) and cover roughly 44 percent of the global forest land area (Keenan et al.2015). Besides, these forests contribute for less than half of them as tropical dry forest (Murphy & Lugo 1986), and are considered to be most threatened and largely unprotected ecosystem than moist and wet tropical forest ecosystem (Lerdau et al. 1991; Laurance 1999; Trejo & Dirzo 2000; Li et al. 2006; Gerhardt 1993; Songer 2006; Janzen 1988; Olson & Dinerstein 2002; Miles et al. 2006). These forests are distributed in Central and South America; Africa; India; South-East Asia; and Australia (Gerhardt & Hytteborn 1992), and also have high phonological adaptation such as leaf trait so that tree species show leaf habits from evergreen to deciduous (Eamus 1999; Sandquist & Cordell 2007). According to Waeber et al. (2012), Tropical dry forest accounts for up to 60% of total forest extent in India, and Tropical dry deciduous forest occupies approximately 40.86% of total forest extent (ISFR 2019). Due to floral attributes, Rzedowski (1991) has used the term ecological island for the tropical dry deciduous forest that has originated by geographical isolation. This ecosystem is also designated as "Tall deciduous forest" (Ogawa et al. 1961) or "Mixed deciduous forest" (Royal Forest Department, 1962), and is found on the mainland of Southeast Asian countries, including Vietnam, Laos, Cambodia, Thailand, Burma, and India. This forest ecosystem is dominated by a large number of deciduous tree species, exclusively Teak (*Tectona grandis*) (Bunyavechewin 1983).

Tree and forest of dry forest provide a wealth of environmental services and support the world's poorest people (Campbell 1996; Cunningham et al. 2008; Waeber et al. 2012). Henceforth, Tropical dry forest is vulnerable to anthropogenic disturbance; for example, conversion to agriculture, burning, extraction of valuable timber species, and unsustainable use of Non-timber forest product, which in turn reflect the forest fragmentation, degradation of forest land, and change in forest regeneration pattern (Rodger 1907; Lieberman & Li 1992; Menaut et al. 1995; Saha & Howe 2003). The mature primary deciduous forest is also being transformed into a degraded forest because of human-induced disturbance. For instance, the dry deciduous forest in India has been converted into dry deciduous scrub, dry savannah, and dry grasslands (Champion & Seth 1968; Singh & Singh 1989; Sagar & Singh 2004). According to Menon et al. (2010), It is estimated that 75% of the total forest cover comes under highly fire-prone forest types such as moist deciduous, dry deciduous, and thorn forests of India.

The concept of quantitative inventories that provide information on the structural characteristics and species diversity within a particular forest ecosystem (Vankateswaran & Parthasarathy 2003) and its implication for conservation and management has been widely studied across the world. There is a vast amount of literature on structural characteristics of tree species and their regeneration in a tropical forest because tree species potentially lead to stability and complexity of forest ecosystem (Khan et al. 1997; Rennolls et al. 2000; Rennolls & Laumonier 2000). They are also responsible for the development of other plant-dependent species (Whitemore 1990), such as herb layer by creating environmental heterogeneity in the lower forest layer (Beatty 2003; Gilliam 2007; Barbier et al. 2008).

In South-West China, The changes between the primary forest vegetation and the secondary plant communities in the Tropical forest of Xishuangbanna were studied by Zhang & Cao (1995), who also suggested local nature conservation. By using field plots data with the combination of mapped environmental data and Landsat Thematic Mapper imagery, Ohman & Gregory (2002) were able to evaluate a method for predictive mapping of forest composition and structure that can probably be used for regional level planning not to local management. On the other hand, Banda et al. (2006) sampled tree species composition and their structural characteristics in four different levels of protection gradient from non-disturbed to highly disturbed area in the Miombo ecosystem of western Tanzania, and Duran et al. (2006) analyzed the variability of structure and tree diversity pattern at the landscape level of Mexican tropical deciduous forest. So did Tarrason et al. (2010) compare the structure, species richness, and diversity of the different types of tropical dry forest remnants in Nicaragua, Central America, and evaluated the new index viz, Social simplified Importance value Index (SsIVI) to assess the conservation status. Webb et al. (2011) studied the tree community structure and composition of Mixed Evergreen Deciduous tropical forest in Western Thailand and concluded that tree recruitment can be inhibited by the overgrowth of Bamboo cover. In favor of understanding the plant diversity in a Mixed Albies holophylla- Broad-leaved deciduous forest, Lee et al. (2012) assessed the spatial distribution pattern and association of dominant canopy tree species in Odaesan National Park, South Korea by using Ripley's K function. Marood et al. (2012) studied the vegetation structure and floristic composition along the edge of Montane forest and agricultural land to reforestation in the degraded forest landscape. Similarly, Phongoudome et al. (2012) determined the natural regeneration and tree species composition of primary and secondary forest of Tropical Mixed deciduous forest in Lao concerning manage secondary forest by natural or man-made restoration after logging and shifting cultivation. Usually, forests tend to have dynamic likely to be affected by both climatic and anthropogenic disturbance therefore Henri et al. (2013) addressed the reconstruction of the woody species regeneration in a semi-deciduous forest of Cote d'Ivoire. On the contrary, Apgaua et al. (2014) investigated the tree community structure of remained Seasonally dry tropical forests in the ecotonal area between the Cerrado and Caatinga, Brazil. Measuring the impact of selective logging, Djagbletey et al. (2018) assessed the floristic composition and carbon stock of tree species in logged and unlogged sites of the moist semi-deciduous forest in Ghana. In India, Rawat & Singh (1988), Parthasarathy & Karthikeyan (1997), Swamy et al. (2000), Panchal & Pandey (2004), Kar et al. (2012) and Subba et al. (2020) have investigated species diversity and structural characteristics of Oak forest in Central Himalaya, Tropical dry evergreen forest in South India, Humid tropical forest in Veerapuli and Kalamalai forest reserve, Semi-arid forest in Saurashtra region of Gujarat, Moist deciduous forest in Similipal Biosphere reserve, Moist Sal bearing tropical forest in Sumbuk reserve forest respectively. Additionally, India has also received attention along with the aspect of biophysical and Livelihood research. Sagar et al. (2003) studied tree species composition, dispersion, and diversity in response to disturbance gradient in a tropical dry forest, and reproductive and vegetative phenology of tropical tree at Kodayar in the Western Ghats was investigated by Sundarapandian et al. (2005). To provide information on the tremendous effect of anthropogenic fire on juvenile trees, Saha & Howe (2006) surveyed the tropical dry deciduous forest of Central India. However, Singh & Kushwaha (2006) demonstrated variability in flowering and fruiting phenology of tropical deciduous trees in Uttar Pradesh, India. In favor of producing high-quality seedlings, Singh & Raizada (2010) analyzed the impact of fire and smoke on seed germination of tropical dry deciduous trees. Moreover, Quamar & Bera (2014) studied the pollen production and deposition behavior of Teak (*Tectona grandis*) and Sal (*Shorea robusta*) in the tropical deciduous forest of Madhya Pradesh, India. On the other hand, several studies have been conducted in the context of resource extraction that has adversely affected the vegetation structure and diversity of forest area. Accordingly, Purushothaman et al. (2000) accounted about 124 plant species that utilized by people living along the periphery of the forest area in Madhya Pradesh as used for fuelwood, fodder, and medicinal purpose and Narendran et al. (2001) was also evaluate the utilization and valuation of non-timber forest product from Nilgiri Biosphere Reserve, South India. In contrast, Arjunan et al. (2005) compared vegetation structure, diversity, basal area, and regeneration between sites with heavy human pressure and another site have no extraction or human pressure. Besides the negative effect of Non-timber forest product extraction on forest community, Mahapatra & Tiwari (2005) analyzed the importance of Non-timber forest products in the economic valuation of dry deciduous forest of India.

2 Study Area

Panna Tiger Reserve is a more sensitive habitat for Tiger and is located in Vindhya hill in northern Madhya Pradesh. In the year 1981, the forest of the area was declared as Panna National Park following that included in the Project Tiger Reserve in the year 1994. It is situated in the Panna and Chattarpur district of Madhya Pradesh. It covers about 2998.98 km² out of which 792.53 km² including 191.35 Km² of the North forest division of Panna, is managed as the core area. It lies between coordinates 24°15'-24°20' latitude N and 80°00'-80°15' longitude E within Biogeographic province 6A "Deccan Peninsula- Central Highland" (Rodgers and Panwar, 1988) with an elevation range from 212 to 538 M.S.L. According to Champion and Seth (1968), the park has six forest types such as; Southern tropical dry deciduous teak forest, Northern tropical dry deciduous mixed forest, Dry deciduous scrub forest, *Anogeissus pendula* forest, *Boswellia* forest, and Dry Bamboo brakes. This forest is dominated by extensive plateau and gorges. The study area has four distinct seasons, hot summer from March to June, Monsoon (July to August), a short Post Monsoon from September to October, and Winter from Mid-November to February. The mean temperature range from - 0.7°C in January to 47°C in May (Sharma et al. 2007). The forest is characterized by the Ken river that has become a lifeline for reserve and also creates a waterfall on its way to the valley (FIGURE 1).

3 Methodology

3.1 Data collection

Random sampling along the transect was carried out to assess the structural characteristics and species diversity of different tree species, seedlings, and saplings in the Tropical dry Deciduous forest of Panna Tiger Reserve. A total of 338 plots (covering a total area of 10.6132 ha) were sampled in different ranges during March 2019. The size of the plot varied from 10m radius for trees to 5m radius for seedling and sapling. In each plot, stems having > 10 cm GBH at 1.3 m height were considered as adult trees while stem up to the height of 30 cm was considered as seedling and > 30 cm height as a sapling.

