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Phytosociological assessment and carbon stock estimation and valuation in the tropical dry deciduous forest of Bihar

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Abstract

Purpose – This study aims to assess the biodiversity of the study area and estimate the carbon stock of two dry deciduous forest ranges of Banka Forest Division, Bihar, India.

Design/methodology/approach – The phytosociological analysis was performed and C stock estimation based on volume determination through nondestructive methods was done.

Findings – Phytosociological analysis found total 18,888 [14,893 < 10 cm (diameter at breast height) dbh] and 2,855 (1,783 < 10 cm dbh) individuals at Banka and Bounsi range with basal area of 181,035.00 cm^2 and 32,743.76 cm^2, respectively. Importance value index was highest for Shorea robusta in both the ranges. Species diversity index and dominance index, 1.89 and 1.017 at Banka and 1.99 and 5.600 at Bounsi indicated the prevalence of biotic pressure. Decreased dbh and tree height resulted in a lowered growing stock volume as 59,140.40 $cm^3\ ha^{-1}$ (Banka) and 71,306.37 $cm^3\ ha^{-1}$ (Bounsi). Total C stock at Banka and Bounsi range was 51.8 $t\ ha^{-1}$ and 12.56 $t\ ha^{-1}$, respectively where the highest C stock is recorded for Shorea robusta in both the ranges (9.8 $t\ ha^{-1}$ and 2.54 $t\ ha^{-1}$, respectively). A positive correlation between volume, total biomass and basal area of tree species with C stock was observed. R^2 value for Banka range was 0.9269 (volume-C stock), 1 (total biomass-C stock) and 0.647 (basal area-C stock). Strong positive correlation was also established at Bounsi range with R^2 value of 1. Considering the total forest area enumerated, C sequestration potential was

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about 194.25 *t* CO_2 (Banka) and 45.9 *t* CO_2 (Bounsi). The valuation of C stock was therefore US$2,525.25 (Banka) and US$596.70 (Bounsi).

Practical implications – The research found the potentiality of the study area to sequester carbon. However, for future, the degraded areas would require intervention of management strategies for restoration of degraded lands and protection of planted trees to increase the carbon sequestration potential of the area.

Originality/value – Present study is the first attempt to assess the phytosociology and estimate the regulatory services of forest with respect to biomass and carbon stock estimation for the Banka forest division of Bihar.

Keywords Species diversity, Crop volume, Biomass, Carbon stock

Paper type Research paper

Abbreviation

AGB = above ground biomass;
BGB = below ground biomass;
DBH = diameter at breast height; and
IVI = importance value index.

1. Introduction

One of the richest terrestrial ecosystems is constituted in tropical forests supporting various life forms that indeed maintain high biodiversity (Shi and Singh, 2002). Eighty-six percent of the forest land is contributed by tropical forests in India while contribution of tropical dry deciduous forest and moist deciduous forest is 53% and 37%, respectively. Share of wet evergreen and semi-evergreen forests is only 10%. Tree species diversity is both complex and varies in different places in its structure and composition due to the prevalence of varying climate and topographical characteristics (Raturi, 2012). Depending upon the structure and composition of forests functionality is determined where forests act as carbon sink and have potential to sequester carbon (Lal and Singh, 2000). The phytosociological studies are significant to understand the structure, composition and distribution pattern of plant communities (Rout *et al.*, 2018) and also to estimate the biomass of the area. Estimation of biomass eventually contributes to estimate C stock of an area (Fahey *et al.*, 2010; Kushwaha *et al.*, 2014; Salunkhe *et al.*, 2016; Jhariya, 2017; Banik *et al.*, 2018). Studies have depicted that carbon stocks are dependent on forest tree density, volume, above- and below-ground biomass (Gibbs *et al.*, 2007; Banik *et al.*, 2018). The estimates of percentage indicate higher priority for tropical dry deciduous forests but limited studies have been conducted in these forests. Many of the forests are subjected to maltreatment and are degraded. Both biotic and edaphic factors have accelerated the process of degradation finally turning the rich dense forests into open degraded and scrub lands (Singh *et al.*, 1991; Chaturvedi *et al.*, 2011). Banka forest division is tropical dry deciduous forest with forest fringe villages and is under immense biotic pressure on forested land causing degradation of forest area leading to loss of biodiversity, habitat fragmentation, removal of top soil, etc. The loss of biodiversity in dry deciduous forest of tropics is comparable to tropical forests (Gentry, 1992).

