

Controls of plant diversity attributes over above ground biomass in Sal forests of Eastern India

Rahul Kumar

Central University of Jharkhand

Amit Kumar

Central University of Jharkhand

Purabi Saikia (✉ purabi.saikia@cuja.ac.in)

Central University of Jharkhand <https://orcid.org/0000-0001-5481-282X>

Research

Keywords: Tree diversity, density, basal cover, above ground biomass (AGB), carbon stock (Cp)

Posted Date: June 5th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-33057/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

Background

Above ground biomass (AGB) is a useful measure for assessing changes in forest structure and functional, and play a significant role in studying carbon stocks, the effect of deforestation and carbon sequestration on the global carbon balance. The present study aimed to study the relationship between AGB and community parameters in Sal forests of Eastern India through stratified random sampling by lying 92 belt transects each of 0.5 ha size.

Results

It recorded a high AGB (410.70 Mg ha⁻¹), and carbon stock (Cp) (193.06 Mg C ha⁻¹), and forest wise AGB ranged from 0.19 to 24.75 Mg ha⁻¹ (mean 4.45 ± 0.45 SE). The spatial pattern of AGB showed that maximum studied forests (65%) had very low AGB (<5.00 Mg ha⁻¹), and only one forests (1%) located in the northwest corner of Ranchi had very high AGB (>20 Mg ha⁻¹). Species wise AGB ranged from 0.001 to 7074.94 Mg ha⁻¹ (mean 106 ± 71 SE) and *Shorea robusta* with maximum basal area (120.81 m² ha⁻¹) contributed maximum AGB (64.87% of the total AGB), however, no similar trends have been observed in any other tree species. A significant positive correlation was observed between AGB and Cp ($r=1.00$, $p<0.01$), H' ($r= .58$, $p<0.01$), Dmg ($r= .31$, $p<0.01$), Dmn ($r= .49$, $p<0.01$), ENS ($r= .57$, $p<0.01$), E ($r= .26$, $p<0.05$), and basal area ($r= 0.71$, $p<0.05$). However, a negative correlation of AGB was evident with CD ($r= -.57$, $p<0.01$), and density ($r= -0.17$).

Conclusions

The relationships differed greatly among plant diversity attributes, basal area, density, AGB, and Cp within and among various forests and the strongest relationships within each forests were always those having greater richness (Dmg, Dmn), diversity (H, ENS), basal area or evenness (E). Estimation of forest Cp enables us to assess the amount of carbon loss during deforestation or the amount of carbon stored during forest regeneration. The present study will directly help in studying the response of climate change on ecosystem productivity, energy and nutrient flow, and for assessing the patterns of carbon sequestration in Indian forests under global climate change.

Background

Forests are considered as important terrestrial carbon reserves and pools (Whittaker and Likens, 1975) that greatly influence the lives of humans as well as other organisms. Forests act as natural carbon sinks, and play the most significant role by producing large carbon pools stored as vegetation biomass including storage of carbon in the soil (Brown and Lugo, 1992). The carbon acquired from the atmosphere is fixed through photosynthesis to form organic compounds (Alexandrov, 2007). Thus, atmospheric carbon becomes a part of the plant body and stored for a longer period of time in different plant parts. Forest biomass is an important source of food, fodder and fuel, and its exploitation leads to

forest degradation (Rawat and Nautiyal, 1988). Forest biomass quantification has attracted renewed interests as it represents *ca.* 44 % of the world forest carbon pool (Pan *et al.*, 2011), thereby playing a key role in climate change mitigation. Above ground biomass (AGB) is a useful measure for assessing changes in forest structure and functional (Brown *et al.*, 1999; Kumar *et al.*, 2019) and play a significant role in studying carbon stocks, the effect of deforestation and carbon sequestration on the global carbon balance (Ketterings *et al.*, 2001). AGB estimates are critical to analyze the carbon stocks and fluxes of forests (Brown *et al.*, 1997; Návar, 2009) and also help in quantification of the structural attributes of forest ecosystems across a wide range of environmental conditions (Brown *et al.*, 1999) as well as the amount of carbon lost from sinks through deforestation and degradation (Ketterings *et al.*, 2001; Houghton, 2005). The biomass in tropical deciduous forest is not uniformly distributed and exhibits patchy distribution (Chaturvedi *et al.*, 2011). Estimating the amount of forest biomass gives an idea of carbon sequestration potential of forests (Murthy *et al.*, 2013). Absolute measurements of biomass can be taken up only at the time of felling which is not possible in all situations (Murali *et al.*, 2005). Measurements for GBH, height, and species-specific gravity in the field are good criteria for estimating biomass as nondestructive methods (de Gier, 2003). Therefore, carbon stock of trees can be estimated using an allometric/volumetric equation (Thapa-Magar and Shrestha, 2015). Tree diameter and height data used to estimate carbon stocks through the calculation of AGB by using species specific allometric/volumetric equations (Ketterings *et al.*, 2001; Chave *et al.*, 2005). Plant biomass has a direct relationship with the amount of carbon present in that plant biomass. Based on the results of different studies related to the estimation of carbon in wood, it was observed that carbon varied from 45 % to 50 % for different ecosystems and all biomass pools contained 47.5 % carbon (Kotto-Same *et al.*, 1997).

Ecosystem stability, and its resilience are dependent on plant diversity attributes, such as species richness, evenness, and composition (identity of species) (Tilman and Downing, 1994; Naeem *et al.*, 2000). The impacts of land clearing due to proliferation of agriculture, urban sprawl, natural hazards (forest fires, insects, diseases, droughts, frosts), and exploitation activities (illegal forest clearance, *etc.*) on forests can only be understood by these plant diversity attributes (Dogan and Dogan, 2003). These visual tools enable us to understand the nature, and characteristics of land cover, and species distributions. Species diversity is the combination of species richness, and evenness, and it is the number of biological units present at a given location at a given time taking into account the distribution pattern of individuals amongst the species. The most commonly used measures of species diversity are the Shannon function, species richness, and evenness (the distribution of abundance among the species, also known as equitability) (Feroz *et al.*, 2015). Species richness is a measure being more influenced by seedlings recruitment, whereas species evenness is influenced by species interactions like competition (Wilsey and Gray, 2007). The consideration of species richness without any other key attributes of species assemblages could be a misleading indicator of plant diversity in terms of conservation perspective (Stirling and Wilsey, 2001; Ma, 2005). On the other hand, species evenness has an important role in conservation of biological diversity (Mattingly *et al.*, 2007) as with the changes in evenness, the distribution of functional traits of an ecosystem used to be affected (Chapin *et al.*, 2000; Hillebrand *et al.*, 2008). The shift in evenness used to be occurred much earlier than the species richness in any

community. Therefore, tracking species evenness can provide some kind of early warning regarding the disturbances going on in the community (Anonymous, 2015). The variation in both evenness and diversity is being regulated by richness (Hill, 1973), and evenness significantly determines the change in species diversity than richness (Mlilo, 2018) as it holds a major contribution in the diversity (Triin *et al.*, 2009). Thus, species evenness provides adequate information on change in plant diversity with comparatively higher gradients than richness (Mlilo, 2018).

Tropical deciduous forests of India are species rich with irregular distribution of tree densities and basal covers as well as multistoried canopy structures with different microclimate makes it complex to understand the patterns of AGB over space and time within and among the different forests (Behera *et al.*, 2012). Additionally, species diversity, richness, evenness, or dominance represent critical attributes of plant diversity that may have associations with AGB. A very limited study has examined the AGB-plant diversity attributes relationships in forests, perhaps because of the difficulty of using AGB as a substitute for productivity in long-lived trees (Vance-Chalcraft *et al.*, 2010). However, describing the relationship between species richness and AGB in forests is useful beyond the context of forest productivity. Therefore, the present study aimed to assess spatial pattern of tree diversity, and AGB by using species specific volumetric equations in *Sa/* forests of Ranchi, Jharkhand, Eastern India as well as estimation of carbon stock (Cp) based on the AGB results. An effort has also been made to examine the relationships between multiple attributes of plant diversity and AGB.

Materials And Methods

Study area

The study was conducted in Ranchi district, Jharkhand, Eastern India (*Figure 1*). Ranchi is situated between 23.13°N to 23.21°N latitude and 85.51°E to 85.54°E longitude, where the altitude varies from 400 to 700 m above mean sea level (msl). Forests of Ranchi are considered as tropical moist deciduous forests mostly dominated by *S. robusta* (Dipterocarpaceae), locally known as *Sa/* forests (Champion and Seth, 1968). The study area falls under a humid subtropical climate (as per Koppen Climate Classification) and experiences 23.7°C of mean annual temperature and 397 mm precipitation at an average elevation of 650 m leading to pleasant climatic conditions.

Vegetation sampling and analyses

We carried out a comprehensive, and comparative evaluation of tree species diversity, stand basal area, density, and AGB through stratified random sampling to survey 92 plots each of 0.5 ha *Sa/* forests of Ranchi during September 2016 to October 2018. Location of transects was decided based on grid generation technique following Kumar and Saikia (2020). Girth at breast height (1.37 m above ground) and height of all individual trees (≥ 10 cm GBH) was measured using measuring tape and range finder in each transect, respectively. GPS locations of each transect at both starting and ending points were also

collected to prepare the spatial maps of different plant diversity attributes. Community parameters such as density, basal area were determined according to Misra (1968), and diversity attributes (vegetation indices) including Margalef's index of species richness (Dmg) (Margalef, 1958), Menhinick's index of species richness (Dmn) (Whittaker, 1977), Shannon-Wiener diversity index (H') (Magurran, 1988), Simpson's index (CD) (Simpson, 1949), Pielou's evenness index (E) (Pielou, 1966), and effective number of species (ENS) (Jost, 2006) were calculated using standard formula.

The nondestructive method of biomass estimation was used to determine the AGB of all documented trees, where the basal area, tree height, species-specific gravity and volume equations were used as inputs. The GBH data collected from the field were converted into DBH by using formula GBH/π . The volumetric equations and wood specific gravity provided by the forest survey of India (FSI, 1996) has been used for further analysis of AGB. The general equation used for the volume estimation is-

$$\text{Biomass} = \text{Volume} \times \text{Wood density}$$

$$\text{Volume} = (\pi d)^2 h$$

In the present research, species-specific volumetric equations were used as mentioned in *Table 1*. The general equation proposed by the Ministry of Agriculture & Irrigation, Government of India (1977) was used to estimate the volume of the select species, for which species-specific volumetric equations are not available in literature. AGB to carbon conversions was performed pursuant to the guidelines established in the IPCC 2006, and postulate conversion formula to estimates carbon from AGB:

$$C_p = \text{AGB} * CF$$

Where, C_p = carbon stock (Mg C ha^{-1}),

AGB = above-ground dry biomass (Mg ha^{-1}),

CF = carbon fraction (Mg C Mg^{-1} dry matter).

For tree vegetation, Carbon Fraction (CF) value fixed $0.47 \text{ Mg C Mg}^{-1}$ (IPCC, 2006).

Various plant diversity attributes were linked with transect location and spatially correlated in GIS to deduce the control of AGB over plant diversity attributes. Statistical analyses were performed with SPSS (*Version 20*) and maps were prepared by using ArcGIS *version 10.3*.