3.2 Data analysis

3.2.1 Density

The density of the tree, seedling and sapling was estimated as "number of individuals/ ha" by following formula

Density = number of individuals of the species / Area (ha)

3.2.2 Frequency

frequency of a species was calculated by using following formula

Frequency (%) = (Number of plots in which species occurred/ Total number of plots)*100

3.2.3 Basal area

The basal area of the tree was measured as girth of stem at breast height at 1.37m from the ground level (Curtis and McIntosh 1950) and calculated by using following formula.

Basal area = $c^2 / 4\pi$

Where, C = Circumference at Breast Height

3.2.4 Important Value Index (IVI)

IVI is the sum of relative density, relative frequency and relative basal area of a species (Philips 1959). The relative density, relative frequency and relative basal area were estimated using following formula

Relative density (RD) = (Density of the individual species/ Total density of all Species)*100

Relative frequency (RF) = (Frequency of the individual species/ Total frequency of all Species)*100

Relative basal area (RBA) = (Basal area of the individual species/ Total basal area of all Species)*100

IVI = RD + RF + RBA

3.2.5 Regeneration

The regeneration status of the forest was estimated based on the following categories: as per Shankar (2001) and Singh et al. (2017).

1. Good if the density of Seedlings > Sapling > Trees
2. Fair if the density of Seedling > Sapling $\leq$ Trees
3. Poor if the species present only in sapling stage but not in seedling stage.
4. Not regenerating if the species is absent in both seedling and sapling stage but only found as adult tree

3.2.6 Species Diversity

Species diversity was estimated using the Simpson index (Simpson 1949) and Shannon-Wiener index (Shannon & Wiener 1949). It was computed using Past 3.1 software. (version 3.1; Øyvind Hammer, Natural History Museum, University of Oslo).

3.2.6.1. Shannon-Wiener's index

$$H = -\sum_{i=1}^S P_i \log P_i$$

Where $P_i = n_i / N$ (n_i is the number of individuals of the species i , and N is the total number of individuals).

3.2.6.2 Simpson index

$$D = 1/c$$

$$\text{Where } c = \sum_{i=1}^S P_i^2$$

P_i = importance of its species in the stand (proportion of number, biomass etc.)

S = number of species present, and

$\sum_{i=1}^S$ denotes summation of P_i^2 values for $i = 1$ all species.

3.2.7 Equitability or Evenness

Evenness that range from zero to one was calculated by the following formula (Pielou 1966).

$$E = H/\log s$$

Where, H = Shannon Index and s = the number of species.

3.2.8 Species richness

Species richness was calculated by the following formula (Margalef 1958).

$$d = S-1 / \ln N$$

Where, S = total number of species, N = basal area of all species (m^2ha^{-1})

3.2.8.1 Non-parametric estimators of species richness

To observe tree species richness, a variety of non-parametric estimators were graphically plotted by using the software EstimateS version 9.1.0 (Colwell 2013). This program calculates sample-based rarefaction curves and their associated values by replicating a set of samples.

Chao1 is an abundance-based estimator and relies on rare species in the sample i.e. the number of singleton and the number of doubletons. However, Chao 2 requires only incidence-based data and depends on the number of unique and the number of duplicates.

The Jackknife is a technique for reducing the bias of estimates (Miller 1964). Thus, the first-order Jackknife (Jack 1) estimate of species richness is based on the no of unique species and the number of samples, but second-order Jackknife (Jack 2) similar to Chao 2 that relies on the number of unique and duplicates and number of samples as well.

Bootstrap is based on a proportion of samples containing each species and requires only incidence data. On the other hand, the Abundance-based coverage estimator (ACE) and Incidence-based coverage estimator (ICE) are depended on sample coverage that requires a pattern of relative abundance of species in samples. Hence, ACE is based on those species which have < 10 individuals in the samples (Chao et al. 1993) while the corresponding Incidence-based coverage estimator likewise is based on species that found in < 10 sampling units (Lee and Chao 1994).

3.2.8.2 Extrapolation of sample-based rarefaction curve

To predict an asymptotic true species richness for a larger set of samples from the same assemblage, extrapolation of empirical sample-based rarefaction curve can be used which provides associated confidence interval as well.

4 Results

4.1 Sample-based rarefaction curve

According to Chazdon et al. (1998), "observed species richness is a biased estimator of true richness for the assemblage sampled", so sample-based rarefaction curves were generated by plotting the cumulative number of tree species against the number of individuals censused in a 10.6132-ha area based on 100 randomizations of the sample order. Though, a total of 46 ± 1.93 species was recorded as observed species richness from the study area (FIGURE 2).

For reliable estimation of species richness, The comparison of the number of species recorded by different estimators was made using the same individual sampled, which resulted in a rarefaction curve was initially steep up to 546–1092 individuals followed by gradual species accumulation and flattening till the 1638 individuals sampled.

In all estimators, more than 50% of the total species were recorded within 546–1092 individuals sampled in a 10.6132ha area. The second-order Jackknife (Jack 2) was best satisfied the estimation of species richness among the estimators as it reached a stable value of 54 after only 1092 individuals were sampled. While other estimator reached a stable value after 1638 individual sampled and yielded a low estimate of species richness than second-order Jackknife (Jack 2) (FIGURE 3)

4.2 Extrapolation of sample-based rarefaction curve

FIGURE 4 shows the result for species richness extrapolation to two times the empirical number of plots for an empirical data set. A total of 49.34 ± 3.0 species were predicted for large sample size from the same data set that reached an asymptote after 600 plots.

4.3 Species richness, diversity and evenness

The tropical dry deciduous forest inventory in 10.6132-ha yielded a total of 46 woody species of > 10 cm GBH, belonged to 23 Families and 40 genera. The regeneration represented 27 species of < 30 cm height (seedling) under 16 families and 24 genera while sapling, which ranges from >30cm to 1.3m, showed 24 species of 13 families and 32 genera (Table 1).

TABLE 1 provides the diversity parameters, viz. Shannon diversity and Simpson index, and evenness of Tree, seedling, and sapling. The result indicates that the values of Shannon diversity between trees, seedlings, and saplings were closer to each other. A similar trend was also observed in the Simpson index except for Evenness. Remarkably, the Shannon diversity of Trees, seedlings, and saplings was 2.684, 2.525, and 2.401 respectively. The Simpson index was recorded for trees 0.891, for seedling 0.887, and sapling 0.880. Similarly, Evenness was recorded as 0.318, 0.462, 0.459 for Trees, seedling, and Sapling respectively.

Table 1
QUANTITATIVE ANALYSIS IN PANNA TIGER RESERVE.

Parameter	Tree	Seedling	Sapling
Sampled Area (ha)	10.613	2.653	2.653
Species Richness			
Observed Species Richness	46	27	24
Non-Parametric Species Richness estimator			
Chao 1	48.05 (2.91)	-	-
Chao 2	50.13 (4.9)	-	-
Jackknife 1	53.27(2.68)	-	-
Jackknife 2	55.29 (2.7)	-	-
Abundance-based coverage estimator (ACE)	49.37 (1.32)	-	-
Incidence-based coverage estimator (ICE)	51.59 (1.53)	-	-
Bootstrap	49.59 (0.37)	-	-
Number of Families	23	16	13
Diversity Indices			
Shannon-Weiner	2.684	2.525	2.401
Simpson	0.891	0.887	0.880
Dominance	0.108	0.112	0.119
Evenness	0.318	0.462	0.459
Margalef Richness	5.784	3.931	3.357
<i>Note</i> : Standard deviation in parantheses for Non-parameter Species Richness estimator			

4.4 Stand density and basal area

A total stand density and basal area of 2391 stems of trees, sampled from 338 plots (10.6132 ha) were estimated as 225.285 stand ha^{-1} and 90.016 m^2ha^{-1} respectively (Table 2).

4.5 Species density, dominance and rarity (Singleton and Doubleton)

Analysis of species density, basal area, and IVI of different tree species (> 10 cm GBH and > 1.3m Height) area given in Table 2. The maximum species density was recorded for *Tectona grandis* (56.53 individual ha^{-1}) which was followed by *Acacia catechu* (22.99 individual ha^{-1}), *Zizyphus xylopyra* (19.69 individual ha^{-1}), *Lagerstroemia parviflora* (18.65 individual ha^{-1}), *Anogeissus latifolia* (15.54 individual ha^{-1}), and *Aegle marmelosa* (14.22 individual ha^{-1}). In contrast, *Moringa oleifera*, *Ficus benghalensis*, *Pterocarpus marsupium*, *Holoptelea integrifolia*, and *Careya arborea* had minimum species density (0.094 individual ha^{-1})

In terms of basal area, *Tectona grandis* also showed the highest basal area (18.39 $\text{m}^2 \text{ha}^{-1}$) that was followed by *Adina cordifolia* with the value of 8.34 $\text{m}^2 \text{ha}^{-1}$, but *Pterocarpus marsupium* and *Moringa oleifera* had the lowest basal area.

Additionally, based on the IVI score (> 10), it was observed that out of 46 tree species only 10 species have high IVI value and contributed to 76.20% of the total IVI values in the tropical dry deciduous forest of Panna. *Tectona grandis* scored the highest IVI value of 59.44 (19.81% of total IVI for all species) among the dominated tree species, followed by *Acacia catechu* (24.94), *Abrus precatorius* (23.25), *Zizyphus xylopyra* (22.94), *Anogeissus latifolia* (22.16) and *Lagerstroemia parviflora* (22.18) while the 22 species had IVI value in the range of 1 to 7 and contributed to 21.26% of total IVI so *Bassia latifolia* (7.23) had the highest IVI within

this range. Moreover, 14 species viz. *Lannea coromandelica*, *Tamarindus indica*, *Feronia elephantum*, *Ceriscoides turgida*, *Gmelina arborea*, *Azadirachta indica*, *Soymida febrifuga* scored a very low IVI value of < 1 .