Deforestation and land degradation causes loss of carbon stocks or in other words emits CO_2, which estimates about 7%–14% of the total CO_2 emissions from anthropogenic activities (Harris *et al.*, 2012; Achard *et al.*, 2014). A decreasing trend in carbon stocks of tropical forests in India is noticed since 2003 (Sheikh *et al.*, 2011) with reduction in native forests at the rate of 3.5% annually (Puyravaud *et al.*, 2010). Similarly, the decrease in global forest area was noticed by 4.1 and 6.4 million ha annually and 3% of world's forest were disturbed by several biotic factors, namely, fire, pests, logging, etc. as reported by FAO (2012), while it was also reported by FAO (2006) that about 60% of forests are recovering.

Extensive studies were made by several researchers on the deforestation having impact on climate and what role is played by tropical forests in climate change mitigation (Masera *et al.*, 1995; De Jong *et al.*, 1999, 2000; Grace *et al.*, 2006). It was further estimated that 89% of total carbon stored in an ecosystem is lost due to deforestation that leads to loss of living biomass (Keith *et al.*, 2014). However, United Nations Framework Convention on Climate Change was set and estimation of forest carbon sinks, as well as sources, was in demand to inventories (UNFCCC, 1992). Major sources of carbon sink are the forests and are, thus, required to assess the total amount of sequestered carbon. Higher priority for adaptation and mitigation of climate change issues was set for conservation and protection of biological diversity and carbon sequestration (Diaz *et al.*, 2009). In recent past, under REDD+ programs for implementation of climate change mitigative policies, the developing countries are required to furnish baseline data for carbon stock estimation in forests (Saatchi *et al.*, 2011; Salimon *et al.*, 2011).

The estimated area for Sal forest in India is about 13 million hectares where in most cases the primary Sal forest is replaced by secondary regenerated Sal forest. The major cause for the shift was due to forest land degradation, over-exploitation, deforestation, grazing, change in land use pattern and several other biotic and anthropogenic activities (Deka *et al.*, 2012). As the species diversity and composition is dependent on potential regeneration of secondary forests (Ayyappan and Parthasarthy, 1999), the biomass of forest is also modified that has direct impact on carbon storage. Thus, forests being largest pool of biomass and carbon, different percent coverage has been estimated for aboveground, belowground, dead woody and litter compartment, which is about 234 Pg C, 62 Pg C, 42 Pg C and 23 Pg C, respectively with soil carbon pool of 398 Pg C (Kindermann *et al.*, 2008). Therefore, considering the carbon pool although many studies were carried out by many researcher but limited studies are done in tropical dry deciduous forest in eastern zone of India. Few studies on biomass and carbon estimation shows total carbon pools of 52.59 Mg ha^{-1}, 34.17 Mg ha^{-1} and 33.61 Mg ha^{-1} at *Ailanthus excels – Cassia fistula* forest, *Acacia leucophloea – Balanites aegyptica* forest and *Anoegeissus pendula – Acacia leucophloea* dominated forest, respectively, in North-east India (Singh *et al.*, 2016). Biomass allometric equations were used by few researchers to estimate biomass and carbon stock in tropical forest of Tripura that recorded biomass in the range of 37.85 to 85.58 Mg ha^{-1} (Majumdar *et al.*, 2016). Forest of Manipur showed carbon stock in the range of 60.09 to 121.43 *t* ha^{-1} (Thokchom and Yadava, 2017) Similar studies at Garhwal Himalaya, India recorded 132.74 and 66.36 Mg ha^{-1} of total biomass and carbon density, respectively (Mahato *et al.*, 2016).

In view to the above issues, as vegetation structure and diversity plays a major role in controlling various ecological processes (Gower *et al.*, 1992; Rout *et al.*, 2018), our study was concentrated to Banka Forest Division of Bihar state where traditional process of forest vegetation survey was followed to assess the phytosociology and estimate the regulatory function with respect to biomass and carbon stock estimation in the study area. In our present study, forest structure, distribution and carbon stock is estimated with its valuation in two forest ranges, namely, Banka and Bounsi range of Banka Forest Division, Bihar.