Results And Discussions

Spatial pattern of above-ground biomass (AGB) and carbon stock (Cp)

Field-based AGB estimates, though time and cost ineffective, are vital to characterizing forest ecosystems and to assess the potential production of tropical forests (Behera *et al.*, 2017). The total AGB and Cp of all studied *Sal* forests were 410.69 Mg ha⁻¹, and 193.06 Mg C ha⁻¹ respectively, which is higher than the AGB of *Sal* plantation forest of Meghalaya, Northeast India (406 Mg ha⁻¹) (Baishya *et al.*, 2009) as well as *Sal* forests of the Himalayas (78 to 378 Mg ha⁻¹) (Gautam *et al.*, 2011). The present record of AGB is within the reported range (150 to 698 Mg ha⁻¹) of various tropical forests of the world (Brown and Lugo, 1982; Shrestha *et al.*, 2000; Terakunpisut *et al.*, 2007) as well as comparable with the reported range (28.1 to 330.87 Mg ha⁻¹) of various tropical deciduous forests of India (Ranawat and Vyas, 1975; Singh and Singh, 1981; Negi *et al.*, 1995; Salunkhe *et al.*, 2016) (Table 2). The forest wise AGB and Cp of tree species in different studied *Sal* forests were ranged from 0.19 to 24.75 Mg ha⁻¹ (mean 4.46 ± 0.45 SE) and 0.09 to 11.63 Mg C ha⁻¹ (mean 2.10 ± 0.21 SE) respectively. AGB (24.75 Mg ha⁻¹) and Cp (11.63 Mg C ha⁻¹) were maximum at Chirua, Kanke (JH019) and minimum (0.19 Mg ha⁻¹ and 0.09 Mg C ha⁻¹ respectively) at Agartoli, Angara (JH016) (Table 3). The spatial pattern of AGB showed that maximum studied forests (65 %) had very low AGB (<5.00 Mg ha⁻¹) followed by low AGB (5.01 to 10.00 Mg ha⁻¹) forests (25 %), moderate AGB (10.01 to 15.00 Mg ha⁻¹) forests (7 %), high AGB (15.01 to 20.00 Mg ha⁻¹) forests (2 %) and only one forests (1 %) had very high AGB (>20 Mg ha⁻¹) located in the northwest corner of Ranchi. The carbon sequestration potential of forests depends on forest type, age of forest, and age of trees, as well as its basal cover and density (Terakunpisut *et al.*, 2007). Species wise AGB ranged from 0.001 to 7074.94 Mg ha⁻¹ (mean 106 ± 71 SE) and Cp ranged from 0.0005 to 3325.22 Mg C ha⁻¹ (mean 49.76 ± 33.54 SE) in *Sal* forests of Ranchi. Out of 103 recorded tree species, *Shorea robusta* had the highest AGB, and Cp (7074.94 Mg ha⁻¹, and 3325.22 Mg C ha⁻¹) followed by *Madhuca longifolia* (1875.67 Mg ha⁻¹ and 881.5649 Mg C ha⁻¹), *Diospyros melanoxylon* (1014.12 Mg ha⁻¹ and 476.63 Mg C ha⁻¹), *Semecarpus anacardium* (221.81 Mg ha⁻¹ and 104.25 Mg C ha⁻¹), *Syzygium cumini* (99.80 Mg ha⁻¹ and 46.90 Mg C ha⁻¹), and *Buchanania cochinchinensis* (84.43 Mg ha⁻¹ and 39.68 Mg C ha⁻¹) (Table 4). More diverse plant communities have a higher chance of including highly productive species that dominates the community, as *S. robusta* dominated the whole AGB in *Sal* mixed tropical moist deciduous forest in the upper Gangetic plains adjoining Himalayan foothills in Uttar Pradesh, India (Behera *et al.*, 2017). Among all the tree species, *S. robusta* individually shared 64.87 % of the total AGB and only three species (*S. robusta*, *M. longifolia* and *D. melanoxylon*) had AGB >1000 Mg ha⁻¹ and shared 93.40 % of the total AGB. Most of the tree species (65 tree species) (63.11%) had AGB <1 Mg ha⁻¹, and 34 species (33.01 %) had AGB between 1 to 100 Mg ha⁻¹.

On the other hand, AGB in different regions of Ranchi ranged from 0.90 to 111.74 Mg ha⁻¹ (mean 6.21 ± 0.45 SE) and the highest AGB recorded in Namkum with 111.74 Mg ha⁻¹ (mean 6.21 ± 0.45) followed by Kanke with 50.56 Mg ha⁻¹ (mean 5.62 ± 0.45 SE), Burmu with 42.85 Mg ha⁻¹ (mean 4.46 ± 0.45 SE),

Tamar 40.21 Mg ha⁻¹ (3.09±0.41 SE), and the lowest AGB was recorded in Ormanjhi (0.90 Mg ha⁻¹). Tree biomass in forests vary with forest type, species composition, stand age, size class of trees, site conditions, rainfall pattern, edaphic factors and altitude (Sharma *et al.*, 2011; Zhao *et al.*, 2014; Cao *et al.*, 2018). Similarly, highest carbon stock was recorded in Namkum with 52.52 Mg C ha⁻¹ (2.26 ± 0.26 SE) followed by Kanke with 23.76 Mg C ha⁻¹ (2.09 ± 0.21 SE), Burmu with 20.14 Mg C ha⁻¹ (2.53 ± 0.58 SE), Tamar with 18.90 Mg C ha⁻¹ (2.53 ± 0.58 SE), Bero 18.50 Mg C ha⁻¹ (2.61 ± 0.47 SE), and the lowest Cp was recorded in Rahe (0.21 Mg C ha⁻¹) (*Table 5*). Maximum AGB and Cp in Namkum mainly due to greater basal area 3344.54 m² ha⁻¹ (185.80 ± 21.74 SE) and maximum numbers of sampled transects (18) as compared to other regions of Ranchi.

The total basal area as well as density of trees in all studied *Sal* forests were 144.63 m² ha⁻¹ and 515 ind. ha⁻¹ respectively. Species wise basal area of trees ranged from 0.0002 to 120.81 m² ha⁻¹ (mean 1.40 ± 1.17 SE) and density ranged from 0.02 to 416 ind. ha⁻¹ (mean 5 ± 4.04 SE). *S. robusta* had maximum basal cover (120.81 m² ha⁻¹) as well as density (416 ind. ha⁻¹) among all tree species and is the reason for its maximum AGB and Cp. However, no similar trends were observed in all other trees. *B. cochinchinensis* had the second largest basal area (4.63 m² ha⁻¹) followed by *Mangifera indica* (3.06 m² ha⁻¹), *D. melanoxylon* (1.64 m² ha⁻¹) and *Terminalia arjuna* (1.48 m² ha⁻¹). While, *D. melanoxylon* had the second highest density (23 ind. ha⁻¹) followed by *B. cochinchinensis* (15 ind. ha⁻¹) (*Table 4*). On the other hand, forest wise stand basal area and stand density of trees ranged from 30.72 to 367.84 m² ha⁻¹ (mean 135.28 ± 7.24 SE), and 136 to 1712 ind. ha⁻¹ (mean 515 ± 34.16 SE) respectively. Maximum tree density (1712 ind. ha⁻¹) was recorded in Paina Pahar, Lapung (JH059) and minimum (136 ind. ha⁻¹) in Silway, Namkum (JH01), while, basal area of trees was highest (367.84 m² ha⁻¹) in Harbul, Namkum (JH061), and minimum (30.72 m² ha⁻¹) in Kojiam, Burmu (JH029) (*Table 2*). Maximum studied forests (30 %) had moderate basal cover (100.1 to 150 m² ha⁻¹) followed by high basal cover (150.1 to 200 m² ha⁻¹) forests (24 %), while maximum studied forests (47 %) had less tree density (150 to 300 ind. ha⁻¹) followed by very less tree density (<150 ind. ha⁻¹) forests (27 %), moderate tree density (301 to 450) forests (13 %) and rest 14 % forests had high and very high tree density (>450 ind. ha⁻¹).

Spatial pattern of plant diversity attributes

A total of 103 tree species belonging to 81 genera and 33 families are recorded in 46 ha study plots, which is lower than the earlier records from moist *Sal* forests of northern West Bengal (134 trees) (Kushwaha and Nandy, 2012), and tropical deciduous forest in Mudumalai Wildlife Sanctuary (124 trees in 6.1 ha sampled plots) (Reddy and Ugle, 2008), but quite higher than Western Terai *Sal* forests of Nepal (28 trees) (Timilsina *et al.*, 2007). Fabaceae (20 spp.) is the most species rich family followed by Moraceae (08 spp.), Euphorbiaceae (07 spp.) and 14 families are monotypic. On the other hand, *Ficus* (06 spp) is the most species rich genera followed by *Terminalia* (05 spp.) and 68 genera are monotypic. Tree diversity ranged from 01 to 27 species (mean 12 ± 0.60 SE) in all 92 studied *Sal* forests of Ranchi. Tree

diversity in terms of Shannon-Weiner diversity index (H') was ranged from 0.45 to 2.76 (mean 1.65 ± 0.48 SE), which is falls within the range (0.62–3.96) reported by earlier workers for various tropical deciduous forests of India (Tripathi and Singh, 2009; Naidu and Kumar, 2016; Sahoo *et al.*, 2020). Maximum studied forests (42 %) had moderate tree diversity (H' : 1.51 to 2.00) followed by less diversity (H' : 1.00 to 1.50) forests (28 %), high diversity (H' : 2.01 to 2.50) forests (17 %), very less diversity (H' : <1.00) forests (9), and very high diversity (H' >2.50) forests (3 %). The possible reason of lower H' in the studied *Sal* forests may possibly be due to anthropogenic disturbances resulting in habitat destruction, which leads to the survival of less number of tree species and their individuals. The highest tree diversity in terms of Shannon H' (2.76) was recorded in *Sal* forest located at Koijam, Burmu (JH029) and the highest E (0.87) was recorded in Siram, Burmu (JH030). The values of H' , CD, E, Dmg, Dmn, and ENS do not follow a definite pattern in all studied *Sal* forests of Ranchi (*Table 2*). Evenness index also known as species equitability ranged from 0.25 to 0.87 (mean 0.68 ± 0.11 SE), while ENS ranged from 2 to 16 (mean 6 ± 0.30). ENS denotes the amount of diversity directly compared with the within-community, and among community components, provides more interpretable, and comparable assessments of biodiversity as compared to species richness, H' , and CD (Jost, 2007). It is the true diversity of community used to assess species diversity on the basis of H' , and responds to either known alteration in assemblage or environmental variables (Cao and Hawkins, 2019). On the other hand, CD ranged from 0.10 to 0.72 (mean 0.34 ± 0.01), which was within the reported range of CD (0.19 to 0.99) for forest vegetation (Whittaker, 1965). Lower CD (0.10) in few studied *Sal* forests (JH029, and JH030) indicate that dominance is shared by more than one species, and values of CD were lower in contrast with high species diversity (H') (2.76 and 2.74) as species diversity behaves inversely to the index of dominance (CD) (Odum, 1971). Dmg ranged from 0.17 to 11.68 (mean 2.06 ± 0.15) and Dmn ranged from 0.11 to 2.03 (mean 0.78 ± 0.04) in various studied *Sal* forests of Ranchi. The species richness in terms of Dmg and Dmn were 10.23 and 0.68 respectively for all studied *Sal* forests of Ranchi.

On the basis of H' and E, *Sal* forests were classified into highly diverse (HD) with H' > 2.00, moderately diverse (MD) (H' = 1.6–2.0), low diversity (LD) (H' <1.6) forests and highly even (HE) with $E > 0.75$, moderately even (ME), $E = 0.6–0.75$, and poorly even (LE) $E < 0.06$ forests. Further, unique combination of H' and E (HD-LE, HD-ME, HD-HE, MD-LE, MD-ME, MD-HE, LD-LE, LD-ME, LD-HE) was used to classify all the studied *Sal* forests of Ranchi (*Table 3*). Grouping of H' -E at different nine combinations illustrates that only 03 (3.26%) studied forests (JH003, JH070, and JH077) showed extreme tree diversity with high H' and low E (ETDFs). Similarly, very high tree diversity forests with high H' and moderate E (VHTDFs) was recorded in 11 (11.96 %) studied forests and high tree diversity forests with high H' and high E (HTDFs) was recorded in 04 (4.35 %) studied forests, while only one studied forests (JH002) classified as tree diversity forests with moderate H' and low E (TDFs) (*Figure 2*).