Species with one and two individuals are considered as singleton and doubleton or rare species. Nearly 23.913% of the total number of species was recorded as rare species. These were stabilized at the value of 7.35 ± 1.97 for singleton and 4.03 ± 1.79 for doubleton (FIGURE 2).

Table 2
IVI VALUES OF TREE SPECIES IN PANNA TIGER RESERVE.

Tree Species	Families	N	Density(Individual ha ⁻¹)	Basal Area(m ²)	Basal Area (m ² ha ⁻¹)	RD	RF	R Do	IVI
<i>Aegle marmelos</i>	Rutaceae	151	14.227	22.048	2.077	6.315	4.556	2.307	13.179
<i>Anogeissus latifolia</i>	Combretaceae	165	15.546	57.148	5.384	6.900	9.279	8.679	22.161
<i>Abrus precatorius</i>	Fabaceae	148	13.944	88.612	8.349	6.189	7.787	9.275	23.253
<i>Adina cordifolia</i>	Rubiaceae	4	0.376	10.746	1.012	0.167	0.331	1.124	1.623
<i>Anogeissus pendula</i>	Combretaceae	120	11.306	35.079	3.305	5.018	3.065	3.671	11.756
<i>Acacia catechu</i>	Fabaceae	244	22.990	52.941	4.988	10.204	9.196	5.541	24.942
<i>Acacia latifolia</i>	Fabaceae	12	1.130	5.359	0.504	0.617	0.911	0.560	1.974
<i>Allangium salvifolium</i>	Fabaceae	8	0.753	10.513	0.990	0.334	0.165	1.100	1.600
<i>Azadirachta indica</i>	Meliaceae	2	0.188	0.237	0.022	0.083	0.165	0.024	0.274
<i>Balanites aegyptiaca</i>	Zygophyllaceae	46	4.334	7.713	0.726	1.923	2.236	0.807	4.967
<i>Bassia latifolia</i>	Sapotaceae	20	1.884	44.526	4.195	0.836	1.739	4.660	7.236
<i>Bauhinia racemosa</i>	Fabaceae	25	2.355	7.421	0.699	1.045	1.988	0.776	3.810
<i>Butea monosperma</i>	Fabaceae	55	5.182	45.902	4.324	2.300	3.396	4.804	10.501
<i>Boswellia serrata</i>	Burseraceae	19	1.790	27.307	2.572	0.794	1.077	2.858	4.729
<i>Bombax ceiba</i>	Malvaceae	6	0.565	4.261	0.401	0.250	0.579	0.446	1.276
<i>Buchanania lanzan</i>	Anacardiaceae	9	0.848	3.625	0.341	0.376	0.745	0.379	1.501
<i>Ceriscoides turgida</i>	Rubiaceae	4	0.376	0.382	0.035	0.167	0.331	0.039	0.538
<i>Cassia fistula</i>	Fabaceae	23	2.167	2.812	0.264	0.617	1.408	0.294	2.664
<i>Careya arborea</i>	Myrtaceae	1	0.094	0.108	0.010	0.041	0.082	0.011	0.135
<i>Diospyros melanoxylon</i>	Ebenaceae	148	13.944	49.045	4.621	6.189	6.959	5.133	18.282
<i>Euginea jambolana</i>	Myrtaceae	10	0.942	26.157	2.464	0.418	0.497	2.737	3.653
<i>Feronia elephantum</i>	Rutaceae	4	0.376	4.779	0.450	0.167	0.331	0.500	0.998

Tree Species	Families	N	Density(Individual ha ⁻¹)	Basal Area(m ²)	Basal Area (m ² ha ⁻¹)	RD	RF	R Do	IVI
<i>Ficus infectoria</i>	Moraceae	5	0.471	9.502	0.895	0.209	0.165	0.994	1.369
<i>Ficus benghalensis</i>	Moraceae	1	0.094	10.032	0.945	0.041	0.082	1.049	1.174
<i>Ficus religiosa</i>	Moraceae	2	0.188	4.575	0.431	0.083	0.165	0.478	0.728
<i>Gmelina arborea</i>	Verbenaceae	3	0.282	0.134	0.012	0.125	0.082	0.014	0.222
<i>Holoptelea integrifolia</i>	Ulmaceae	1	0.094	3.629	0.341	0.041	0.082	0.379	0.504
<i>Limonia acidissima</i>	Rutaceae	16	1.507	1.834	0.172	0.669	0.828	0.191	1.689
<i>Lannea coromandelica</i>	Anacardiaceae	2	0.188	0.126	0.011	0.083	0.082	0.012	0.179
<i>Lagerstroemia parviflora</i>	Lythraceae	198	18.656	44.205	4.165	8.281	9.279	4.627	22.187
<i>Moringa oleifera</i>	Moringaceae	1	0.094	0.086	0.008	0.041	0.082	0.009	0.133
<i>Mangifera indica</i>	Anacardiaceae	2	0.188	21.320	2.008	0.083	0.081	2.231	2.398
<i>Phyllanthus emblica</i>	Euphorbiaceae	26	2.449	9.244	0.870	1.087	1.905	0.967	3.960
<i>Pterocarpus marsupium</i>	Fabaceae	1	0.094	0.067	0.006	0.041	0.082	0.007	0.131
<i>Stephegyne parvifolia</i>	Rubiacea	23	2.167	38.205	3.599	0.961	1.242	3.998	6.203
<i>Saccopetalum tomentosum</i>	Anonaceae	15	1.413	3.263	0.307	0.627	0.662	0.341	1.631
<i>Sterculia urens</i>	Sterculiaceae	5	0.471	2.500	0.235	0.209	0.165	0.261	0.636
<i>Schleichera trijuga</i>	Sapindaceae	2	0.188	0.897	0.084	0.083	0.248	0.093	0.426
<i>Soymdia febrifuga</i>	Meliaceae	4	0.376	4.729	0.445	0.167	0.331	0.494	0.993
<i>Tamarindus indica</i>	Fabaceae	1	0.094	2.269	0.213	0.041	0.082	0.235	0.362
<i>Terminalia arjuna</i>	Combretaceae	10	0.942	25.741	2.425	0.418	0.662	2.694	3.775
<i>Tectona grandis</i>	Verbenaceae	600	56.533	195.199	18.392	25.094	13.918	20.431	59.444
<i>Terminalia tomentosa</i>	Combretaceae	18	1.696	6.646	0.626	0.752	1.325	0.695	2.774
<i>Terminalia bellirica</i>	Combretaceae	6	0.565	23.049	2.171	0.250	0.331	2.412	2.994
<i>Wrightia tintoria</i>	Apocynaceae	16	1.507	1.473	0.138	0.669	1.242	0.154	2.066

Tree Species	Families	N	Density(Individual ha ⁻¹)	Basal Area(m ²)	Basal Area (m ² ha ⁻¹)	RD	RF	R Do	IVI
<i>Zizyphus xylopyra</i>	Rhamnaceae	209	19.692	39.934	3.762	8.741	10.024	4.179	22.945
Total		2391	225.285	955.364	90.016	100	100	100	300
<i>Note:</i> N = no of Individuals, RD = Relative Density, RF = Relative Frequency, RDo = Relative Dominance.									

4.6 Regeneration density and Status

Regeneration density in the form of seedling and sapling was enumerated in the 2.653ha area. The overall density for seedling and sapling was estimated to be 70.289 seedling ha⁻¹ and 89.04 sapling ha⁻¹. *Diospyros melanoxylon* had the highest density in the seedling stage, followed by *Zizyphus xylopyra* (10.81 seedling ha⁻¹), *Aegle marmelos* (7.349 seedling ha⁻¹), *Wrightia tinctoria* (6.784 seedling ha⁻¹), *Tectona grandis* with the value of 5.276 seedling ha⁻¹ and so on. However, the overall sapling density was considerably highest (89.04 sapling ha⁻¹) than seedling density and showed a reverse pattern. As *Tectona grandis* had the highest (19.032 sapling ha⁻¹) sapling density and then followed by *Aegle marmelos* (13.66 sapling ha⁻¹), *Wrightia tinctoria* (11.118 sapling ha⁻¹), and *Diospyros melanoxylon* (10.647 sapling ha⁻¹).

Overall, 19 tree species were considered as good regeneration because these species were able to establish in all three categories viz. tree, seedling, and sapling that contributed to 41.304% of total tree species. On the other hand, a total of 15.217% of tree species that were available in the tree and seedling stage considered as fair in status, but 36.956% of tree species was found to fail to establish in the community because species were represented by an only adult or tree stage that listed as Not-regenerating. Among the tree species, only four species viz. *Holoptelea integrifolia*, *Stephegyne parviflora*, *Feronia elephantum*, and *Gmelina arborea* were accounted as poor regenerating, for these species could not be found in seedling rather possessed in tree and sapling stage only (Table 3).