2. Materials and methods

2.1 Study area

The study was conducted in Banka and Bounsi Range with geographical location as latitude 24°30′00″ N to 25°15′00″ N, longitude 86°30′00″ E to 87°15′00″E. The total area of Banka and Bounsi forest Range is 15,106.579 ha and 6,760.000 ha, respectively. The area receives rain during onset of southwest monsoon in the month of June scaling to 1,200 mm precipitation annually.

2.2 Sampling plots

Sampling plots were selected based on geo-referenced toposheets of 1:50000 scale. The study area was cropped and 15′ × 15′ grid was subdivided into 144 sub-grids. Each sub-grid of size 1.25′ × 1.25′ was further subdivided into to nine sub-grids of 25″ × 25″ using Arc GIS software.

2.3 Vegetation enumeration

Vegetation was enumerated following nested quadrat was laid in each sampling plots of 25″ × 25″ covering 0.5 ha. The phytosociological analysis was done to assess the structure of vegetation following Misra (1968) where diameter at breast height (DBH) in cm and tree height (in m) was measured. Frequency, density and abundance were recorded (Curtis and McIntosh, 1950). Relative values were calculated following Philips (1959). The importance value index (IVI) was estimated as sum of relative frequency, relative density and relative dominance of each species (Curtis, 1959). Shannon Weiner index (H′) was used to calculate species diversity (Shannon and Wiener, 1963). The equations are as follows:

$$\text{Frequency} = \frac{\text{No. of quadrats in which species appeared}}{\text{Total no. of quadrat studied}} \times 100 \tag{1}$$

$$\text{Relative frequency} = \frac{\text{Frequency of one species}}{\text{Total no. of frequency of all species}} \times 100 \tag{2}$$

$$\text{Density} = \frac{\text{Total no. of individuals of a species in all quadrats}}{\text{Total no. of quadrat studied}} \tag{3}$$

$$\text{Relative density} = \frac{\text{Density of the species}}{\text{Total density of all species}} \times 100 \tag{4}$$

$$\text{Abundance} = \frac{\text{Total no. of individuals of a species in all quadrats}}{\text{Total no. of quadrats in which teh species appears}} \tag{5}$$

$$\text{Relative dominance} = \frac{\text{Total dominance (basal area) of the species in all quadrats}}{\text{Total dominance (basal area) of all species in all quadrats}} \times 100 \tag{6}$$

$$\text{Species diversity } (H') = -\sum\left[\left(\frac{n_i}{N}\right)\log_2\left(\frac{n_i}{N}\right)\right] \tag{7}$$

where n_i is the total number of individuals of species i and N is the total number of individuals of all species.

2.4 Carbon stock estimation

$$\text{Tree Basal Area (TBA) was calculated based upon the formula Area (A)} = \pi r^2, \tag{8}$$

Therefore,

$$\text{Tree basal area (TBA)} = \left(\frac{\text{DBH}}{200}\right)^2 \times 3.14 \tag{9}$$

where DBH = diameter at breast height in cm, $\pi = 3.14$

Tree volume was determined by using equation given below

$$\begin{aligned} \text{Tree Volume}(\text{m}^3) &= \left(\tfrac{\text{DBH}}{200}\right)^2 \times 3.14 \times \left(\frac{\text{Height}}{3}\right) \\ \text{Or Tree Volume} &= \left(\frac{\text{TBA}}{3}\right) \text{X Height} \end{aligned} \tag{10}$$

Volume ($\text{m}^3\text{tree}^{-1}$) of each tree in a sampling quadrat obtained is converted into the volume on hectare basis.

Above ground biomass (AGB) was calculated following IPCC (2003). Below ground biomass (BGB) was calculated following the equation given by Mokany *et al.* (2006). The carbon storage for each species was computed by multiplying total biomass with constant factor 0.50 (IPCC, 2006).

3. Results

3.1 Vegetation structure

The vegetation in both the ranges comprises of dominant tree species of *Shorea robusta* and its associates species, namely, *Madhuca indica, Diospyros melanoxylon, Butea monosperma, Terminalia tomentosa, Buchanania latifolia, Anoegeissus latifolia, Phylanthus emblica, Acacia catechu*, etc. Total numbers of individuals recorded are 18,888 individuals (14,893 individuals within 0–10 dbh class) and 2,855 individuals (1,783 within 0–10 dbh class) in Banka and Bounsi range, respectively. DBH class wise distribution of trees shows lesser number of trees within dbh class >10 cm, thus numbers of matured trees are much less in the study area. Total basal area in Banka and Bounsi range is 181,035.03 cm^2 and 32,743.76 cm^2, respectively. Extent of tree density at Banka (0.02–22.74) is higher than Bounsi (0.02–15.58) while the abundance of tree species ranges between 0.34–31.55 and 1.00–23.60, respectively (Tables 1 and 2).