Relationship between plant diversity attributes and AGB

The relationships between tree basal cover, density, plant diversity attributes (Dmg, Dmn, H' , CD, ENS, and E), and AGB was documented in *Sal* forests of Ranchi. Correlation of basal area with AGB was positive,

and statistically significant ($r = 0.71$, $p < 0.05$) indicating that basal area is a major indicator of AGB. Strong relationships between AGB and basal area have also been reported by several workers in various types of forests (Cannell, 1984; Rai and Proctor, 1986). Likewise, high AGB indicate high C_p , so correlation between AGB and C_p was positive and highly significant ($r = 1.00$, $p < 0.01$). AGB showed insignificant, negative correlation with tree density ($r = -0.17$) indicating that forests with higher tree density have reduced AGB. Generally, in dense forests, the availability of soil nutrients and water, due to high intraspecific competition cannot properly be availed by plants for their growth and development may be the reason of lower AGB in higher tree density forests. Inverse relationship of total tree density with AGB was also observed in Terai *Shorea* forest and *Shorea-Terminalia* forest of south-western part of Nepal (Giril *et al.*, 1999), while a strong positive relationship of density and AGB was observed in Katarniaghat Wildlife Sanctuary, a tropical moist deciduous forest in the upper Gangetic plains adjoining Himalayan foothills in Uttar Pradesh, India (Behera *et al.*, 2017). Again, basal area had insignificant negative relationship with H' ($r = -0.13$), ENS ($r = -0.11$) and Dmg ($r = -0.004$), while it has significant negative correlation with E ($r = -0.27$, $p < 0.01$) and Dmn ($r = -0.26$, $p < 0.05$). On the other hand, a positive linear relationship had been observed between diversity and total tree basal area (a substitute for biomass) in tropical deciduous forests in India (Sagar and Singh, 2006). The highest AGB ($>20 \text{ Mg ha}^{-1}$) was recorded at high basal area ($>160 \text{ m}^2 \text{ ha}^{-1}$) as AGB increases with the increase in basal area, but no similar trends had been followed by all studied *Sal* forests (Figure 3a). Similarly, very low density forests ($<150 \text{ ind. ha}^{-1}$) (Figure 3b) had highest AGB ($>20 \text{ Mg ha}^{-1}$), as well as highest species diversity (>2.0) (Figure 3c). A highly significant positive correlations of AGB with H' ($r = 0.58$, $p < 0.01$), Dmg ($r = 0.31$, $p < 0.01$), Dmn ($r = 0.49$, $p < 0.01$), and ENS ($r = 0.57$, $p < 0.01$) were observed in the present study, while AGB-E relationship was statistically significant and positive ($r = 0.26$, $p < 0.05$) (Table 7, Figure 4a-f), possibly due to continual disturbance does not allow biomass to concentrate in only the strongest competitors. AGB increased with increase in tree diversity, as high species richness helps in increased nutrient use efficiency (Ruijven and Berendse, 2005). On the other hand, species richness is highly correlated with other plant diversity attributes and a high correlation exists between H' and species richness across tropical forests (Gentry, 1988). The present study also recorded highly significant positive correlation of H' with Dmg ($r = 0.49$, $p < 0.01$), and Dmn ($r = 0.84$, $p < 0.01$). The tropical deciduous forests in India experience frequent, large-scale human disturbances from mining, power generation, grazing, tree felling, and extraction of forest resources (Kumar and Saikia, 2020). Disturbance regimes differ greatly among tropical forests as they experience more frequent or smaller scale disturbances and may account for differences in species richness-AGB relationships in tropical forests (Phillips *et al.*, 1994). In conformity with the present study, positive relationships have been observed between plant diversity/richness and AGB in various forests (Caspersen and Pacala, 2001; Erskine *et al.*, 2006; Houle, 2007). However, negative (Lugo, 1992; Wardle *et al.*, 1997), and no relationships (Vila *et al.*, 2003) between plant diversity/richness and AGB have also been documented in forests. Although results are not consistent regarding the species richness-AGB relationship in forests, trees grow faster and attain greater biomass in forests (Erskine *et al.*, 2006; Potvin and Gotelli, 2008). Therefore, positive relationships may be the most obvious expectation for the species richness-AGB relationship in forests. High and positive correlation of AGB with H' and ENS signifies the diversity of tree species in studied forests did have major effects on growth and development by intraspecific competition

among the species. However, AGB was negatively correlated with CD ($r = -.57$, $p < 0.01$) may be because of CD inversely related to H'. The negative CD-AGB relationships suggest that a few species become more dominant at high biomass, instead of the biomass being distributed evenly among all species (Vance-Chalcraft *et al.*, 2010).

Conclusions

The present study showed that tree density, basal area, AGB and Cp used to be varied in different studied forests as well as tree species. The higher basal cover ($144.63 \text{ m}^2 \text{ ha}^{-1}$), and tree density (515 ind. ha^{-1}) in all studied forests supports higher AGB ($410.69 \text{ Mg ha}^{-1}$), and Cp ($193.06 \text{ Mg C ha}^{-1}$) in the region. *S. robusta* being the most dominant tree species, adapts better in sub-tropical climate conditions and has the highest AGB ($7074.94 \text{ Mg ha}^{-1}$) and Cp ($3325.23 \text{ Mg C ha}^{-1}$). However, attention should be given for the conservation of other native tree species like *Bauhinia variegata* (0.015 Mg ha^{-1} , and $0.007 \text{ Mg C ha}^{-1}$), *Sterculia urens* (0.021 Mg ha^{-1} , and $0.10 \text{ Mg C ha}^{-1}$), *Azadirachta indica* (0.256 Mg ha^{-1} , and $0.120 \text{ Mg C ha}^{-1}$), and *Bauhinia purpurea* (0.280 Mg ha^{-1} and $0.132 \text{ Mg C ha}^{-1}$) with low AGB and Cp as these species have also lower density as well as basal cover in the studied *Sal* forests of Ranchi. Positive, and statistically significant correlation ($r = 0.81$, $p < 0.05$) of basal area with AGB indicates that basal area is a major contributor of AGB. Furthermore, it was found that the carbon storage potential in the forests is influenced by tree basal area, density, and diversity attributes (Dmg, Dmn, CD, H', ENS, and E). Estimation of forest Cp enables us to assess the amount of carbon loss during deforestation or the amount of carbon stored during forest regeneration. The present study will directly help in studying the response of climate change on ecosystem productivity, energy and nutrient flow, and for assessing the patterns of carbon sequestration in Indian forests under global climate change. Further research is needed to depict the long-term effects of tree harvesting to maintain their productivity and soil fertility status in relation to the sustainability of *Sal* dominated forests of Ranchi, Jharkhand, Eastern India.

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material

All data generated or analysed during this study are included in this published article.

Competing interests

The authors declare that they have no competing interests.

Funding

This is the outcome of Science and Engineering Research Board (SERB), New Delhi, Govt. of India sponsored R & D project entitled 'Status, Distribution and Composition of *Sa*/ Forests of Ranchi, Jharkhand, Eastern India in relation to Microclimatic as well as Edaphic Conditions' sanctioned to Dr. Purabi Saikia under SERB-Young Scientist Scheme (Ref. No. YSS/2015/000479 dated 12th January 2016).

Authors' contributions

RK participated in the field data collection, analyses, and interpretation, and drafted the manuscript; *AK* helped in analyses as well as preparation of maps and also in finalizing the MS; *PS* conceived the study, helped in species identification and also finalized the manuscript. All authors read and approved the final manuscript.

Acknowledgements

Authors are thankful to Science and Engineering Research Board (SERB), New Delhi, Govt. of India for financial support for the project 'Status, Distribution and Composition of *Sa*/ Forests of Ranchi, Jharkhand, Eastern India in relation to Microclimatic as well as Edaphic Conditions' (Ref. No. YSS/2015/000479 dated 12th January 2016). The support and assistance provided by the Jharkhand State Forest Department, Ranchi and the local people involved during the field survey are highly acknowledged.

References

1. Alexandrov, G. A. (2007). Carbon stock growth in a forest stand: the power of age. *Carbon Balance and Management*, 2, 4.
2. Anonymous (2015). Evenness effect on ecosystem functioning. Retrieved from: <https://biologyforfun.wordpress.com/2015/02/20/evenness-effect-on-ecosystem-functioning/>; accessed on: 30/05/2019.
3. Baishya, R., Barik, S.K., & Upadhaya, K. (2009). Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in north-east India. *Ecol.* 50, 295-304.
4. Behera, S. K., Mishra, A. K., Sahu, N., Kumar, A., Singh, N., Kumar, A., Bajpai, O., Chaudhary, L. B., Khare, P. B., & Tuli, R. (2012). The study of microclimate in response to different plant community

- association in tropical moist deciduous forest from northern India. *Biodiversity and Conservation*, 21, 1159-1176.
5. Behera, S. K., Sahu, N., Mishra, A. K., Bargali, S. S., Behera, M. D., & Tuli, R. (2017). Aboveground biomass and carbon stock assessment in Indian tropical deciduous forest and relationship with stand structural attributes. *Ecological Engineering*, 99, 513-524.
 6. Brown, S. L., Schroeder, P., & Kern, J. S. (1999). Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management*, 123(1), 81-90.
 7. Brown, S., & Lugo, A. E. (1982). The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropica*, 14, 161-187.
 8. Brown, S., & Lugo, A. E. (1992). Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia*, 17(1), 8-18.
 9. Brown, S., Schroeder, P., & Birdsey, R. (1997). Aboveground biomass distribution of US eastern hardwood forests and the use of large trees as an indicator of forest development. *Forest Ecology and Management*, 96(1-2), 37-47.
 10. Cannell, M. G. R. (1984). Woody biomass of forest stands. *Forest Ecology and Management*, 8(3-4), 299-312.
 11. Cao J, Zhang X, Deo R, Gong Y, Feng Q (2018) Influence of stand type and stand age on soil carbon storage in China's arid and semi-arid regions. *Land Use Policy*, 78, 258–265.
 12. Cao, Y., & Hawkins, C. P. (2019). Weighting effective number of species measures by abundance weakens detection of diversity responses. *Journal of Applied Ecology*, 56(5), 1200-1209.
 13. Caspersen, J. P., & Pacala, S. W. (2001). Successional diversity and forest ecosystem function. *Ecological Research*, 16, 895–903.
 14. Chapin III, F. S., Zavaleta, E. S., Eviner, V. T., Naylor, R. L., Vitousek, P. M., Reynolds, H. L., Hooper, D. U., Lavorel, S., Sala, O. E., Hobbie, S. E., Mack, M. C., & Diaz, S. (2000). Consequences of changing biodiversity. *Nature*, 405, 234-242.
 15. Champion, S. H., & Seth, S. K. (1968). *A revised survey of the forest types of India*. A revised survey of the forest types of India. of India, New Delhi.
 16. Chaturvedi, R. K., Raghubanshi, A. S., & Singh, J. S. (2011). Carbon density and accumulation in woody species of tropical dry forest in India. *Forest Ecology and Management*, 262(8), 1576-1588.
 17. Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., & Lescure, J. P. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145(1), 87-99.
 18. de Gier, A. (2003). A new approach to woody biomass assessment in woodlands and shrublands. Faculty of Geo-Information Science and Earth Observation, Department of Natural Resources, Netherlands. <https://research.utwente.nl/en/publications/a-new-approach-to-woody-biomass-assessment-in-woodlands-and-shrublands> (dd62ead2-a58c-4fb6-8054-c1e3215c917d).html.

19. Dogan, H.M., & Dogan, M. (2003). Investigation of Erenler forest ecosystem in Ankara-Nallihan (A3) region of Turkey. Xiith World Forestry Congress, Quebec City, Canada.
20. Erskine, P. D., Lamb, D., & Bristow, M. (2006). Tree species diversity and ecosystem function: Can tropical multi-species plantations generate greater productivity? *Forest Ecology and Management*, 233, 205–210.
21. Feroz, M., Kabir, M. E., & Hagihara, A. (2015). Species composition, diversity and stratification in subtropical evergreen broadleaf forests along a latitudinal thermal gradient in the Ryukyu Archipelago, Japan. *Global Ecology and Conservation*, 4, 63-72.
22. FSI (1996). Volume equations for forests of India, Nepal and Bhutan. Forest Survey of India, Ministry of Environment and Forests, Govt. of India, Dehradun.
23. FSI (2019). State of Forest Report 2019. Forest Survey of India, Govt. of India, Dehradun.
24. Gautam, M. K., Tripathi, A. K., & Manhas, R. K. (2011). Assessment of critical loads in tropical sal (*Shorea robusta* F.) forests of Doon Valley Himalayas, India. *Water, Air, & Soil Pollution*, 218(1-4), 235-264.
25. Gentry, A. H. (1988). Changes in plant community diversity and floristic composition on environmental and geographical gradients. *M. Bot. Gard.*, 75, 1-34.
26. Giril, A., Aryal, B., Bhattarai, B., Ghimire, S. K., Shrestha, K. K., & Jha, P. K. (1999). Vegetation Composition, Biomass Production and Regeneration in *Shorea robusta* Forests in the Royal Bardia National Park, Nepal. *Nepal Journal of Science and Technology*, 1, 47-56.
27. GlobAllomeTree (2013). Available at: <http://www.globallometree.org/data/allometric-equations/>), last access: 12 November 2019.
28. Hill, M. O. (1973). Diversity and Evenness: A unifying notation and its consequences. *Ecology*, 54, 427-432.
29. Hillebrand, Helmut, Bennett, D. M., & Cadotte, M. W. (2008). Consequences of dominance: a review of evenness effects on local and regional ecosystem processes. *Ecology*, 89(6), 1510-1520.
30. Houghton, R. A. (2005). Aboveground forest biomass and the global carbon balance. *Global Change Biology*, 11(6), 945-958.
31. Houle, G. (2007). Determinants of fine-scale plant species richness in a deciduous forest of northeastern North America. *Veg. Sci.*, 18, 345-354.
32. IPCC (Intergovernmental Panel on Climate Change). (2006). Guidelines for National Greenhouse gas inventories. Vol. 4. Agriculture, forestry and other land use (AFLOLU), Institute for Global Environmental Strategies, Kamiyamaguchi, Japan.
33. Jost, L. (2006). Entropy and diversity. *Oikos*, 113(2), 363-375.
34. Jost, L. (2007). Partitioning diversity into independent alpha and beta components. *Ecology*, 88, 2427–2439.
35. Ketterings, Q. M., Coe, R., Van Noordwijk, M., & Palm, C. A. (2001). Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary

- forests. *Forest Ecology and Management*, 146(1-3), 199-209.
36. Kotto-Same, J., Woomer, P. L., Appolinaire, M., & Louis, Z. (1997). Carbon dynamics in slash-and-burn agriculture and land use alternatives of the humid forest zone in Cameroon. *Agriculture, Ecosystems & Environment*, 65(3), 245-256.
 37. Kumar, A., Kishore, B. S. P. C., Saikia, P., Deka, J., Bharali, S., Singha, L. B., Tripathi, O. P., & Khan, M. L. (2019). Tree diversity assessment and above ground forests Biomass estimation using SAR Remote Sensing: A case study of Higher Altitude vegetation of North-East Himalaya, India. *Physics and Chemistry of the Earth*, 111, 53-64.
 38. Kumar, R., & Saikia, P. (2020) Floristic analysis and dominance pattern of a Sal (*Shorea robusta* F. Gaertn.) Forests of Ranchi, Jharkhand, Eastern India. *Journal of Forestry Research*, 31(2), 415-427.
 39. Kushwaha, S. P. S., & Nandy, S. (2012). Species diversity and community structure in sal (*Shorea robusta*) forests of two different rainfall regimes in West Bengal, India. *Biodiversity and Conservation*, 21(5), 1215-1228.
 40. Lugo, A. E. (1992). Comparison of tropical tree plantations with secondary forests of similar age. *Ecological Monographs*, 62, 1–41.
 41. Ma, M. (2005). Species richness vs evenness: independent relationship and different responses to edaphic factors. *Oikos*, 111, 192–198.
 42. Magurran, A. E. (1988). *Ecological diversity and its measurement*. Springer, Dordrecht.
 43. Margalef, R. (1958). Information theory in biology. *General Systems Yearbook*, 3, 36-71.
 44. Mattingly, W. B., Hewlate, R., & Reynolds, H. L. (2007). Species evenness and invasion resistance of experimental grassland communities. *Oikos*, 116, 1164-1170.
 45. Ministry of Agriculture & Irrigation, Govt. of India (1977). *Report on Forest Resources of S.W. Bihar (Part)*, Vol. I, pp. 72.
 46. Misra, R. (1968). *Ecological workbook*. Oxford & IBH, New Delhi, India.
 47. Mligo, C. (2018). Application of regression model to identify a parameter that best defines species diversity in the coastal forests of Tanzania. *Tanzania Journal of Science*, 44(3), 31-45.
 48. Murali, K. S., Bhat, D. M., & Ravindranath, N. H. (2005). Biomass estimation equations for tropical and evergreen forests. *International Journal of Agricultural Resources, Governance and Ecology*, 4, 81-92.
 49. Murthy, I. K., Gupta, M., Tomar, S., Munsi, M., Tiwari, R., Hegde, G. T., & Ravindranath, N. H. (2013). Carbon sequestration potential of agroforestry systems in India. *Journal of Earth Science and Climatic Change*, 4(1), 1-7.
 50. Naeem, , Knops, J., Tilman, D., Howe, K., Kennedy, T., & Gale, S. (2000). Plant diversity increases resistance to invasion in the absence of covarying extrinsic factors. *Oikos*, 91, 97-108.
 51. Naidu, M. T., & Kumar, O. A. (2016). Tree diversity, stand structure, and community composition of tropical forests in Eastern Ghats of Andhra Pradesh, India. *Journal of Asia-Pacific Biodiversity*, 9(3), 328-334.

52. Návar, J. (2009). Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. *Forest Ecology and Management*, 257(2), 427-434.
53. Negi, M. S., Tandon, Y. N., & Rawat, H. S. (1995). Biomass and nutrient distribution in young teak (*Tectona grandis*) plantations in Tarai region of Uttar Pradesh. *Indian Forester*, 121(6), 455-464.
54. Odum, E. P. (1971). *Fundamentals of Ecology*, 3rd, WB Saunders Co., Philadelphia, Pennsylvania.
55. Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., & Ciais, P. (2011). A large and persistent carbon sink in the world's forests. *Science*, 333(6045), 988-993.
56. Pande, P. K. (2005). Biomass and productivity in some disturbed tropical dry deciduous teak forests of Satpura plateau, Madhya Pradesh. *Tropical Ecology*, 46(2), 229-240.
57. Phillips, O. L., Hall, P., Gentry, A. H., Sawyer, S. A., & Vasquez, R. (1994). Dynamics and species richness of tropical rain forests. *Proceedings of the National Academy of Sciences, U.S.A.*, 91, 2805-2809.
58. Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology*, 13, 131-144.
59. Potvin, C., & Gotelli, N. J. (2008). Biodiversity enhances individual performance but does not affect survivorship in tropical trees. *Ecology Letters*, 11, 217-223.
60. Rai, S. N., & Proctor, J. (1986). Ecological studies on four rainforests in Karnataka, India: I. Environment, structure, floristics and biomass. *The Journal of Ecology*, 74(2), 439-454.
61. Ranawat, M. P. S., & Vyas, L. N. (1975). Litter production in deciduous forests of Koriyat, Udaipur (South Rajasthan), India. *Biologia*, 30, 41-47.
62. Rawat, J. K., & Nautiyal, J. C. (1988). Forest biomass-a source for food, feed and fuel. *Indian Forester*, 114(8), 429-439.
63. Reddy, C. S., & Ugle, P. (2008). Tree species diversity and distribution patterns in tropical forest of Eastern Ghats, India: a case study. *Life Science Journal*, 5(4), 87-93.
64. Ruijven, J. V., & Berendse, F. (2005). Diversity-productivity relationships: initial effects, long-term patterns, and underlying mechanisms. *Natl. Acad. Sci. U.S.A.*, 102(3), 695-700.
65. Sagar, R., & Singh J. S. (2006). Tree density, basal area and species diversity in a disturbed dry tropical forest of northern India: Implications for conservation. *Environmental Conservation*, 33, 256-262.
66. Sahoo, T., Acharya, L., & Panda, P. C. (2020). Structure and composition of tree species in tropical moist deciduous forests of Eastern Ghats of Odisha, India, in response to human-induced disturbances. *Environmental Sustainability*, 3, 1-14.
67. Salunkhe, O., Khare, P. K., Sahu, T. R., & Singh, S. (2016). Estimation of tree biomass reserves in tropical deciduous forests of Central India by non-destructive approach. *Tropical Ecology*, 57(2), 153-161.
68. Sharma, C. M., Gairola, S., Baduni, N. P., Ghildiyal, S. K., & Suyal, S. (2011). Variation in carbon stocks on different slope aspects in seven major forest types of temperate region of Garhwal Himalaya,

- India. *Journal of Biosciences*, 36(4), 701-708.
69. Shrestha, R., Karmacharya, S. B., & Jha, P. K. (2000). Vegetation analysis of natural and degraded forests in Chitrepani in Siwalik region of Central Nepal. *Tropical Ecology*, 41(1), 111-114.
 70. Simpson, E. H. (1949). Measurement of diversity. *Nature*, 163(4148), 688-688.
 71. Singh, K. P. (1989). Mineral nutrients in tropical dry deciduous forest and savanna ecosystems in India. *Special Publications Series of the British Ecological Society*, 9, 153-168.
 72. Singh, K. P., & Singh, R. P. (1981). Seasonal variation in biomass and energy of small roots in tropical dry deciduous forest, Varanasi, India. *Oikos*, 37(1), 88-92.
 73. Singh, R. P. (1975). Biomass, nutrient and productivity structure of a stand of dry deciduous forest of Varanasi. *Tropical Ecology*, 16, 104-109.
 74. Stirling, G., & Wilsey, B. (2001). Empirical relationships between species richness, evenness and proportional diversity. *The American Naturalist*, 158, 286–299.
 75. Terakunpisut, J., Gajasen, N., & Ruankawe, N. (2007). Carbon sequestration potential in aboveground biomass of Thong Pha Phum national forest, Thailand. *Applied Ecology and Environmental Research*, 5(2), 93-102.
 76. Thapa-Magar, K. B., & Shrestha, B. B. (2015). Carbon stock in community managed hill sal (*Shorea robusta*) forests of central Nepal. *Journal of Sustainable Forestry*, 34(5), 483-501.
 77. Tilman, J., & Downing, J. A. (1994). Biodiversity and stability in grasslands. *Nature*, 367, 363-365.
 78. Timilsina, N., Ross, M. S., & Heinen, J. T. (2007). A community analysis of sal (*Shorea robusta*) forests in the western Terai of Nepal. *Forest Ecology and Management*, 241(1-3), 223-234.
 79. Triin, R., Martin, T.S., Lotten, J.J., Mikael, L., Karin, H., Marie, V., & Honor, C.P. (2009). Small-scale plant species richness and evenness in semi-natural grasslands respond differently to habitat fragmentation. *Biological Conservation*, 142, 899-908.
 80. Tripathi, K. P., & Singh, B. (2009). Species diversity and vegetation structure across various strata in natural and plantation forests in Katarniaghat Wildlife Sanctuary, North India. *Tropical Ecology*, 50(1), 191.
 81. Vance-Chalcraft, H. D., Willig, M. R., Cox, S. B., Lugo, A. E., & Scatena F. N. (2010). Relationship Between Aboveground Biomass and Multiple Measures of Biodiversity in Subtropical Forest of Puerto Rico. *Biotropica*, 42(3), 290–299.
 82. Vila, M., Vayreda, J., Gracia, C., & Ibanez, J. J. (2003). Does tree diversity increase wood production in pine forests? *Oecologia*, 135, 299–303.
 83. Wardle, D. A., Zackrisson, O., Hornberg, G., & Gallet, C. (1997). The influence of island area on ecosystem properties. *Science*, 277, 1296–1299.
 84. Whittaker, R. H. (1965). Dominance and diversity in land plant communities: numerical relations of species express the importance of competition in community function and evolution. *Science*, 147(3655), 250-260.

85. Whittaker, R. H. (1977). Evolution of species diversity in land communities. In: *Evolutionary Biology*, Hecht, M. K., Streere, W. C., & Wallace, B. (eds.), Plenum, New York, Vol. 10, pp. 1-67.
86. Whittaker, R. H., & Likens, G. E. (1975). The biosphere and man. In: *Primary productivity of the biosphere*, Springer, Berlin, Heidelberg, pp. 305-328.
87. Wilsey, B., & Gray, S. (2007). Species richness and evenness respond in a different manner to propagule density in developing prairie microcosm communities. *Plant Ecology*, 190, 259-273.
88. Zhao, J., Kang, F., Wang, L., Yu, X., Zhao, W., Song, X., & Han, H. (2014). Patterns of biomass and carbon distribution across a Chrono sequence of Chinese pine (*Pinus tabulaeformis*) forests. *PloS one*, 9(7), e104464.

Tables

Table 1: Volume equations and wood density used for computation of above ground biomass of different tree species in studied *Sal* forests of Ranchi, Jharkhand, Eastern India.