Table 3
REGENERATION OF TREE SPECIES IN PANNA TIGER RESERVE

Species	Tree (Individual ha ⁻¹)	Seedling (Individual ha ⁻¹)	Sapling (Individual ha ⁻¹)	Regeneration Status
<i>Aegle marmelos</i>	14.227	7.349	13.662	Good
<i>Anogeissus latifolia</i>	15.546	0.659	0.094	Good
<i>Abrus precatorius</i>	13.944	0	0	Non-regenerating
<i>Adina cordifolia</i>	0.376	0	0	Non-regenerating
<i>Anogeissus pendula</i>	11.306	4.711	3.580	Good
<i>Acacia catechu</i>	22.990	1.507	1.224	Good
<i>Acacia latifolia</i>	1.130	0.188	0.188	Good
<i>Allangium salvifolium</i>	0.753	0.094	0	Fair
<i>Albizzia procera</i>	0	0.848	0.188	Good
<i>Azadirachta indica</i>	0.188	0.282	0.282	Good
<i>Balanites aegyptiaca</i>	4.334	1.978	1.413	Good
<i>Bassia latifolia</i>	1.884	0.188	0	Fair
<i>Bauhinia racemosa</i>	2.355	0.753	0.848	Good
<i>Butea monosperma</i>	5.182	0.188	0.848	Good
<i>Boswellia serrata</i>	1.790	0	0	Non-regenerating
<i>Bombax ceiba</i>	0.565	0.094	0	Fair
<i>Buchanania lanzan</i>	0.848	0.188	0	Fair
<i>Ceriscoides turgida</i>	0.376	1.978	0.565	Good
<i>Cassia fistula</i>	2.167	0.659	1.884	Good
<i>Careya arborea</i>	0.094	0	0	Non-regenerating
<i>Diospyros melanoxylon</i>	13.944	16.206	10.647	Good
<i>Euginea jambolana</i>	0.942	3.109	2.826	Good
<i>Feronia elephantum</i>	0.376	0	0.942	Poor
<i>Ficus infectoria</i>	0.471	0	0	Non-regenerating
<i>Ficus benghalensis</i>	0.094	0	0	Non-regenerating
<i>Ficus religiosa</i>	0.188	0	0	Non-regenerating
<i>Gmelina arborea</i>	0.282	0	0.094	Poor
<i>Holoptelea integrifolia</i>	0.094	0	0.094	Poor
<i>Limonia acidissima</i>	1.507	3.015	3.768	Good
<i>Lannea coromandelica</i>	0.188	0	0	Non-regenerating
<i>Lagerstroemia parviflora</i>	18.656	2.544	6.124	Good
<i>Moringa oleifera</i>	0.094	0	0	Non-regenerating
<i>Mangifera indica</i>	0.188	0	0	Non-regenerating
<i>Phyllanthus emblica</i>	2.449	0.094	0	Fair

Species	Tree (Individual ha ⁻¹)	Seedling (Individual ha ⁻¹)	Sapling (Individual ha ⁻¹)	Regeneration Status
<i>Pterocarpus marsupium</i>	0.094	0	0	Non-regenerating
<i>Stephegyne parvifolia</i>	2.167	0	0.471	Poor
<i>Saccopetalum tomentosum</i>	1.413	0	0	Non-regenerating
<i>Sterculia urens</i>	0.471	0	0	Non-regenerating
<i>Schleichera trijuga</i>	0.188	0	0	Non-regenerating
<i>Soyimida febrifuga</i>	0.376	0	0	Non-regenerating
<i>Tamarindus indica</i>	0.094	0	0	Non-regenerating
<i>Terminalia arjuna</i>	0.942	0.094	0	Fair
<i>Tectona grandis</i>	56.533	5.276	19.032	Good
<i>Terminalia tomentosa</i>	1.696	1.319	0	Fair
<i>Terminalia bellirica</i>	0.565	0	0	Non-regenerating
<i>Wrightia tintoria</i>	1.507	6.784	11.118	Good
<i>Zizyphus xylopyra</i>	19.692	10.081	8.951	Good

4.7 Plant family

Taxonomic data on family-wise contribution to genera, species, and their density in different categories of plant community viz. Tree, seedling, sapling are summarized in Table 4.

In terms of the most diverse family among the plant categories, Fabaceae had the highest species richness. However, 14 families of trees, 12 families of seedlings, and 8 families of saplings consisted of single species. Comparing density on the family level, the highest density for tree, seedling, and sapling was found in Sapindaceae (25.104), Ebenaceae (16.206), and Apocynaceae (11.118) respectively.

Table 4
FAMILY-WISE CONTRIBUTION TO GENERA, SPECIES AND DENSITY IN PANNA TIGER RESERVE

Family	Tree			Seedling			Sapling		
	Genera	Species	Density	Genera	Species	Density	Genera	Species	Density
Anacardiaceae	3	3	1.224	1	1	0.188	-	-	-
Anonaceae	1	1	1.413	-	-	-	-	-	-
Apocynaceae	1	1	1.507	1	1	6.784	1	1	11.118
Burseraceae	1	1	1.790	-	-	-	-	-	-
Combretaceae	2	5	30.056	2	4	6.784	2	3	3.863
Ebenaceae	1	1	13.944	1	1	16.206	1	1	10.647
Euphorbiaceae	1	1	2.449	1	1	0.094	-	-	-
Fabaceae	8	9	48.712	6	7	4.240	5	6	5.182
Lythraceae	1	1	18.656	1	1	2.544	1	1	6.124
Malvaceae	1	1	0.565	1	1	0.094	-	-	-
Meliaceae	2	2	0.565	1	1	0.282	1	1	0.282
Moraceae	1	3	0.753	-	-	-	-	-	-
Moringaceae	1	1	0.094	-	-	-	-	-	-
Myrtaceae	2	2	1.036	1	1	3.109	1	1	2.826
Rhamnaceae	1	1	19.692	1	1	10.081	1	1	8.951
Rubiaceae	3	3	2.920	1	1	1.978	2	2	1.036
Rutaceae	3	3	16.112	1	1	10.364	3	3	18.373
Sapindaceae	1	1	0.188	-	-	-	-	-	-
Sapotaceae	1	1	1.884	1	1	0.188	-	-	-
Sterculiaceae	1	1	0.471	-	-	-	-	-	-
Ulmaceae	1	1	0.094	-	-	-	1	1	0.094
Verbenaceae	2	2	56.816	2	2	5.370	2	2	19.127
Zygophyllaceae	1	1	4.334	1	1	1.978	1	1	1.413
Total	40	46	225.280	24	27	70.288	22	24	89.038

4.8 Tree girth class-wise density distribution and Basal area

An analysis of tree girth class-wise distribution of tree showed that tree stand and basal area were consistently decreased with increasing girth class of tree stand. The highest tree stand density ($127.576 \text{ stand ha}^{-1}$) was recorded in the girth class of 31-60cm (48.687% of the total tree stand density) followed by 10-30cm and 61-90cm. Likewise, a total basal area of $20.824 \text{ m}^2\text{ha}^{-1}$ was occupied by 31-60cm that contributed 23.051% of the total basal area (Table 5).

Table 5
TREE DENSITIES AND BASAL AREA IN DIFFERENT GIRTH CLASS IN PANNA TIGER RESERVE

Girth Classes	No of Individual	Density (Individual ha ⁻¹)	Contribution to Density (%)	Basal Area (m ² ha ⁻¹)	Contribution to Basal Area (%)
10–30	644	60.679	23.157	2.782	3.079
31–60	1354	127.577	48.687	20.824	23.051
61–90	473	44.567	17.008	18.808	20.820
91–120	170	16.017	6.112	13.406	14.839
121–150	63	5.936	2.265	8.452	9.356
151–180	27	2.544	0.970	5.349	5.921
181–210	18	1.696	0.647	4.966	5.497
211–240	9	0.848	0.323	3.273	3.623
241–270	7	0.659	0.251	3.339	3.696
271–300	2	0.188	0.071	1.202	1.331
301–330	1	0.094	0.035	0.757	0.838
331–360	2	0.188	0.071	1.680	1.859
361–390	4	0.376	0.143	4.112	4.552
391–420	0	0	0	0	0
421–450	0	0	0	0	0
> 451	1	0.094	0.035	1.606	1.777

5 Discussion

In the year 1994, Panna National Park was renowned as the 22nd Tiger Reserve under the project Tiger to protect large carnivores mainly Tiger. For conserving Tiger, it is necessarily protect to all biodiversity including plants. The main objective of our investigation was to quantify habitat characteristics in terms of species composition and diversity in different categories of plant community such as tree, seedling, and sapling for Tropical Dry Deciduous Forest. According to Myo et al. (2016), the density, composition, and distribution of seedlings and saplings can serve as a robust indicator of forest structure.

The structural and floristic composition of the tropical dry forest is less complex than the wet forest, having about half and less number of tree species than those of wet forest (Murphy & Lugo 1986). Indices for species richness, abundance, dominance, and frequency are an efficient way for describing the structural and floristic composition of the vegetation (Lamprecht 1989).

5.1 Comparison for Sample-based rarefaction curve

The estimation of species richness is mainly influenced by the spatial distribution of species (Palmer & White 1994). In favor of non-parametric estimation for species richness, Chao1 and ACE yielded the lowest species richness with an SD value of 48.05 ± 2.91 and 49.37 ± 1.32 respectively. These estimators are highly sensitive to non-random distribution. However, Chao2 and ICE performed similarly to each other, estimating its richness of 50.13 ± 4.9 and 51.59 ± 1.53 respectively. As these estimators are least sensitive to non-random distribution. The higher value for tree species richness is indicated by the Jackknife (Jack) estimator. Since first-order jackknife (Jack 1) is based on the number of unique species and Second-order Jackknife (Jack 2) is based on the number of unique, number of duplicates, and the number of quadrat sampled (Chazdon et al. 1998). Moreover, in non-random distribution, the unique and duplicate can be distinguishable from singleton and doubleton respectively (Chazdon et al. 1998). For a similar reason, Second-order Jackknife (Jack2) could estimate the highest number of species from an empirical data set.