IVI in both the ranges is highest for *Shorea robusta*. Top 10 tree species with respect to values of IVI at Banka range follows the trend as *Shorea robusta* (56.27) > *Acacia auriculiformis* (46.29) > *Madhuca indica* (36.09) > *Buchanania latifolia* (14.80) > *Butea monosperma* (13.26) > *Acacia catechu* (9.91) >*Terminalia tomentosa* (9.78) > *Cochlospermum religiosum* (8.84) > *Cassia siamea* (8.77) > *Eucalyptus globulus* (8.32) (Table 1). Similarly at Bounsi range the trend is *Shorea robusta* (55.88) > *Madhuca indica* (37.14) > *Acacia auriculiformis* (36.85) > *Butea monosperma* (31.17) > *Terminalia arjuna* (25.65) > *Terminalia tomentosa* (19.02) > *Eucalyptus globulus* (17.76) > *Diospyros melanoxylon* (9.62) > *Buchanania latifolia* (9.37) > *Acacia catechu* (9.91) (Table 2).

Tree species richness at Banka and Bounsi range is 32 and 25 that belongs to 18 and 15 families, respectively. No significant difference in species diversity index is observed (Banka – 1.89 and Bounsi – 1.99). Shannon Weiner index ranges between 0.001–0.370 in Banka range and 0.010–0.350 in Bounsi range (Tables 1 and 2). Dominance index of Bounsi range (5.600) is found to be much higher than Banka range (1.017). Based upon the phytosociological study, hierarchical clustering was done where the dendrogram in Figure 1

Name of species	TNI	NQO	TQS	VEA	A	F	A:F	D	Basal area	IVI	H′
Acacia auriculiformis	6,594	209	290	145.00	31.55	72.07	0.44	22.74	33,184.91	46.29	0.367
Acacia catechu	524	104	185	92.50	5.04	56.22	0.09	2.83	4,391.59	9.91	0.099
Acacia nilotica	14	2	10	5.00	7.00	20.00	0.35	1.40	19.39	3.05	0.005
Aegle marmelos	77	16	50	25.00	4.81	32.00	0.15	1.54	847.49	4.66	0.022
Albizia lebbeck	24	8	25	12.50	3.00	32.00	0.09	0.96	212.91	3.75	0.008
Anoegeissus latifolia	238	23	70	35.00	10.35	32.86	0.31	3.40	2,770.42	7.58	0.055
Anona squamosal	1	3	5	2.50	0.33	60.00	0.01	0.20	46.34	5.30	0.001
Artocarpus heterophyllus	1	1	5	2.50	1.00	20.00	0.05	0.20	9.33	1.89	0.001
Azadirachta indica	34	22	90	45.00	1.55	24.44	0.06	0.38	499.14	2.71	0.011
Buchanania latifolia	1,129	94	175	87.50	12.01	53.71	0.22	6.45	7,321.70	14.80	0.167
Butea monosperma	715	74	165	82.50	9.66	44.85	0.22	4.33	9,582.81	13.26	0.123
Cassia siamea	210	22	55	27.50	9.55	40.00	0.24	3.82	3,098.79	8.77	0.050
Cochlospermum religiosum	196	34	80	40.00	5.76	42.50	0.14	2.45	5,228.45	8.84	0.047
Dalbergia sisso	73	26	75	37.50	2.81	34.67	0.08	0.97	1,102.36	4.48	0.021
Diospyros melanoxylon	404	101	240	120.00	4.00	42.08	0.10	1.68	2,090.03	6.34	0.082
Eucalyptus globulus	104	12	25	12.50	8.67	48.00	0.18	4.16	462.13	8.32	0.028
Ficus benghalensis	17	13	50	25.00	1.31	26.00	0.05	0.34	1,009.93	3.09	0.006
Gmelin aarborea	25	9	35	17.50	2.78	25.71	0.11	0.71	152.77	2.95	0.009
Holarrhena antidysenterica	31	2	10	5.00	15.50	20.00	0.78	3.10	97.15	4.73	0.010
Madhuca indica	1,810	161	240	120.00	11.24	67.08	0.17	7.54	41,924.90	36.09	0.224
Mangifera indica	20	10	40	20.00	2.00	25.00	0.08	0.50	1,222.30	3.27	0.007
Mimusops elengi	12	2	5	2.50	6.00	40.00	0.15	2.40	40.05	5.72	0.005
Phyllanthus emblica	190	19	45	22.50	10.00	42.22	0.24	4.22	1,068.34	8.22	0.046
Schleichera oleosa	16	5	20	10.00	3.20	25.00	013	0.80	97.42	2.94	0.006
Semecarpus anacardium	30	8	40	20.00	3.75	20.00	0.19	0.75	479.23	2.68	0.010
Shorea robusta	5918	205	300	150.00	28.87	68.33	0.42	19.73	57,067.52	56.27	0.363
Soyemida febrifuga	68	15	50	25.00	4.53	30.00	0.15	1.36	937.91	4.37	0.020
Syzygium cumini	17	7	35	17.50	2.43	20.00	0.12	0.49	275.84	2.31	0.006
Terminalia arjuna	7	4	15	7.50	1.75	26.67	0.07	0.47	132.40	2.78	0.003
Terminalia bellerica	32	9	40	20.00	3.56	22.50	0.16	0.80	542.62	2.97	0.011
Terminalia tomentosa	356	54	115	57.50	6.59	46.96	0.14	3.10	5,115.94	9.78	0.074
Ziziphus mauritiana	1	1	5	2.50	1.00	20.00	0.05	0.20	2.92	1.89	0.001
Total	18,888	1,275	2,590	1,295.00	221.59	1,180.88	5.72	104.02	181,035.03	300.00	1.890