Sl. No.	Species name	¥Volumetric equation	€Wood density
1	<i>Acacia nilotica</i> (L.) Delile <i>Adina cordifolia</i> (Roxb.)	$V=(0.043849-0.55235*D+2.9523*D^2+0.334508*D^2*H)$	0.67
2	Brandis	$V=(0.036+0.279 D^2*H)$	0.59
3	<i>Aegle marmelos</i> (L.) Corrêa <i>Albizia</i>	$V/ D^2=(0.0697/ D^2-1.4597/D+11.79933-2.35397*D)$	0.75
4	<i>procera</i> (Roxb.) Benth.	$\sqrt{V}=(-0.07109+2.99732*D-0.26953*\sqrt{D})$	0.58
5	<i>Albizia lebbeck</i> (L.) Benth.	$V= (-0.034+0.291* D^2*H)$	0.57
6	<i>Alstonia scholaris</i> (L.) R. Br.	$V=(0.0697D^2-1.4597/D+11.79933-2.353*D)$	0.36
7	<i>Anacardium occidentale</i> L.	$V=(4.5899* D^2-0.422*D+0.0148)$	0.41
8	<i>Annona squamosa</i> L. <i>Artocarpus</i>	$V/D2=(0.0697/ D^2-1.4597/D+11.79933-2.35397*D)$	0.62
9	<i>heterophyllus</i> Lam. <i>Artocarpus</i>	$\sqrt{V}=(-0.15154+2.79983*D)$	0.45
10	<i>lacucha</i> Buchanan-Hamilton ex D. Don	$V=(0.012951+0.000027* D^2*H)$	0.53
11	<i>Azadirachta indica</i> A. Juss.	$V=(-0.3510+5.32981* D^2)$	0.69
12	<i>Bauhinia purpurea</i> L.	$\sqrt{V}=(-0.07109)+2.99732*(D)-0.26953*\sqrt{D})$	0.61
13	<i>Bauhinia variegata</i> L.	$V=(-0.0236+0.3078D+1.2361*D^2)$	0.61
14	<i>Bombax ceiba</i> L.	$V=(0.00978-0.21005*D+5.62160* D^2)$	0.33
15	<i>Boswellia serrata</i> Roxb. ex Colebr.	$V=(0.03356-1.124*D+10.306* D^2)$	0.50
16	<i>Bridelia retusa</i> (L.) A. Juss.	$V=(-0.032-0.0619*D+7.208* D^2)$	0.50
17	<i>Butea monosperma</i> (Lam.) Taub.	$V=(0.0417-0.47789*D+3.50714*D2+9.76048* D^3)$	0.47
18	<i>Careya arborea</i> Roxb.	$\sqrt{V}=(0.23738+2.33289*D+0.48512*\sqrt{D})$	0.63
19	<i>Casearia graveolens</i> Dalzell	$V=(0.14031-2.06478D+11.2575D^2)$	0.62
20	<i>Cassia fistula</i> L.	$V=$	0.75

$$(0.05159*0.53331*D+3.46016*D^2+10.1843*D^3)$$

<i>Chloroxylon</i>			
21	<i>swietenia</i> (Roxb.) DC.	$V=(-0.094+0.376*D+2.817*D^2)$	0.46
<i>Cleistanthus collinus</i> (Roxb.)			
22	Benth. Ex Hook.f.	$V=(-0.03915+0.16295*D+4.09182*D^2)$	0.88
23	<i>Dalbergia latifolia</i> Roxb.	$V=0.04422+2.328465*D^2+0.309150*D^2*H$	0.75
24	<i>Dalbergia sissoo</i> DC.	$V=(0.00331+0.000636*D^2*10000)$	0.67
<i>Desmodium</i>			
25	<i>oojeinense</i> (Roxb.) H.Ohashi	$V=(0.037269/D^2*H-0.45979*D)$	0.70
26	<i>Dillenia pentagyna</i> Roxb.	$V=(0.070-1.295*D+9.429*D^2)$	0.57
<i>Diospyros</i>			
27	<i>melanoxylon</i> Roxb.	$V=(0.12401-2.00966*D+10.87747*D^2)$	0.68
<i>Elaeodendron</i>			
28	<i>kamerunense</i> (Loes.) Villiers	$V/D^2=(0.0697/D^2-1.4597/D+11.79933-2.35397*D)$	0.62
29	<i>Eucalyptus globulus</i> Labill.	$\sqrt{V}=(-0.0868)+2.8335*(D)$	0.64
30	<i>Ficus benghalensis</i> L.	$V=(0.088074-1.449236*D+8.760534*D^2)$	0.65
31	<i>Ficus geniculata</i> Kurz	$V=(0.088074-1.449236*D+8.760534*D^2)$	0.39
32	<i>Ficus hispida</i> L. fil.	$\sqrt{V}=(0.03629+3.95389D-0.84421*D^2)$	0.52
33	<i>Ficus racemosa</i> L.	$V=(0.05339-0.82031*D+6.17975*D^2)$	0.62
34	<i>Ficus religiosa</i> L.	$V=(0.05396-0.82031*D+6.17975*D^2)$	0.39
<i>Ficus semicordata</i> Buch. ex			
35	J. E. Smith	$V=(0.088074-1.449236*D+8.760534*D^2)$	0.39
<i>Flacourtia indica</i> (Burm.			
36	Fil.) Merr.	$\sqrt{V}=(-0.153973+2.724109*D)$	0.62
<i>Gardenia latifolia</i> Aiton			
37		$V=(0.078-1.188+6.751*D^2)/0.078$ $1.188*D+6.751\sqrt{D}$	0.64
<i>Gmelina arborea</i> Roxb. Ex			
38	Sm.	$V=(0.1156+0.21230*D+5.10448*D^2)$	0.45
<i>Holarrhena</i>			
<i>pubescens</i> (Buch.-Ham.)			
39	Wall. Ex G. Don	$V=(0.17994-2.78776*D+14.44961*D)$	0.64
<i>Lagerstroemia</i>			
40	<i>parviflora</i> Roxb.	$V=(0.0568-1.19611*D+9.11319*D^2)$	0.65
<i>Lannea</i>			
<i>coromandelica</i> (Houtt.)			
41	Merr.	$V=(0.57424-1.153088*D+8.542648*D^2)$	0.51

42	<i>Madhuca longifolia</i> (J.Koenig ex L.) J.F.Macbr.	$V=(-0.00092-0.55547*D+7.3446* D^2)$	0.73
43	<i>Mallotus philippensis</i> (Lam.) Müll.Arg.	$V=(0.14749-2.87503*D+19.61977* D^2-19.11630* D^3)$	0.57
44	<i>Mangifera indica</i> L.	$V=(0.108-1.706*D+7.559* D^2)$	0.55
45	<i>Melia azedarach</i> L.	$V=(-0.03510+5.32981* D^2)$	0.62
46	<i>Miliusa velutina</i> (Dunal) Hook. F. & Thomson	$\sqrt{V}=(0.66382 + 7.03093*D - 3.68133*\sqrt{D})$	0.63
47	<i>Mitragyna parvifolia</i> (Roxb.) Korth.	$V=(0.099768-1.744274*D+10.086934* D^2)$	0.54
48	<i>Murraya koenigii</i> (L.) Spreng.	$V/ D^2= (0.00342/ D^2-0.0922/D+2.28178+9.46641*D)$	0.61
49	<i>Phyllanthus emblica</i> L.	$V= (-0.038+0.344*D^2*H)$	0.80
50	<i>Pongamia pinnata</i> (L.) Pierre	$V=(0.013+0.271*H)$	
51	<i>Pterocarpus marsupium</i> Roxb.	$V=(0.58424-1.233468*D+9.433633* D^2)$	0.67
52	<i>Schleichera oleosa</i> (Lour.) Oken	$V/ D^2= (-0.00342/ D^2*0.0922/D + 2.28178 + 9.46641*D)$	0.84
53	<i>Semecarpus anacardium</i> L. fil.	$\sqrt{V}=1.67447 + 14.83747*D -9.43386*\sqrt{D})$	0.50
54	<i>Senegalia catechu</i> (L.f.) P. J. H. Hurter & Mabb.	$V=(0.16609-2.78851*D+17.22127* D^2-11.60248* D^3)$	0.87
55	<i>Senna siamea</i> (Lam.) H.S. Irwin & Barneby	$V=(0.05159-0.53331*D+3.46016* D^2+4.60460* D^3)$	0.50
56	<i>Shorea robusta</i> Gaertn.	$V=(0.08565-1.51685*D+10.24871* D^2)$	0.72
57	<i>Sterculia urens</i> Roxb.	$V=(0.001*\sqrt{D}+0.0366*D-0.128)$	0.53
58	<i>Stereospermum chelonoides</i> (L. fil.) DC.	$\sqrt{V}=0.49746+5.98454*D-2.84986*\sqrt{D})$	0.50
59	<i>Syzygium cumini</i> (L.) Skeels	$\sqrt{V}=(0.30706+5.12731*D-2.0987*\sqrt{D})$	0.65
60	<i>Tamarindus indica</i> L.	$V=(0.088074-1.449236*D+8.760534* D^2)$	0.75
61	<i>Tectona grandis</i> L.f.	$\sqrt{V}=(-0.405890+1.98158*D+0.987373*\sqrt{D})$	0.58
62	<i>Terminalia alata</i> Heyne ex Roth	$V=(0.33695-1.23004*\sqrt{D}+11.86676* D^2)$	0.69
63	<i>Terminalia anogeissiana</i> Gere & Boatwr.	$\sqrt{V}=(-0.0738+2.592167*D)$	0.79

64	<i>Terminalia arjuna</i> (Roxb.) Wight & Arn.	$V=0.50603-6.64203*D+25.23882*D^2-9.19797*D^3$	0.68
65	<i>Terminalia bellirica</i> (Gaertn.) Roxb.	$\sqrt{V}=(-0.14325+3.07937*D)$	0.63
66	<i>Terminalia chebula</i> Retz.	$V=(0.1249+0.3707*H)$	0.69
67	<i>Toona ciliata</i> M. Roem.	$\sqrt{V}=(-0.05514+2.67753*D)$	0.50
68	<i>Wrightia tinctoria</i> R. Br.	$\sqrt{V}=(0.050294+3.115497*D-0.687813*\text{SQRT}(D))$	0.75
69	<i>Ziziphus jujuba</i> Miller	$V/D^2=(0.0697/D^2-1.4597/D+11.79933-2.35397*D)$	0.60

V volume (m³), D= DBH (m), H height (m), SQRT= Square root, Wood density (g cm⁻³)

€FSI Report, ¥Forest Survey of India report (FSI, 1996, 2019) and Global Tree
<http://www.globalmetree.org/data/allometric-equations/>

Table 2: Above ground biomass (AGB) (t ha^{-1}) in different tropical deciduous forests of India.

Study area	AGB (t ha^{-1})	Source
Dry deciduous forests (Varanasi, Uttar Pradesh)	205.5	Singh (1975)
Deciduous forests (Udaipur, Rajasthan)	28.2	Ranawat and Vyas (1975)
Tropical dry deciduous forest (Varanasi, Uttar Pradesh)	64.3	Singh and Singh (1981)
Tropical dry deciduous forests, (Chandraprabha, Uttar Pradesh)	95	Singh (1989)
<i>Tectona grandis</i> plantations (Tarai region, Uttar Pradesh)	74.6-164	Negi <i>et al.</i> (1995)
<i>Shorea-Terminalia</i> forests (Nepal)	348	Giril <i>et al.</i> (1999)
Terai <i>Shorea</i> forests (Nepal)	330.87	Giril <i>et al.</i> (1999)
Tropical dry deciduous teak forests (Satpura plateau, Madhya Pradesh)	28.1-85.3	Pande (2005)
Dry deciduous forests (Madhya Pradesh)	54.9	Salunkhe <i>et al.</i> (2016)
Mixed deciduous forests (Madhya Pradesh)	44.5	Salunkhe <i>et al.</i> (2016)
Tropical moist deciduous (Ranchi, Jharkhand)	410.69	Present study (2020)

Table 3: Details of Margalef's index of species richness (Dmg), Menhinick's index of species richness (Dmn), Shannon-Weiner diversity index (H'), concentration of dominance (CD), evenness index (E), effective number of species (ENS), density (ind. ha⁻¹), basal area (BA) (m² ha⁻¹), above ground biomass (AGB) (Mg ha⁻¹), and carbon stock (Cp) (Mg C ha⁻¹) of all studied *Sal* forests of Ranchi, Jharkhand, Eastern India.

Transect No.	Dmg	Dmn	H'	CD	E	ENS	Density	BA	AGB	Cp
JH001	1.90	1.09	1.87	0.25	0.85	6	136	47.68	18.13	8.52
JH002	1.86	0.89	1.67	0.32	0.34	5	254	337.84	10.79	5.07
JH003	1.70	0.71	1.94	0.21	0.37	7	400	157.50	12.94	6.08
JH004	0.96	0.44	1.23	0.43	0.69	3	368	154.94	1.91	0.90
JH005	1.12	0.65	1.14	0.48	0.64	3	172	58.58	1.48	0.69
JH006	2.58	1.13	1.99	0.25	0.76	7	306	111.48	7.89	3.71
JH007	0.62	0.35	0.90	0.54	0.65	2	256	273.92	1.02	0.48
JH008	2.40	1.22	1.87	0.28	0.75	6	194	44.60	2.88	1.35
JH009	0.41	0.26	0.72	0.60	0.66	2	274	160.04	0.46	0.22
JH010	2.40	0.94	2.22	0.17	0.84	9	448	124.86	9.5	4.46
JH011	0.54	0.25	1.92	0.50	0.37	7	516	168.10	1.35	0.64
JH012	1.82	0.70	1.61	0.36	0.67	5	492	83.28	1.64	0.77
JH013	11.68	0.16	0.71	0.61	0.65	2	688	188.44	0.67	0.32
JH014	2.46	0.99	2.09	0.22	0.79	8	398	179.36	6.73	3.16
JH015	1.97	1.02	1.97	0.20	0.85	7	194	120.74	6.49	3.05
JH016	0.33	0.15	0.69	0.62	0.63	2	824	189.02	0.19	0.09
JH017	1.46	0.58	1.34	0.45	0.61	4	474	125.06	3.16	1.49
JH018	1.58	0.71	1.59	0.33	0.73	5	320	136.96	8.98	4.22
JH019	2.68	1.23	2.17	0.18	0.82	9	258	160.26	24.75	11.63
JH020	2.06	0.98	1.84	0.27	0.77	6	254	62.76	3.40	1.60
JH021	4.03	1.62	2.50	0.16	0.81	12	368	84.54	1.37	0.64
JH022	0.78	0.38	1.26	0.37	0.78	4	344	52.02	0.23	0.11
JH023	2.41	1.08	2.17	0.17	0.84	9	288	48.82	7.35	3.45
JH024	0.55	0.27	0.87	0.56	0.63	2	454	251.72	0.45	0.21