5.2 Comparison for Diversity Indices

To compare species richness from other sites, a total of 46 tree species were enumerated as observed species richness on a 10.6132ha area. This value is higher than the values reported from other tropical dry deciduous forest (TDDF) in the country such as in Western Ghats of Tamil Nadu (22; Sundarapandian et al. 2005), Piranmalai forest of Eastern ghats (16; Pitchairamu et al. 2008), Katghora forest division of Chattisgarh (6–12; Pawar et al. 2012), Bhoramdeo Wildlife Sanctuary in Chattisgarh (12–20; Jhariya et al. 2012), Open and Closed forest in Barnawapara Wildlife Sanctuary (10–18; Bargali et al. 2014), Dharwad district of Karnataka (27–36; Khaple et al. 2015), Panchmahal district of Gujarat (31; Pilania et al. 2015), Birbhum district of West Bengal (20; Pradhan & Rahman 2015) and Mixed forest of Barah in Jabalpur (28; Fayiah et al. 2018). Even higher than the tropical forest in South-west China (14–43; Zhang & Cao 1995) and Dry semi-evergreen forest of Yucatan peninsula, Mexico (39; Cairns et al. 2003). In contrast, the observed species richness in the present study close to the values recorded in the dry deciduous forest of Cuixmala Biosphere Reserve in Western Mexico (44–73; Segura et al. 2003), Providencia island in Columbia (23–49; Ruiz et al. 2005), Kalakad-Mundanthurai Tiger Reserve, India (52; Arjunam et al. 2005), Northern Part of India (49; Sagar & Singh 2005), and Anaikatty Reserve forest in the Western Ghats, India (45–98; Anitha et al. 2009). Despite TDDF, this value is also closer to Moist-mixed deciduous forest of Peppara Wildlife Sanctuary, Neyyar Wildlife sanctuary and Agasthayavanam Biological park, India (49; Varghese & Menon 1998) and upper montane forest, an evergreen forest type, of Doi Inthanon National park, Thailand (47; Khamyang et al. 2004). However, observed species richness is lower than the values reported from other tropical forests like the tropical semi-evergreen forest in the Shervarayan and Kalrayan hills of Eastern ghats (70 and 89; Kadavul & Parthasarathy 1999 a, b), tropical rain forest of Western ghats (144; Muthuram Kumar et al. 2006), tropical moist deciduous and semi-evergreen forest of Similipal Biosphere Reserve (76; Reddy et al. 2007), in Nallamalais, Seshachalan and Nigidi hill range of Eastern ghats (137; Reddy et al. 2008), Sal bearing moist deciduous forest in North-East India (216; Majamdar et al. 2014), Tropical moist deciduous forest of Eastern ghats (177; Sahoo et al. 2017) and Moist-mixed deciduous forest, Assam (90; Dutta and Devi 2017). This study coincides with the statement that given by Holdridge (1967) who commented the species diversity doubles from dry to the moist forest and triple from dry to wet forest. Consequently, the species richness in the present study was lower than many tropical moist and wet forests.

The general trend is that tropical forests attain the highest values of the Shannon Index (Knight 1975) and ranged from 0.83 to 4.0 in Indian Forest (Singh et al. 1984). During the study, the Shannon Diversity indices for the tree was enumerated with the value of 2.684 which is lower than reported by others in TDDF like 2.5–3.46 in Kalakad-Mundathurai Tiger Reserve (Arjunam et al. 2005), 4.3 in Similipal Biosphere Reserve (Reddy et al. 2007), 5.12 in Keonjhar district of Orissa (Kar et al. 2009), 8.2 in Nicaragua, Central America (Tarrason et al. 2010), 3.40 in Laos (Phongoudome et al. 2012) 3.38 in Malyagiri hill range of Eastern Ghats, India (Sahu et al. 2012), 3.6 in Mahoba district of Bundelkhand region, India (Verma et al. 2013) and 3.6 in Northern Minas Gerais, Brazil (Apgaua et al. 2014) whereas closure to the value (2.65) accounted by Kumar & Kalavathy (2012) who studied status and diversity of trees, seedling and sapling in the TDDF of Northern Gujarat region, India. For indices comparison, the difference in the relative effectiveness of the sample size, lacking uniformity in sampling effort, as well as the diverse method used for vegetation sampling simultaneously affect these indices comparison (Gandhi & Sundrapandian 2014). However, the Shannon index is higher than the estimated 1.3–2.1 in Piranmalai forest of Tamil Nadu (Pitchairamu et al. 2008), 0.67–0.79 in Udaipur district, Rajasthan (Kumar et al. 2010), 1.99 in the Eastern Ghats (Panda et al. 2013), 0.63–2.20 in Barnawapara Wildlife Sanctuary (Bargali et al. 2014), 2.10 in Tiruvannamalai district, Tamil Nadu (Gandhi & Sundarapandian 2014), 1.18 in Barah forest of Jabalpur (Fayiah et al. 2018) and 1.61–1.86 in Dhamtari forest division, Chhattisgarh (Raj 2019) which reflecting high species diversity than these reported forests.

In comparison with the Simpson diversity reported from TDDF of Providencia Island in Columbia (0.05–0.15; Ruiz et al. 2005), the Eastern Ghats, India (0.015; Panda et al. 2013), Sathanur Reserve Forest (0.29; Gandhi & Sundarapandian 2014), Barnawapara Wildlife Sanctuary (Ranges from 0.08–0.16; Bargali et al. 2014), Barah Forest in Jabalpur (0.11; Fayiah et al. 2018), it substantially becomes evident that our study area has higher heterogeneity than these tropical forests. However, the estimated Simpson value of 0.89 is closer to the value where 0.6–0.9 in Vindhya Hill Ranges (Sagar et al. 2003), 0.82 in Similipal Biosphere reserve (Reddy et al. 2007), 0.9 in Laos (Phongoudome et al. 2012), 0.12–0.95 in Bhamawapara Wildlife Sanctuary, India (Lal et al. 2015) consequently it seems like heterogenous as these forests are. The previous study has been showing that habitat heterogeneity is caused by mosaic on landscape level in the physical environment of tropical forest.

The evenness index (0.318) was found minimum than in Providencia Island, Columbia (0.70–0.86; Ruiz et al. 2005), North-eastern Ethiopia (0.82; Wale et al. 2012), Laos (0.62; Phongoudome et al. 2012), Eastern Ghats (0.98; Panda et al. 2013), Mahoba district,

Bundelkhand region (0.93; Verma et al. 2013) Bhamawapara Wildlife Sanctuary (1.12–2.39; Lal et al. 2015), Panchmahal district of Gujarat (0.67; Pilania et al. 2015), Kanyakumari Wildlife Sanctuary (0.45–0.62; Kothandaroman & Sundrapandian 2017), Dhamrati forest division, Chhattisgarh (0.60–0.82; Raj 2019), indicating less evenly distribution of species in it than above mentioned tropical forest while similar to value (0.35) reported by Fayiah et al (2018) in Mixed Dry Deciduous forest of Barah forest, Jabalpur.

In the present study, the lowest value of dominance (0.108) than Simpson (0.891) and Shannon (2.684) is indicated its higher number of dominant species. This has been reported by Bajpai et al.(2020) who found the lowest value of dominance in comparison with Simpson and Shannon diversity index, therefore, representing more number of dominant species and highest heterogeneity with highest species diversity in lowland Miscellaneous forest of Tropical moist deciduous forest in Himalayan Terai Eco-region. On the other hand, the highest IVI value for *Tectona grandis* (59.44), *Acacia catechu* (24.94), *Abrus precatorius* (23.25), *Zizyphus xylopyra* (22.94), *Anogeissus latifolia* (22.16), and *Lagerstroemia parviflora* (22.18) is showing the dominance of multispecies rather than monospecies in our study area.

5.3 Comparision for stand density, basal area and rarity

The tree density of TDDF in our study area when compared with densities of the same forest type at other sites, revealed that PTR does not hold reliable estimates of tree density. For tree density in TDDF varies from 262.27 to 947 individuals ha⁻¹ for trees of > 10cm GBH (Bunyavejchewin 1983; Gonzaliz-Rivaz et al. 2006; Banda et al. 2006; Sahu et al.. 2012; Bargali et al. 2014; Apgaua et al. 2014 and Kothandaraman & Sundarapandian 2017). Although the tree density of 208.325 individuals ha⁻¹ was obtained for GBH > 30cm, yet the tree density is not well within the range from 220 to 1520 that reported for other TDDF (Sagar & Singh 2005; Reddy et al. 2007, Pitchairamu et al. 2008; Kumar et al. 2010; Jhariya et al. 2012; Bargali et al 2014).

Though our estimates for the basal area (90.016 m²ha⁻¹) seems higher than the previous study in Tropical Dry Forest (TDF) for > 10cm GBH that ranges from 0.6 in Similipal Biosphere Reserve, Odhisa (Reddy et al. 2007) to 64.2 m²ha⁻¹ in Veerapuli and Kalamalai Forest Reserve in the Western Ghats (Swamy et al. 2000).