Notes: TNI = total number of individuals, NQO = number of quadrat occurrence, TQS = total number of quadrat studied, VEA = vegetation enumeration area, A = abundance, F = frequency (%), A:F = abundance frequency ratio, D = density, BA = basal area (cm^2), IVI = importance value index

Table 1. Phytosociological attributes at Banka Range

reveals two clusters at Banka range. Six tree species, namely, *Acacia catechu, Cochlospermum religiosum, Terminalia tomentosa, Acacia auriculiformis, Madhuca indica* and *Shorea robusta* form a Cluster 1 while other species have similarity among themselves to form another cluster. Cluster 1 includes six tree species of five families (Fabaceae, Bixaceae, Combretaceae, Sapotaceae and Dipterocarpaceae). Cluster 2 includes 26 tree species with 16 families (Anacardiaceae, Phyllanthaceae, Annonaceaea, Fabaceae, Sapotaceae, Rutaceae, Rhamnaceae, Moraceae, Combretaceae, Apocyanaceae, Mimosaceae, Myrtaceae, Lamiaceae, Ebenaceae, Sapindaceae and Meliaceae). Similarly dendrogram in Figure 2 shows three clusters at Bounsi range. Cluster 1 is formed with two species, namely, *Acacia auriculiformis* and *Butea monosperma* belonging to Fabaceae family. Cluster 2 also includes two species, namely, *Madhuca indica* and *Shorea robusta* belonging to Sapotaceae and Dipterocarpaceae family, respectively. Rest of the tree species have similar association and forms another Cluster 3. Cluster 3 includes 21 tree species belonging to 13 families (Anacardiaceae, Bixaceae, Combretaceae, Ebenaceae, Fabaceae, Lamiaceae, Moraceae, Myrtaceae, Meliaceae, Malvaceae, Rhamnaceae, Rutaceae and Sapindaceae).