JH025	0.41	0.27	0.72	0.61	0.65	2	250	139.66	0.96	0.45
JH026	1.76	0.77	1.67	0.31	0.73	5	336	135.5	4.25	2.00
JH027	1.03	0.53	1.16	0.47	0.65	3	254	122.46	1.74	0.82
JH028	1.96	0.85	1.81	0.27	0.76	6	332	113.26	1.72	0.81
JH029	4.65	2.03	2.76	0.10	0.86	16	280	30.72	13.44	6.32
JH030	4.11	1.58	2.74	0.10	0.87	15	424	107.20	5.94	2.79
JH031	2.37	1.03	1.96	0.25	0.76	7	318	52.70	3.29	1.55
JH032	1.72	0.73	1.50	0.40	0.65	4	372	132.78	2.16	1.02
JH033	1.22	0.6	1.65	0.25	0.85	5	276	171.26	1.30	0.61
JH034	1.65	0.54	1.60	0.37	0.67	5	842	77.88	1.71	0.80
JH035	0.17	0.11	0.45	0.72	0.66	2	690	147.28	0.70	0.33
JH036	0.33	0.14	0.82	0.54	0.74	2	912	95.98	1.92	0.90
JH037	0.87	0.34	1.28	0.40	0.72	4	632	175.28	3.79	1.78
JH038	2.73	1.03	1.97	0.29	0.71	7	484	80.60	5.27	2.48
JH039	2.91	1.08	2.28	0.18	0.81	10	492	81.12	3.41	1.60
JH040	0.93	0.41	1.32	0.37	0.74	4	434	192.00	1.17	0.55
JH041	2.87	1.05	2.01	0.27	0.71	7	524	209.02	6.78	3.19
JH042	2.03	0.93	1.77	0.30	0.74	6	278	38.70	1.38	0.65
JH043	0.96	1.16	1.10	0.50	0.62	3	360	56.22	0.40	0.19
JH044	1.37	0.63	1.29	0.46	0.62	4	326	85.08	0.45	0.21
JH045	1.61	0.75	1.53	0.36	0.69	5	286	106.88	0.86	0.41
JH046	3.78	1.37	2.24	0.22	0.72	9	514	110.92	4.17	1.96
JH047	3.97	1.57	2.52	0.16	0.81	12	394	55.26	7.01	3.30
JH048	1.36	0.61	1.34	0.43	0.69	4	344	137.70	8.36	3.93
JH049	1.98	0.52	1.69	0.37	0.64	5	1432	180.26	5.03	2.36
JH050	1.78	0.55	1.69	0.32	0.68	5	966	143.20	8.12	3.82
JH051	2.47	0.88	1.76	0.35	0.65	6	576	48.44	1.86	0.87
JH052	2.33	0.64	1.57	0.37	0.56	5	1236	76.82	3.21	1.51
JH053	1.80	0.56	1.56	0.40	0.26	5	906	251.36	1.65	0.78
JH054	1.37	0.49	1.45	0.40	0.66	4	674	142.94	1.35	0.63

JH055	1.29	0.69	1.34	0.41	0.69	4	208	280.84	5.28	2.48
JH056	1.23	0.47	1.52	0.34	0.73	5	588	179.08	2.97	1.40
JH057	0.83	0.30	1.21	0.44	0.68	3	804	164.76	1.09	0.51
JH058	2.53	0.94	1.96	0.26	0.72	7	508	101.32	9.22	4.33
JH059	1.33	0.34	1.39	0.44	0.61	4	1712	128.34	1.01	0.48
JH060	3.2	1.02	2.19	0.22	0.73	9	762	234.28	10.28	4.83
JH061	3.32	0.93	2.30	0.22	0.74	10	1124	367.84	16.58	7.79
JH062	3.17	1.00	1.96	0.33	0.65	7	798	262.98	7.45	3.50
JH063	3.85	1.01	2.44	0.19	0.75	11	1330	200.06	10.90	5.12
JH064	0.91	0.26	1.24	0.46	0.64	3	1484	184.56	1.18	0.56
JH065	2.59	0.77	1.87	0.33	0.66	6	972	114.82	6.83	3.21
JH066	0.77	0.23	1.34	0.37	0.75	4	1326	159.88	1.88	0.89
JH067	3.96	1.11	2.27	0.25	0.70	10	1106	182.52	9.77	4.59
JH068	3.62	1.45	2.26	0.22	0.75	10	382	170.54	11.61	5.46
JH069	2.46	1.14	1.93	0.26	0.75	7	262	41.56	5.81	2.73
JH070	1.55	0.68	1.25	0.37	0.57	3	354	70.52	2.18	1.02
JH071	1.07	0.42	1.20	0.48	0.61	3	546	130.86	0.82	0.39
JH072	3.90	1.49	2.36	0.20	0.76	11	438	157.90	4.72	2.22
JH073	1.88	0.64	1.90	0.25	0.76	7	698	110.76	2.96	1.39
JH074	1.41	0.66	1.31	0.45	0.63	4	290	41.36	2.47	1.16
JH075	1.64	0.78	1.63	0.30	0.33	5	264	62.74	1.10	0.52
JH076	1.80	0.82	1.61	0.35	0.70	5	298	108.92	2.57	1.21
JH077	1.16	0.39	1.23	0.49	0.59	3	840	77.88	1.74	0.82
JH078	2.85	1.29	1.86	0.32	0.69	6	270	119.36	6.86	3.23
JH079	2.39	1.06	2.05	0.20	0.79	8	302	117.98	3.00	1.41
JH080	2.65	1.07	1.94	0.27	0.72	7	396	67.20	7.47	3.51
JH081	1.56	0.70	1.33	0.46	0.60	4	334	91.00	1.21	0.57
JH082	2.39	1.05	1.74	0.34	0.68	6	304	119.32	3.13	1.47
JH083	1.40	0.65	1.49	0.36	0.72	4	300	102.74	1.04	0.49
JH084	2.13	0.91	1.95	0.22	0.79	7	350	153.54	4.70	2.21

JH085	1.67	0.82	1.60	0.31	0.73	5	240	59.70	1.71	0.81
JH086	0.90	0.37	1.21	0.45	0.67	3	520	241.3	6.24	2.93
JH087	2.21	0.86	1.67	0.37	0.65	5	456	240.44	1.82	0.85
JH088	4.58	1.82	2.34	0.21	0.73	10	376	190.76	5.70	2.68
JH089	0.87	0.34	1.14	0.49	0.63	3	628	239.92	0.89	0.42
JH090	1.42	0.69	1.29	0.46	0.62	4	272	188.94	3.28	1.54
JH091	1.89	1.08	1.78	0.25	0.81	6	138	34.02	1.80	0.85
JH092	2.63	0.40	1.82	0.34	0.66	6	600	125.06	4.26	2.00
Overall	10.13	0.68	2.21	0.34	0.48	9	514.83	144.63	410.69	193.06

Table 4: Above ground biomass (AGB) (Mg ha^{-1}), carbon stock (Cp) (Mg C ha^{-1}), basal area (BA) ($\text{m}^2 \text{ ha}^{-1}$) and density (ind. ha^{-1}) of all tree species recorded in studied *Sal* forest of Ranchi, Jharkhand, Eastern India.

Sl. No.	Species	AGB (t ha^{-1})	Cp (t C ha^{-1})	BA ($\text{m}^2 \text{ ha}^{-1}$)	Density (ind. ha^{-1})
1	<i>Acacia nilotica</i> (L.) Delile	10.38	4.88	0.016	0.22
2	<i>Adenanthera pavonina</i> L.	0.05	0.02	0.003	0.02
3	<i>Adina cordifolia</i> (Roxb.) Brandis	9.60	4.51	0.256	1.17
4	<i>Aegle marmelos</i> (L.) Corrêa	2.13	1.00	0.080	0.35
5	<i>Ailanthus excelsa</i> Roxb.	0.09	0.04	0.007	0.04
6	<i>Albizia odoratissima</i> (L.f.) Benth.	0.06	0.03	0.017	0.07
7	<i>Albizia procera</i> (Roxb.) Benth.	0.29	0.13	0.007	0.02
8	<i>Albizia lebbeck</i> (L.) Benth.	0.12	0.06	0.036	0.11
9	<i>Alstonia scholaris</i> (L.) R. Br.	1.44	0.68	0.013	0.04
10	<i>Anacardium occidentale</i> L.	0.42	0.20	0.038	0.20
11	<i>Annona squamosa</i> L.	0.02	0.01	0.003	0.07
12	<i>Antidesma acidum</i> Retz.	0.07	0.03	0.001	0.04
13	<i>Artocarpus heterophyllus</i> Lam.	0.61	0.29	0.074	0.04
14	<i>Artocarpus lacucha</i> Buchanan-Hamilton ex D. Don	0.01	0.01	0.003	0.02
15	<i>Azadirachta indica</i> A. Juss.	0.26	0.12	0.003	0.11
16	<i>Bambusa vulgaris</i> Schrad. ex J.C. Wendl., nom. cons. Prop	0.13	0.06	0.077	0.13
17	<i>Bauhinia purpurea</i> L.	0.28	0.13	0.013	0.04
18	<i>Bauhinia tomentosa</i> L.	1.40	0.66	0.081	0.33
19	<i>Bauhinia variegata</i> L.	0.02	0.01	0.002	0.02
20	<i>Bombax ceiba</i> L.	0.31	0.15	0.027	0.11
21	<i>Boswellia serrata</i> Roxb. ex Colebr.	4.76	2.24	0.166	0.67
22	<i>Bridelia retusa</i> (L.) A. Juss.	0.39	0.18	0.025	0.37
23	<i>Buchanania cochinchinensis</i> (Lour) M.R. Almeida	84.43	39.68	4.633	14.76
24	<i>Butea monosperma</i> (Lam.) Taub.	38.80	18.24	1.250	5.74
25	<i>Careya arborea</i> Roxb.	0.28	0.13	0.001	0.02
26	<i>Carissa spinarum</i> L.	0.07	0.03	0.002	0.04
27	<i>Casearia graveolens</i> Dalzell	0.38	0.18	0.022	0.24
28	<i>Casearia tomentosa</i> Roxb.	2.43	1.14	0.212	0.74
29	<i>Cassia fistula</i> L.	6.38	3.00	0.115	1.72
30	<i>Catunaregam spinosa</i> (Thumb.)	0.07	0.03	0.003	0.09

Tirveng.					
31	<i>Celastrus paniculatus</i> Willd.	0.80	0.38	0.014	0.15
32	<i>Chloroxylon swietenia</i> (Roxb.) DC.	0.20	0.09	0.023	0.02
33	<i>Cleistanthus collinus</i> (Roxb.) Benth. ex Hook.f.	3.18	1.50	0.495	1.13
34	<i>Cochlospermum religiosum</i> (L.) Alston	0.03	0.01	0.015	0.07
35	<i>Croton persimilis</i> Müll. Arg.	1.06	0.50	0.091	0.30
36	<i>Dalbergia latifolia</i> Roxb.	1.33	0.63	0.042	0.02
37	<i>Dalbergia sissoo</i> DC.	0.06	0.03	0.002	0.02
38	<i>Dendrocalamus strictus</i> (Roxb.) Nees	0.81	0.38	0.006	0.20
39	<i>Desmodium oojeinense</i> (Roxb.) H. Ohashi	0.03	0.01	0.008	0.07
40	<i>Dillenia pentagyna</i> Roxb.	0.02	0.01	0.001	0.04
41	<i>Diospyros melanoxylon</i> Roxb.	1014.12	476.64	1.643	23.26
42	<i>Elaeodendron kamerunense</i> (Loes.) Villiers	0.41	0.19	0.034	0.26
43	<i>Eucalyptus globulus</i> Labill.	0.51	0.24	0.016	0.02
44	<i>Ficus benghalensis</i> L.	58.00	27.26	1.119	0.70
45	<i>Ficus geniculata</i> Kurz	0.12	0.05	0.014	0.04
46	<i>Ficus hispida</i> L. fil.	0.67	0.31	0.013	0.04
47	<i>Ficus racemosa</i> L.	0.15	0.07	0.005	0.02
48	<i>Ficus religiosa</i> L.	8.09	3.80	0.273	0.17
49	<i>Ficus semicordata</i> Buch. ex J. E. Smith	1.07	0.50	0.025	0.04
50	<i>Flacourtia indica</i> (Burm. fil.) Merr.	0.10	0.05	0.000	0.02
51	<i>Gardenia latifolia</i> Aiton	1.46	0.69	0.005	0.04
52	<i>Gmelina arborea</i> Roxb. ex Sm.	0.12	0.06	0.011	0.07
53	<i>Holarrhena pubescens</i> (Buch.-Ham.) Wall. ex G. Don	49.14	23.10	0.086	1.52
54	<i>Holoptelea integrifolia</i> (Roxb.) Planch.	0.42	0.20	0.018	0.04
55	<i>Jasminum auriculatum</i> Vahl	0.06	0.03	0.001	0.02
56	<i>Lagerstroemia parviflora</i> Roxb.	29.65	13.94	1.055	5.13
57	<i>Lannea coromandelica</i> (Houtt.) Merr.	43.64	20.51	0.705	2.63
58	<i>Madhuca longifolia</i> (J. Koenig ex L.) J.F. Macbr.	1875.67	881.57	1.282	6.83
59	<i>Mallotus philippensis</i> (Lam.) Müll.Arg.	1.73	0.81	0.118	0.91
60	<i>Mangifera indica</i> L.	56.15	26.39	3.060	2.96
61	<i>Melia azedarach</i> L.	0.04	0.02	0.001	0.02
62	<i>Miliusa velutina</i> (Dunal) Hook. f. & Thomson	0.66	0.31	0.018	0.17