According to Hett & Loucks (1976) and Denslow (1995), the disturbance impact can be determined within any forest ecosystem by using a girth-class distribution pattern. One study from India studied disturbance level and found that the intermediate size class (60–210cm GHB) attain a lesser degree of tree density and basal area, particularly in the moderate disturbed site because of selective logging of trees for a household purpose (Muthuramkumar et al. 2006). Additionally, these classes are also used for determining the forest age viz. Growing, medium, and climax or mature. The pattern discussed in the result section is manifested that forest structure can be considered as in mid-successional stage but also a human-disturbed. Other studies too have found the forest in the early and intermediate stage to show a higher density of stem with low basal values in contrast as the forest grows toward climax accordingly stem density decreases with high basal values (Yodzis 1986; Begon et al. 2006)

In our dry deciduous forest, rare species (representing < 2 individual) contributed to 23.916%, which is lower than reported for TDDF (18–30% for single individuals; Sagar et al. 2003, 62.71–72.88% for < 4 individuals; Gonzalez-Rivas et al. 2006, 34% for < 2 individuals; Reddy et al. 2007 and 33.33% for < 2 individuals; Gandhi & Sundarapandian 2014), and Tropical dry evergreen forest (26–31% for < 2 individuals; Parasarathy & Karthikeyan 1997, 60–62.5% for < 2 individuals; Swamy et al. 2000) in contrast the recorded value is higher than that reported for TDDF of Eastern Ghats., India (0.760% for < 2 Individuals; Panda et al. 2013). In terms of higher density and basal area, the general trend is the predominance of lower girth plant in lower class- size, decreases with increasing girth class. A similar pattern has been widely obtained for various Tropical Dry Deciduous forest in India (Reddy et al. 2007; Pitchairamu et al. 2008; Kar et al. 2009; Panda et al. 2013), in Tropical moist deciduous forest (Dutta & Devi 2013; Sahoo et al. 2017) and Tropical rain forest (Muthuramkumar et al. 2006) as well.

5.4 Comparision for plant families

The enumerated tree taxa diversity such as genera and species was contributed by 23 plant families which show the closer contribution of families in other TDF of North-East India (Sagar et al. 2003), South and South-West India (Mani & Parthasarathy 2006; Prakash et al. 2008; Gandhi & Sundarapandian 2014), Western India (Kumar et al. 2010; Pilania et al. 2015), and in the other world dry tropical forest such as Coast of Jalisco, Mexico (23; Martinez-Yrizar et al. 1992), New Caledonia, Australia (19–27; Gillespie & Jaffre 2003), Hellshire Hill Forest Reserve, Jamaica (27; McLaren 2005), Chacocente Wildlife Refuge, Nicaragua (29; Gonzalez-Rivas et al. 2006).

Moreover, In terms of the number of species and genera, Fabaceae was found to be the most diverse family then followed by Combretaceae. Likewise, Fabaceae is the most dominated family in Tropical Dry Forest of several Neotropical countries; including Central America (Gonzalez-Rivas et al. 2006; Hilje et al. 2015), and North-South and South America (Ruiz et al. 2005; Duran et al. 2006; Apgaua et al 2015), in North-Western Ethiopia (Wale et al. 2012), Southern and Central India (Ramanujan & Kodamban 2001; Fayiah et al. 2018) as well. Combretaceae is relatively abundant in the region of Udaipur district, Rajasthan (Kumar et al. 2010) while Sapindaceae in Australia (Gillespie & Jaffre 2003), Lauraceae in South-East Asia (Webb et al. 2011), Rubiaceae in Eastern India (Reddy et al. 2007; Kar et al. 2009), Mimosaceae and Caparaceae in Southern and Western India (Parthasarathy & Karthikeyan 1997; Gandhi & Sundrapandian 2014; Pilania et al. 2015).

5.5 Comparision for Seedling and Sapling

The microenvironment likely regulates tree saplings or sprouts which in turn reflect the tree density in the forest (Khan et al. 1986). The density of seedling in the PTR is lower than previous studies within other TDDF, Include a density of 10960–13680 seedling ha⁻¹ in Bhoramdeo Wildlife Sanctuary (Jhariya et al. 2012), 7750–39500 seedling ha⁻¹ in Katghora Forest Division (Pawar et al. 2012), 420 – 380 seedling ha⁻¹ in Barnawapara Wildlife Sanctuary (Bargali et al. 2014), 253–910 seedling ha⁻¹ in Kanyakumari Wildlife Sanctuary (Kothadaraman & Sundarapandian 2017), and 4050 seedling ha⁻¹ in Mixed deciduous forest of Laos (Phongoudome et al. 2012) in such a way the observed species richness of seedling in the study area is also lower than other sites viz. Northern India (57; Sagar et al. 2005), Anaikatty Reserve Forest in the Western Ghats (43–70; Anitha et al. 2009), Northern Gujarat (74; Kumar and Kalavathy 2012).

Similar to seedling density, the density of saplings is also found to be lower than other deciduous forests where values vary from 490 Sapling ha⁻¹ (Bargali et al. 2014) to 2476 Sapling ha⁻¹ (Phongoudome et al. 2012). In the preceding year with a short rainy season, water availability may be insufficient for storing the required resources to produce flowers which in turn reflect the seed production during summer.

The pattern of individual species densities in all three categories viz. Tree, seedling, and sapling mentioned in the previous section cumulatively result in the pattern of regeneration status of tree species (Table 3). Among the top five seedling tree species, the highest seedling density was obtained for *Diospyros melanoxylon* followed by *Zizyphus xylopyra*, *Aegle marmelos*, *Wrightia tintoria*, and *Tectona grandis*, which declined in the subsequent sapling stage and showed a reverse pattern. This pronounced change may be a consequence of herbivory which has been reported in other studies in the Tropical dry forest (Vermeulen 1996; Cumming et al. 1997).

The highest sapling density was recorded for *Tectona grandis* then *Aegle marmelos*, *Wrightia tintoria*, *Diospyros melanoxylon*, and *Zizyphus xylopyra*. McLaren & McDonald (2003) stated that seedling germination, survival, and their size are directly influenced by shading and soil water availability. As the season grows from wet to dry, a high light level will significantly decrease seedling survival (Gerhardt 1996; McLaren & McDonald 2003). Since *Tectona grandis* shows its affinity towards fire because fire can stimulate germination and establishment (Champion & Seth 1968; Khurana & Singh 2001) Similarly, It has been reported that fire can also enhance germination in other deciduous species like *Acacia catechu*, *Bauhinia* spp. (Singh & Raizada 2010).

Lagerstroemia parviflora, *Acacia catechu*, and *Zizyphus xylopyra* were co-dominant tree species and displaying a wide range of tolerance to biotic pressure and ecological amplitude as per Sagar et al. (2003). In 1999, thirteen villages were excited within the core area of PTR (Chundawat 1999). Most of them have been translocated but few villages remained in park boundary. The extent of these translocated villages is well characterized by successional grassland with the scattered tree of *Acacia* and *Zizyphus* that considerably leading to a degeneration of forest stand (Perera 2005). Moreover, *Acacia* and *Zizyphus* species germinates from the dung of Nilgai, wild boar, and feral cattle, for reported by Middleton & Mason (1992) who estimated the amount of germinated seedling density in the dung of Nilgai, Feral cattle, and Wildboar and concluded that *Acacia* seeds germinate in the hot dry season, but *Zizyphus* seeds are germinated in the cool dry season. Thus these species show animal seed dispersal and it is a predominant type of dispersal in tropical forest ecosystem (Howe & Smallwood 1982)

On the other hand, forests are facing a high degree of anthropogenic disturbance in the form of NTFP and cattle grazing, particularly on the forest edge. These forest edges are different than forest interior in terms of higher air temperature and relatively lower humidity and soil moisture (Kapos 1989) ultimately resulting in enhance the light-demanding species along the forest edge (Chazdon et al. 1996, Marod et al. 2004) because these species require light to stimulates seed germination (Ranney et al. 1981; Aide & Cavellier

1994). For this reason, the occurrence of light-demanding species of *Lagerstroemia parviflora* and *Butea monosperma* (Fayiah et al. 2018) was predominantly recorded from less distant areas to the forest edge. Despite, the forest has several commercially important tree species that harvest for livelihood purpose by local communities living around forest area for instance during May and June *Diospyros melanoxylon* leaves collection, fruits of *Eugenia jambolana*, *Ficus* spp, *Terminalia bellirica*, and flower of *Bassia latifolia*, therefore, it might decrease the regeneration of these target species which ultimately reduces the forest cover and biodiversity (Garrigus 1999; Silori & Mishra 2001; Pouchepadaes & Puyravaud 2002)

Of the top five dominating species of seedling and sapling, *Aegle marmelos* and *Wrightia tintoria* could not establish themselves as dominating adult tree species. In our study area, leaf senescence started from the cool dry season that reached to peak in February and March. A study by Singh & Singh (1992) also revealed the initiation of leaf-senescence from a low-temperature dry period. Rainfall, temperature, light, and relative humidity are some of the factors that pronounce leaf phenology in the dry deciduous forest (Singh & Singh 1992; Brochert 1994; Van Schaik et al. 1993; Wright & Van Schaik 1994). This may significantly alter the pattern of seed germination, survival, and seed growth (Khurana & Singh 2000)

Some species like *Buchanania lanzan*, *Phyllanthus emblica*, *Allangium salvifolium*, *Terminalia arjuna*, *Bassia latifolia*, *Terminalia tomentosa*, and *Bombex ceiba* are being characterized by adult or tree and seedling stage. *Tectona grandis* was estimated to be the highest dominated species and its canopy determines the germination, survival, and growth of other seedling species (Faiyah et al. 2018). Usually, canopy openness (Jennings et al. 1999), quality of light (Leakey et al. 2003) and soil moisture (Khurana & Singh 2000) favor the gain and loss under planted seedling (Tuomela et al. 1996; Pena-Carlas et al. 2002; Romell et al. 2008). Also, seedling fitness is influenced by natural or anthropogenic disturbance and biological traits of species, for example, If a sufficient amount of soil moisture does not avail for germination, then *Diospyros melanoxylon* will germinate in the next season because it has the ability to extending its germination until the second wet season (Ghosh et al. 1976; Khurana & Singh 2001). Likewise, could not well thrive in the seedling stage, *Lagerstroemia parviflora* was found to be the second co-dominant species. Because of seed polymorphism, *Lagerstroemia parviflora* tends to produce a variety of seeds within the same individuals that can germinate in a wide range of environmental conditions (Shukla & Ramakrishnan 1981)

Although not regenerating viz. no seedling and sapling, *Boswellia serrata*, *Sterculia urens*, *Adina cordifolia*, *Terminalia bellirica*, and *Pterocarpus marsupium* need consideration. As Dalling et al.1998 stated that a species can locally extinct in near future, not being accounted for in the seedling nor sapling stage. *Boswellia serrata* and *Terminalia bellirica*, being economically important tree species, showed low density. It might be caused by extracting for fruit and medicinal purpose respectively. Pilania et al. (2015) studied the phytosociological and ethnobotanical importance of tropical dry deciduous tree species in Western India who found these species are being exploited for fruits, medicinal and religious purposes.