Name of species	TNI	NQO	TQS	VEA	A	F	A:F	D	Basal area	IVI	H′
Acacia auriculiformis	779	33	50	25.00	23.61	66.00	0.36	15.58	3,690.50	36.85	0.353
Acacia catechu	80	30	75	37.50	2.67	40.00	0.07	1.07	521.33	6.99	0.099
Aegle marmelos	3	3	15	7.50	1.00	20.00	0.05	0.20	4.46	2.31	0.007
Albizia lebbeck	2	1	5	2.50	2.00	20.00	0.10	0.40	196.56	3.14	0.005
Anogeissus latifolia	9	5	20	10.00	1.80	25.00	0.07	0.45	188.46	3.69	0.018
Azadirachta indica	12	9	30	15.00	1.33	30.00	0.04	0.40	137.73	3.98	0.023
Bombax ceiba	10	4	15	7.50	2.50	26.67	0.09	0.67	139.93	3.97	0.019
Buchanania latifolia	54	6	15	7.50	9.00	40.00	0.23	3.60	301.55	9.37	0.074
Butea monosperma	347	29	45	22.50	11.97	64.44	0.19	7.71	4,993.43	31.17	0.253
Casiasiamea	6	2	10	5.00	3.00	20.00	0.15	0.60	38.85	2.90	0.013
Cochlospermum religiosum	27	8	20	10.00	3.38	40.00	0.08	1.35	194.69	6.33	0.043
Diospyros melanoxylon	45	17	25	12.50	2.65	68.00	0.04	1.80	152.18	9.62	0.064
Eucalyptus globulus	43	5	10	5.00	8.60	50.00	0.17	4.30	2,436.21	17.76	0.062
Ficus benghalensis	3	2	10	5.00	1.50	20.00	0.08	0.30	322.09	3.40	0.007
Ficus racemose	3	1	5	2.50	3.00	20.00	0.15	0.60	8.46	2.80	0.007
Madhuca indica	365	34	55	27.50	10.74	61.82	0.17	6.64	7,459.83	37.14	0.260
Mangifera indica	3	2	10	5.00	1.50	20.00	0.08	0.30	94.17	2.70	0.007
Schleichera oleosa	3	1	5	2.50	3.00	20.00	0.15	0.60	47.89	2.92	0.007
Semecarpusanacardium	23	4	15	7.50	5.75	26.67	0.22	1.53	51.02	4.74	0.038
Shorearobusta	775	36	50	25.00	21.53	72.00	0.30	15.50	9,752.37	55.88	0.352
Syzygium cumini	1	1	5	2.50	1.00	20.00	0.05	0.20	116.28	2.65	0.003
Tectona grandis	1	1	5	2.50	1.00	20.00	0.05	0.20	3.23	2.30	0.003
Terminalia arjuna	59	5	5	2.50	11.80	100.00	0.12	11.80	374.53	25.65	0.079
Terminalia tomentosa	197	19	30	15.00	10.37	63.33	0.16	6.57	1,505.01	19.02	0.182
Ziziphus mauritiana	5	2	10	5.00	2.50	20.00	0.13	0.50	13.00	2.70	0.011
Total	2,855	260	540	270.00	147.18	973.93	3.29	82.86	32,743.76	299.99	1.990

Table 2.
Phytosociological attributes at Bounsi range

Notes: TNI = total number of individuals, NQO = number of quadrat occurrence, TQS = total number of quadrat studied, VEA = vegetation enumeration area, A = abundance, F = frequency (%), A:F = abundance frequency ratio, D = density, BA = basal area (cm^2), IVI = importance value index

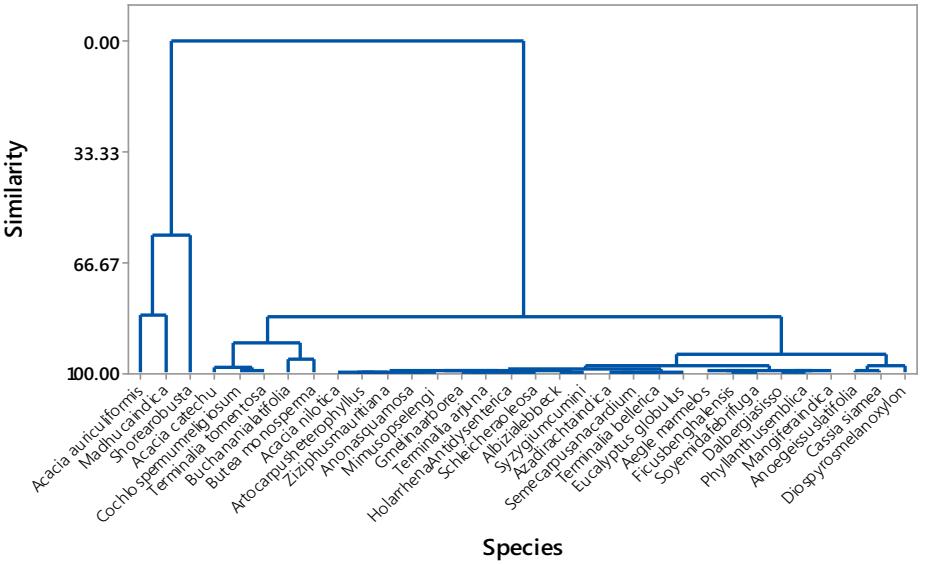

Figure 1.
Dendrogram showing clustering of species with respect to phytosociological data for similarity analysis at Banka range