63	<i>Mitragyna parvifolia</i> (Roxb.) Korth.	0.09	0.04	0.007	0.02
64	<i>Morinda citrifolia</i> L., nom. cons.	0.89	0.42	0.054	0.17
65	<i>Murraya koenigii</i> (L.) Spreng.	0.10	0.05	0.000	0.02
66	<i>Murraya paniculata</i> (L.) Jacq.	0.08	0.04	0.000	0.02
67	<i>Nyctanthes arbor-tristis</i> L.	0.06	0.03	0.001	0.02
68	<i>Oroxylum indicum</i> (L.) Kurz	0.05	0.02	0.004	0.02
69	<i>Phoenix acaulis</i> Roxb.	0.10	0.05	0.010	0.02
70	<i>Phyllanthus emblica</i> L.	1.70	0.80	0.030	0.30
71	<i>Phyllanthus reticulatus</i> Poir.	0.05	0.02	0.010	0.11
72	<i>Pongamia pinnata</i> (L.) Pierre	29.90	14.05	0.230	0.39
73	<i>Psidium guajava</i> L.	0.32	0.15	0.020	0.13
74	<i>Pterocarpus marsupium</i> Roxb.	24.53	11.53	0.142	1.22
75	<i>Pterocarpus santalinus</i> L.f.	0.53	0.25	0.028	0.22
76	<i>Sapindus mukorossi</i> Gaertn.	0.05	0.02	0.008	0.07
77	<i>Schleichera oleosa</i> (Lour.) Oken	24.10	11.33	0.551	0.72
78	<i>Schrebera swietenoides</i> Roxb.	0.09	0.04	0.015	0.07
79	<i>Semecarpus anacardium</i> L. fil.	221.81	104.25	0.714	4.00
80	<i>Senegalia catechu</i> (L.f.) P. J. H. Hurter & Mabb.	7.62	3.58	0.212	0.74
81	<i>Senegalia pennata</i> (L.) Maslin	0.05	0.02	0.010	0.07
82	<i>Senna siamea</i> (Lam.) H.S. Irwin & Barneby	0.24	0.12	0.021	0.02
83	<i>Shorea robusta</i> Gaertn.	7074.94	3325.22	120.814	415.93
84	<i>Soymida febrifuga</i> (Roxb.) Juss.	0.15	0.07	0.000	0.02
85	<i>Spathodea campanulata</i> Beauv.	0.03	0.01	0.005	0.09
86	<i>Spondias pinnata</i> (L. fil.) Kurz	0.05	0.02	0.002	0.02
87	<i>Sterculia urens</i> Roxb.	0.02	0.01	0.009	0.07
88	<i>Stereospermum chelonoides</i> (L. fil.) DC.	0.43	0.20	0.030	0.28
89	<i>Syzygium cumini</i> (L.) Skeels	99.79	46.90	0.814	3.72
90	<i>Syzygium fruticosum</i> (Roxb.) DC.	3.63	1.71	0.034	0.37
91	<i>Tamarindus indica</i> L.	0.45	0.21	0.212	0.24
92	<i>Tectona grandis</i> L.f.	0.12	0.06	0.005	0.04
93	<i>Terminalia alata</i> Heyne ex Roth	32.93	15.48	0.949	3.83
94	<i>Terminalia anogeissiana</i> Gere & Boatwr.	15.01	7.06	0.432	2.28
95	<i>Terminalia arjuna</i> (Roxb.) Wight & Arn.	20.24	9.51	1.484	2.59
96	<i>Terminalia bellirica</i> (Gaertn.) Roxb.	25.39	11.93	0.290	1.52

97	<i>Terminalia chebula</i> Retz.	4.26	2.00	0.083	0.80
98	<i>Toona ciliata</i> M. Roem.	0.00	0.00	0.000	0.02
99	<i>Wendlandia heynei</i> (Schult.) Santapau & Merchant	0.84	0.40	0.000	0.02
100	<i>Woodfordia fruticosa</i> (L.) Kurz	0.20	0.09	0.002	0.04
101	<i>Wrightia tinctoria</i> R. Br.	0.24	0.11	0.002	0.02
102	<i>Ziziphus jujuba</i> Miller	0.02	0.01	0.004	0.02
103	<i>Ziziphus rugosa</i> Lam.	0.08	0.04	0.008	0.04

Table 5: Above ground biomass, carbon stock and basal area of different regions of Ranchi, Jharkhand, Eastern India.

Regions	No of studied transects	AGB (Mg ha ⁻¹)	Carbon stock (Mg C ha ⁻¹)	Basal area (m ² ha ⁻¹)
Angara	7	34.32 (4.90±0.45)	16.13 (2.53±0.58)	944.48 (134.92±17.60)
Bero	8	38.36 (4.72±0.48)	18.50 (2.61±0.47)	1163.24 (145.40±22.35)
Bundu	7	34.32 (4.90±0.45)	16.13 (1.51±0.19)	743.22 (106.17±23.05)
Burmu	9	42.85 (4.46±0.45)	20.14 (2.53±0.58)	899.28 (99.92±15.01)
Chanho	3	9.84 (3.28±0.45)	4.63 (2.26±0.26)	353.72 (117.90±37.04)
Itki	1	2.97	1.4	179.08
Kanke	9	50.56 (5.62±0.45)	23.76 (2.09±0.21)	937.34 (104.14±14.75)
Khelari	2	8.16 (4.08±0.45)	3.84 (2.26±0.26)	247.72 (123.86±17.60)
Lapung	3	12.11 (4.04±0.45)	5.69 (1.4±0.00)	389.54 (129.84±16.92)
Mandar	2	5.70 (2.85±0.45)	2.68 (2.26±0.26)	271.26 (135.63±39.65)
Nagri	1	1.09	0.51	164.76
Namkum	18	111.74 (6.21±0.45)	52.52 (2.26±0.26)	3344.54 (185.80±21.74)
Ormanjhi	2	0.9	0.42	336.8 (168.4±83.32)
Rahe	1	4.72	0.21	157.9
Ratu	3	2.8 (0.93±0.45)	1.32 (0.4± 00)	281.38 (93.79 ± 27.46)
Sili	1	4.7	2.21	153.54
Sonahatu	2	4.34 (2.17±0.48)	2.04 (1.47±0.00)	210.32 (105.16 ±14.16)
Tamar	13	40.21 (3.09±0.41)	18.90 (2.53±0.58)	1668.48 (128.34 ±20.49)

Table 6: Classification of studied *Sal* forests of Ranchi, Jharkhand, Eastern India, based on the Shannon-Weiner diversity (H') and evenness index (E') combination.

Shannon-Weiner diversity (H') - Evenness index (E') combination	Unique name for H' and E combination	Interpretation Code	No. of studied forests	%
HD-LE	Extreme tree diversity forests with high H' and low E	ETDFs	03	3.26
HD-ME	Very high tree diversity forests with high H' and moderate E	VHTDFs	11	11.96
HD-HE	High tree diversity forests with high H' and high E	HTDFs	04	4.35
MD-LE	Tree diversity forests with moderate H' and low E	TDFs	01	1.09
MD-ME	Moderate tree diversity forests with moderate H' and moderate E	MTDFs	23	25.00
MD-HE	Low tree diversity forests with moderate H' and high E	LTDFs	09	9.78
LD-LE	Highly low tree diversity forests with low H' and low E	HLTDFs	04	4.35
LD-ME	Very low tree diversity forests with low H' and moderate E	VLTDfs	25	27.17
LD-HE	Extremely low tree diversity forests with low H' and high E	ELTDFs	12	13.04

Table 7: Pearson Correlation coefficient among various community parameters, Margalef's index of species richness (Dmg), Menhinick's index of species richness (Dmn), Shannon-Weiner diversity index (H'), concentration of dominance (CD), evenness index (E), effective number of species (ENS), density (ind. ha⁻¹), basal area (BA) (m² ha⁻¹), above ground biomass (AGB) (Mg ha⁻¹), and carbon stock (Cp) (Mg C ha⁻¹) of all studied *Sal* forests of Ranchi, Jharkhand, Eastern India.

	Density	BA	AGB	Cp	H'	Dmg	Dmn	E	ENS
BA	.294**	1							
AGB	-.017	.71*	1						
Cp	-.017	.71	1.00**	1					
H'	-.041	-.126	.584**	.584**	1				
Dmg	.034	-.004	.310**	.310**	.494**	1			
Dmn	-.338**	-.259*	.493**	.493**	.841**	.513**	1		
E	-.156	-.271**	.257*	.257*	.398**	.239*	.418**	1	
ENS	-.036	-.105	.565**	.565**	.951**	.546**	.842**	.444**	1
CD	.154	.192	-.567**	-.567**	-.927**	-.418**	-.81**	-.462**	-.848**

N=92

**.. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

Figures

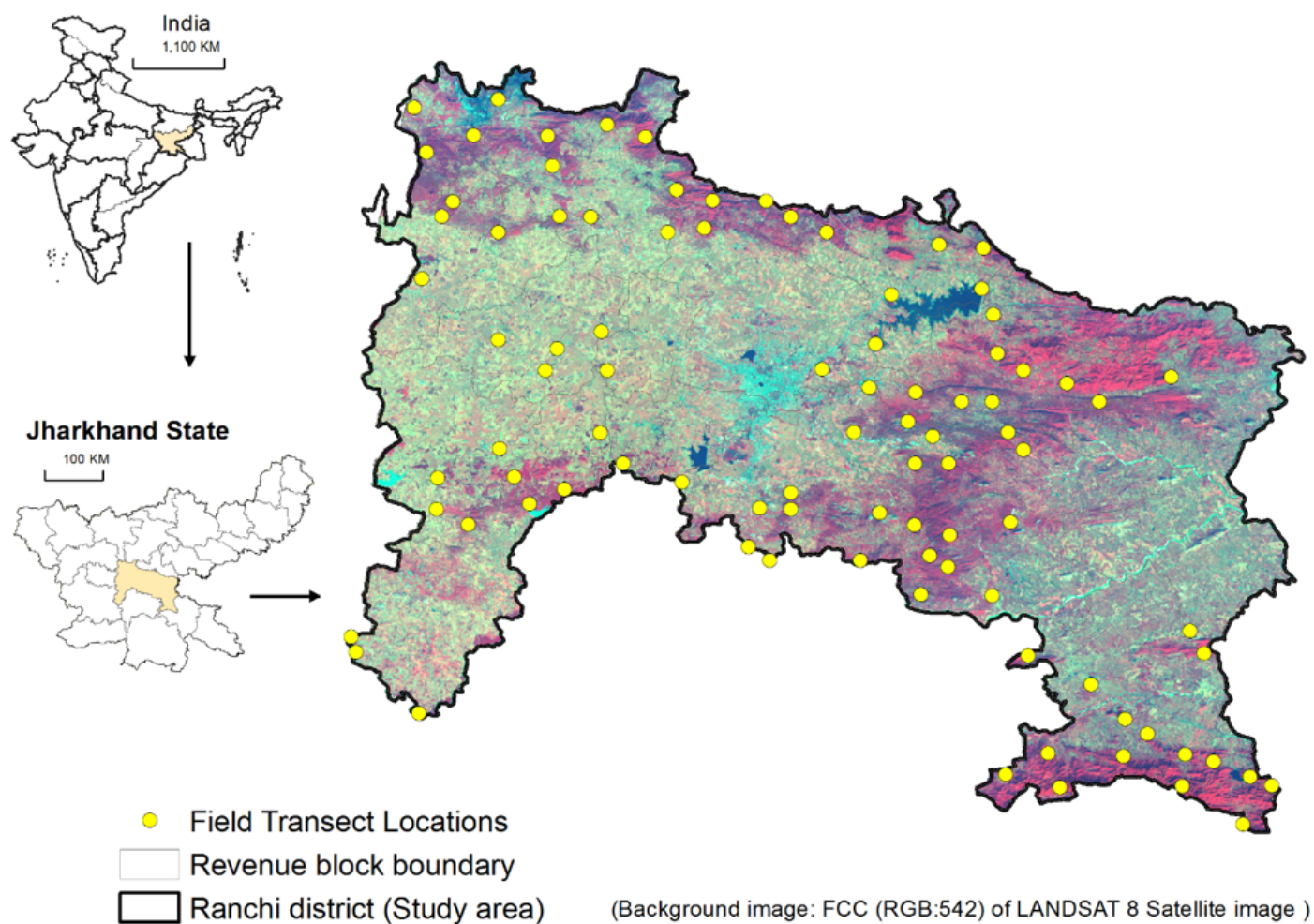


Figure 1

Map of the study area showing the locations of studied transects in Sal forests of the Ranchi, Jharkhand, Eastern India.