6 Conclusion

In the present study, most of the area of Tiger Reserve is characterized by interspersed tall grasses between canopy trees across the two-season viz. Summer and winter may reduce seedling fitness (Perera 2005). Whereas, some areas are badly infested by an invasive shrub species *Lantana Camera* so that this species may promote disturbance by changing resource availability (Vivrette & Muller 1977; Vitousek & Walker 1989; Boswell & Espie 1998).

Our result indicates that the density of large tree species is not only being replaced by small woody species which have relatively low propagules availability for regeneration (Maza-Villalobos 2011) like *Acacia catechu*, *Lagerstroemia parviflora*, and *Zizyphus xylopyra*, but also the extrapolated species richness that was estimated by increasing the sample size, are not showing significant difference than occurred from empirical data set. The population structure also exponentially decreased due to illegal extraction of woody species, particularly those > 60 cm GBH and above (FIGURE 5). The data suggest that the forested area might gradually be converted into degraded savanna grassland in the upcoming year.

Declarations

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Figures

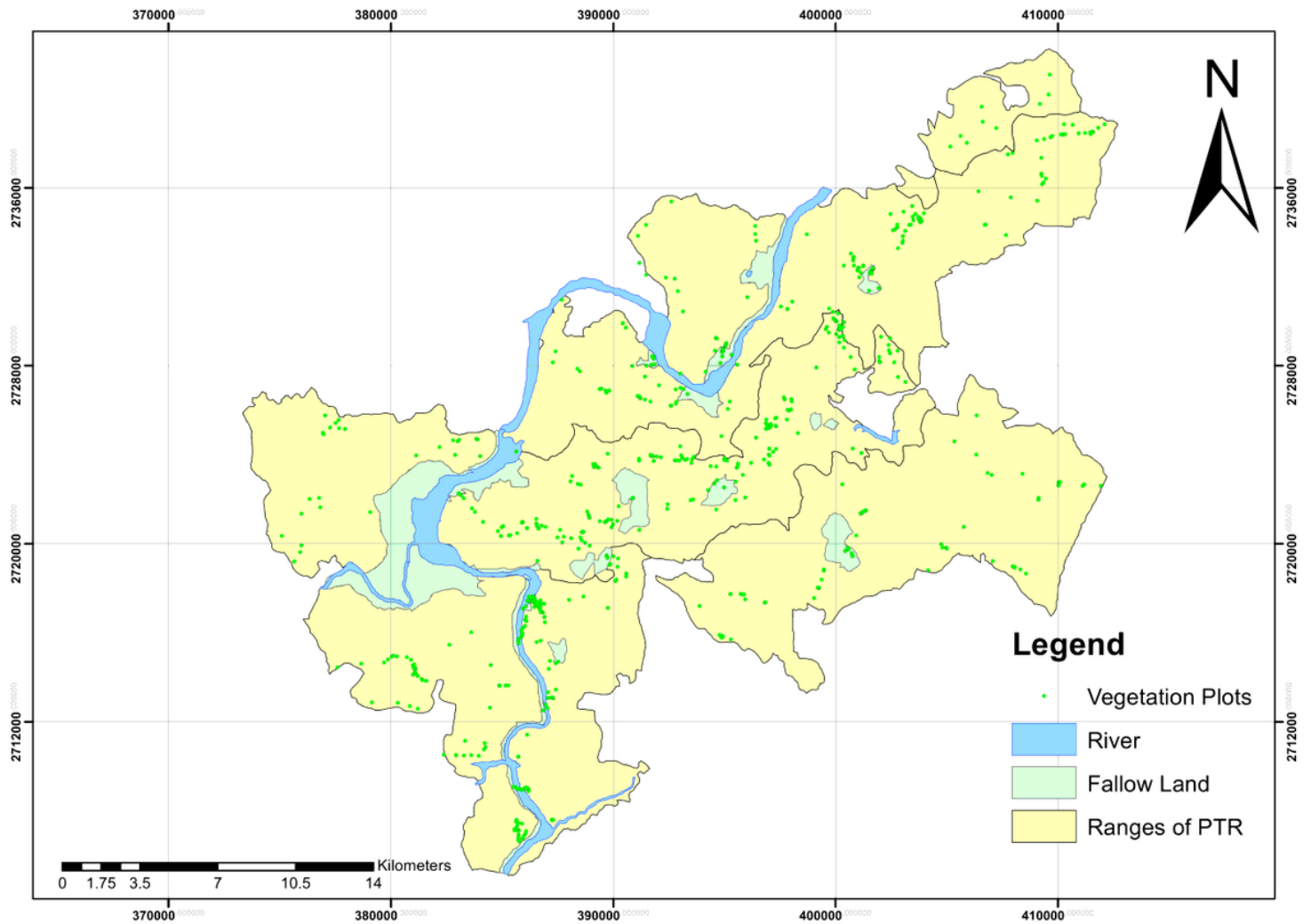


Figure 1

STUDY AREA MAP. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

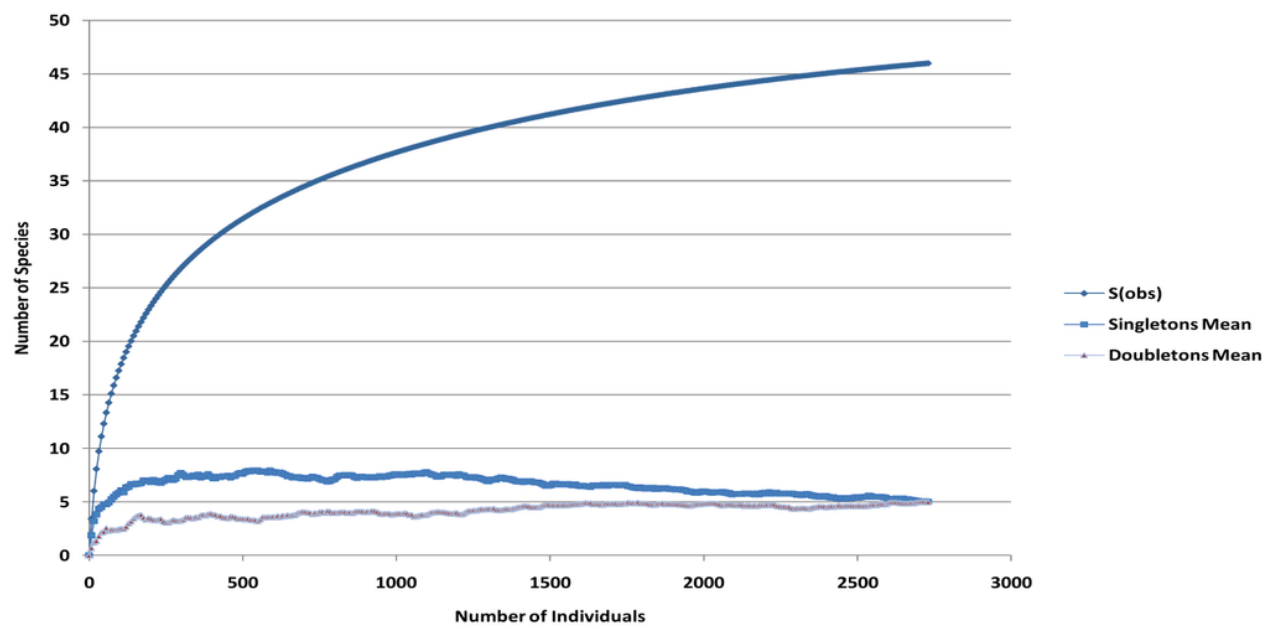


Figure 2

OBSERVED SPECIES RICHNESS AND RARITY (SINGLETON AND DOUBLETON) IN THE PANNA TIGER RESERVE.