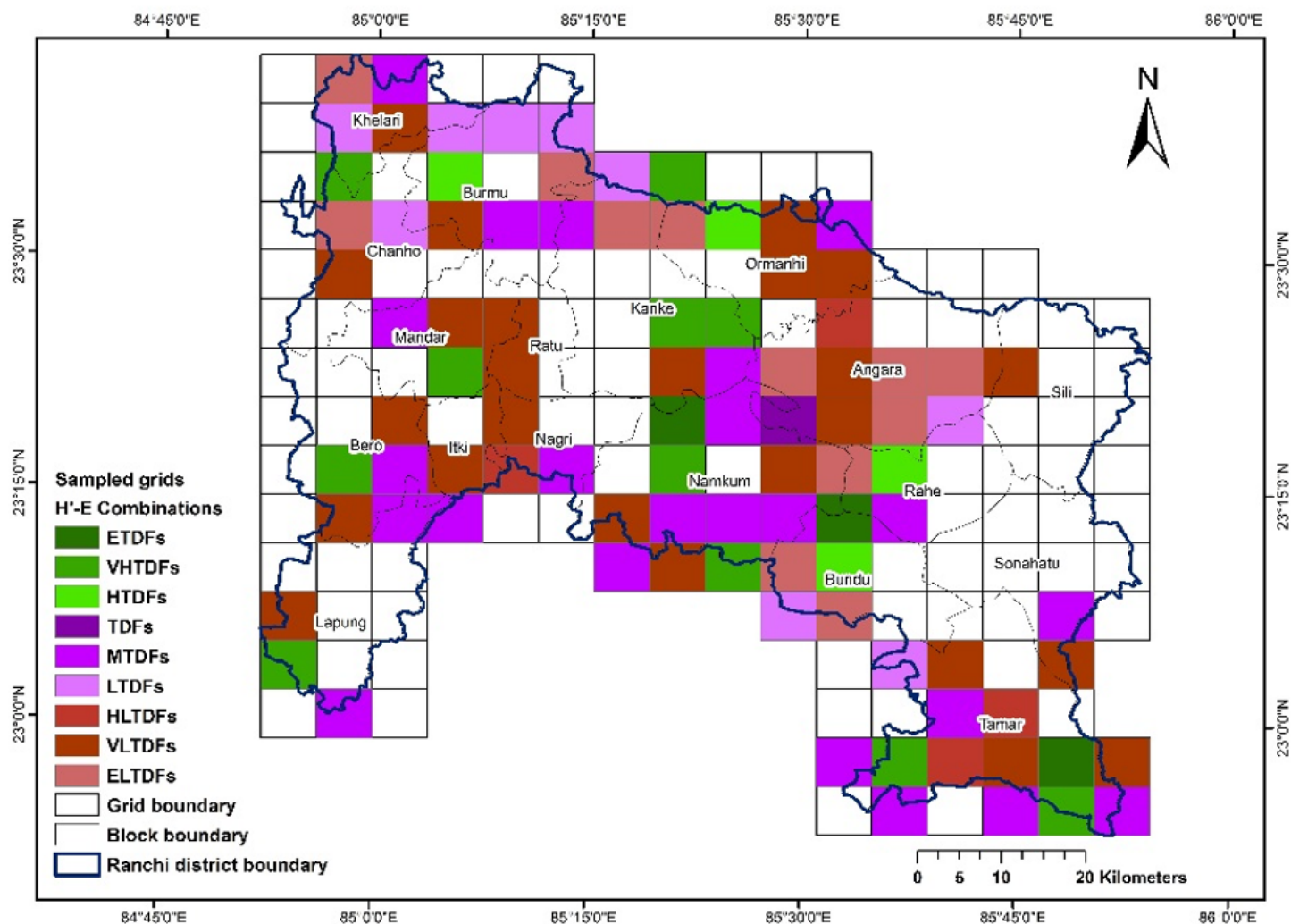


Figure 2

Multiple combinations of Shannon-Weiner diversity index (H') with evenness index (E) of studied Sal forests of Ranchi, Jharkhand, Eastern India (ETDFs: Extreme tree diversity forests with high H' and low E , VHTDFs: Very high tree diversity forests with high H' and moderate E , HTDFs: High tree diversity forests with high H' and high E , TDFs: Tree diversity forests with moderate H' and low E , MTDFs: Moderate tree diversity forests with moderate H' and moderate E , LTDFs: Low tree diversity forests with moderate H' and high E , HLTDFs: Highly low tree diversity forests with low H' and low E , VLTDFs: Very low tree diversity forests with low H' and moderate E , ELTDFs: Extremely low tree diversity forests with low H' and high evenness).

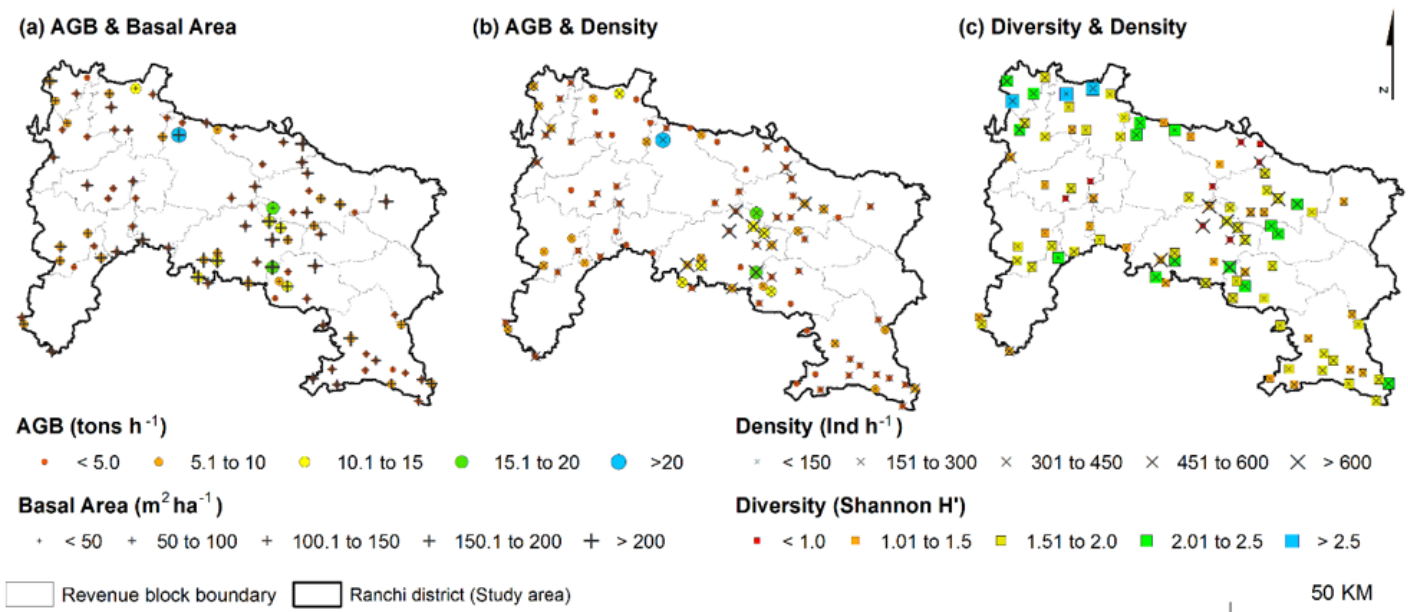


Figure 3

Map showing the spatial distribution and relationship of AGB with (a) basal area, and (b) density, (c) relationship of diversity and density.

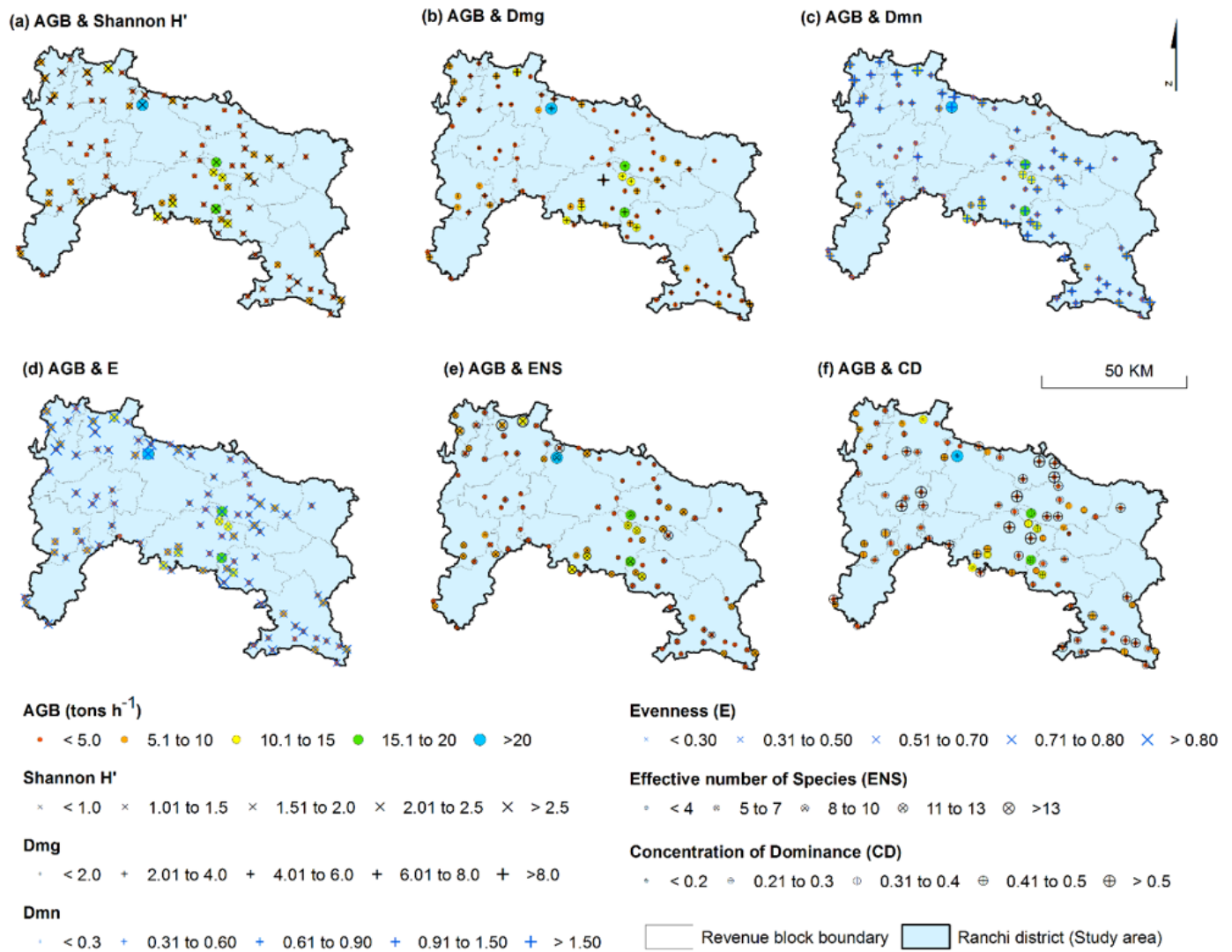


Figure 4

Map showing spatial distribution and relationship of AGB with (a) Shannon H', (b) Dmg, (c) Dmn, (d) E, (e) ENS, and (f) CD.