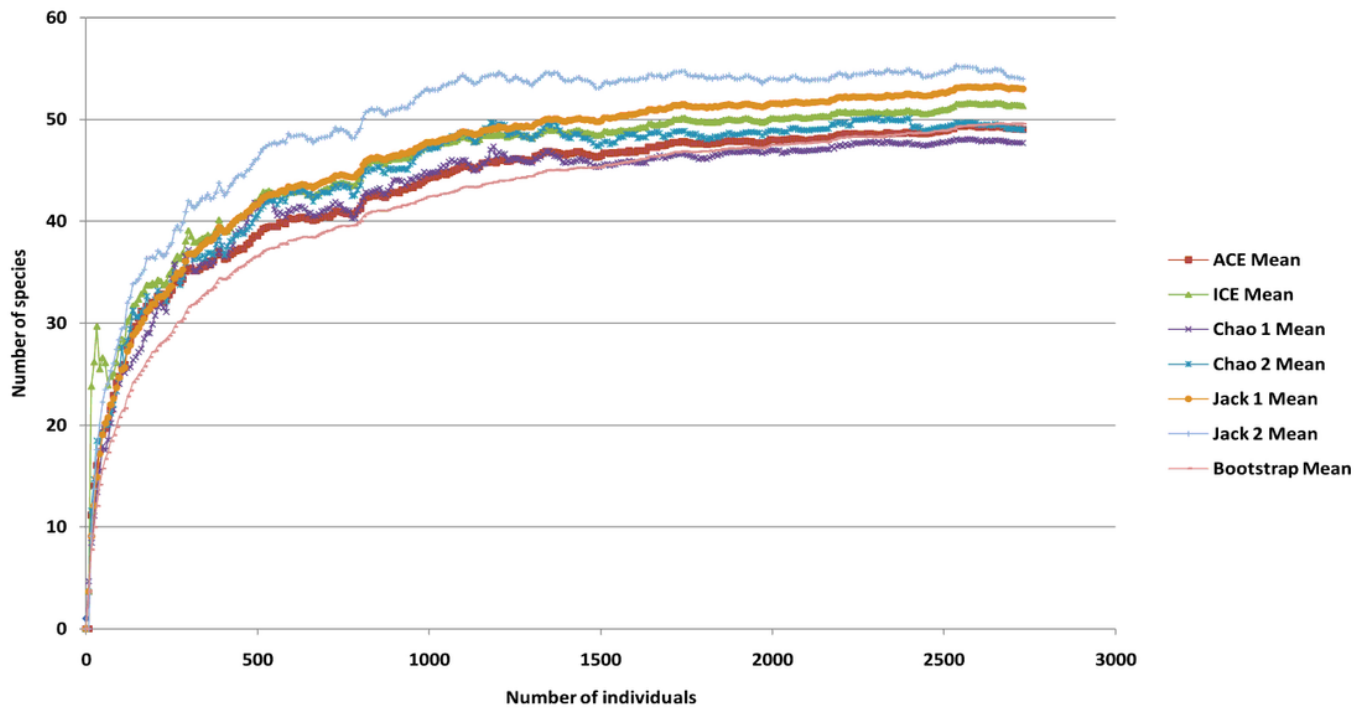


Figure 3

SAMPLE-BASED RAREFACTION CURVE FOR ESTIMATED SPECIES RICHNESS BY USING DIFFERENT ESTIMATORS

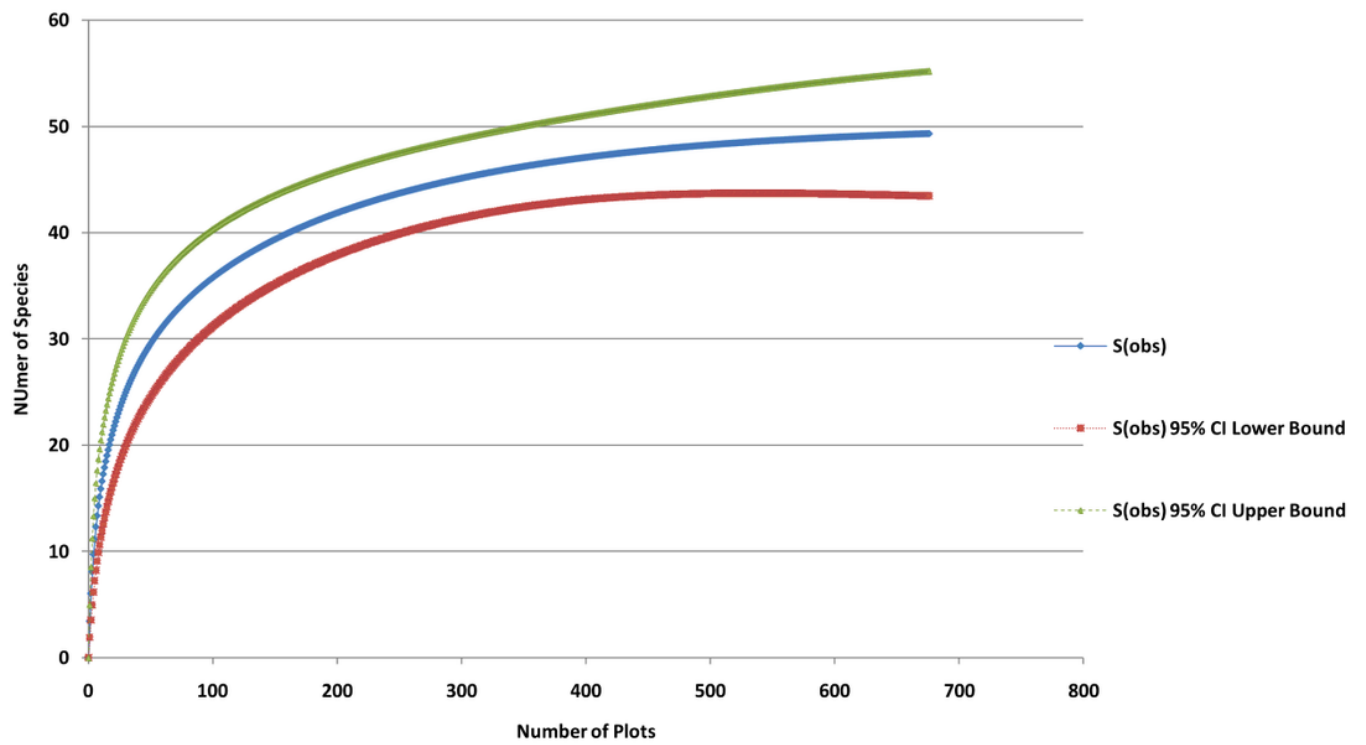


Figure 4

EXTRAPOLATION OF SAMPLE-BASED RAREFACTION CURVE FOR EMPIRICAL DATA SET.

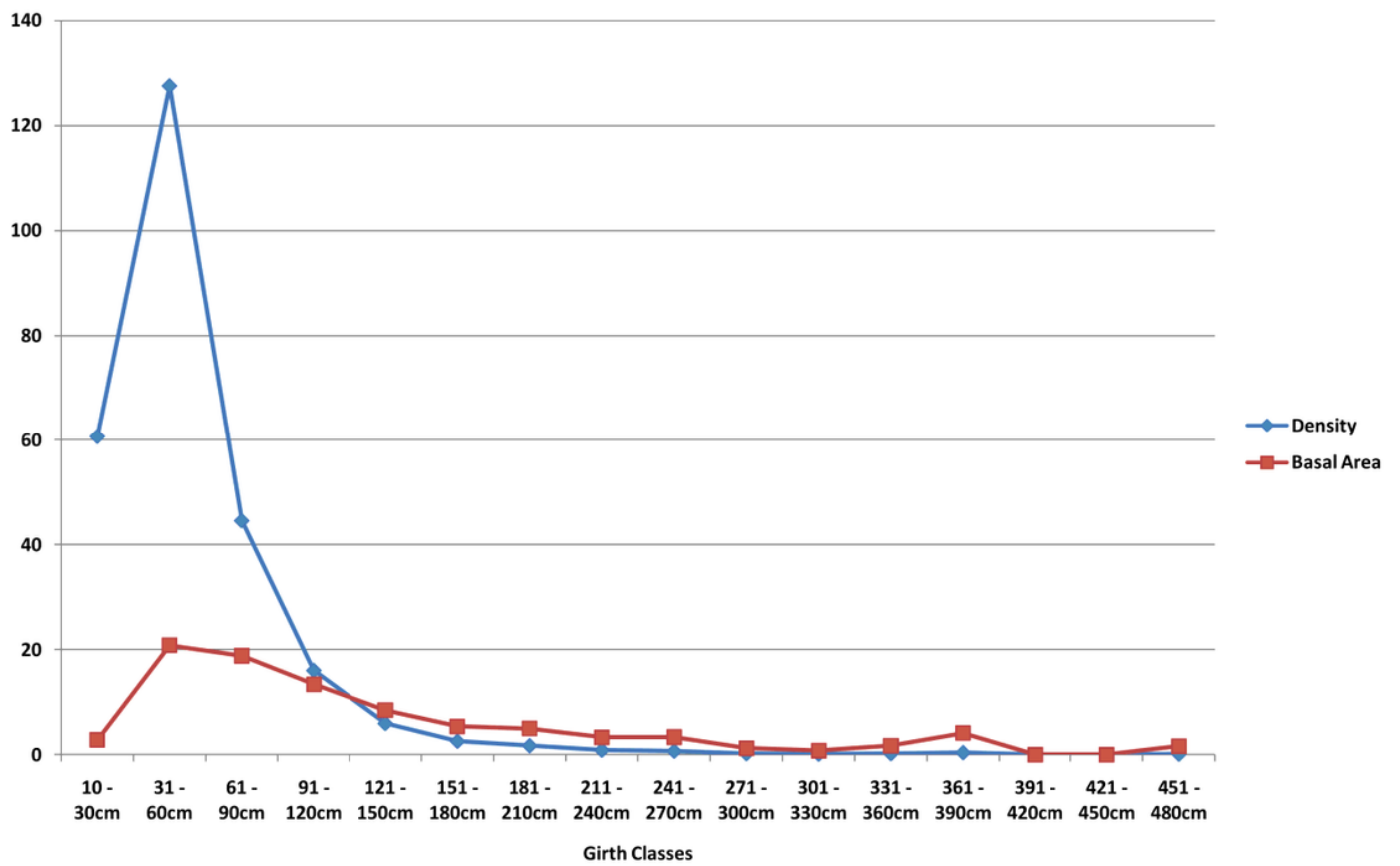


Figure 5

TREE DENSITIES AND BASAL AREA IN DIFFERENT GIRTH CLASS IN PANNA TIGER RESERVE.