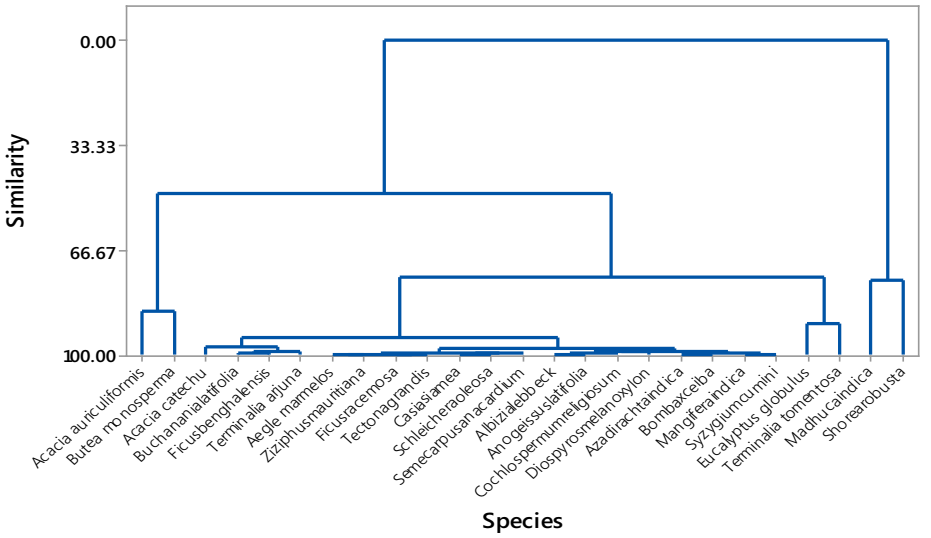

Figure 2.
Dendrogram showing clustering of species with respect to phytosociological data for similarity analysis at Bounsi range

3.2 Growing stock

As the forest is under successional stage and growing stock estimation reveals most of the trees (immature) fall under dbh class 0–10 cm, therefore total carbon stock estimation is determined for all dbh classes. The carbon stock estimation is limited to live tree biomass in our study. Height of trees in all dbh class ranges between 1.0–14 m and 1.5–15 m in Banka and Bounsi range, respectively. The total volume of all the trees enumerated is recorded as 59,140.40 and 71,306.37 cm^3 ha^{-1} in Banka and Bounsi range. Tree height and dbh is one of the major factors for contributing to large amount of stock volume. Although tree height for both the ranges are almost same, the number of trees above 10 cm dbh is more in Bounsi range (37%) than compared to Banka range (26 %). Tree density at Banka is higher than Bounsi but larger number of trees in higher dbh class has contributed to higher volume of growing stock at Bounsi range. In both the ranges, volume of *Shorea robusta* is higher than other species. At Banka range the top five tree species contribution to volume follows the pattern as *Shorea robusta* (9,520.00 cm^3 ha^{-1}) > *Madhuca indica* (9,001.56 cm^3/ha) > *Mangifera indica* (5,946.00 cm^3 ha^{-1}) > *Colchlospermum religiosum* (4,492.38 cm^3 ha^{-1}) > *Acacia auriculiformis* (4,199.68 cm^3 ha^{-1}). Similarly, at Bounsi range the pattern is *Eucalyptus globulus* (32,893.80 cm^3 ha^{-1}) > *Shorea robusta* (13,789.00 cm^3 ha^{-1}) > *Madhuca indica* (6,024.11 cm^3 ha^{-1}) > *Butea monosperma* (4,849.29 cm^3 ha^{-1}) > *Acacia auriculiformis* (2,584.16 cm^3 ha^{-1}) (Tables 3 and 4).

The pattern of AGB for top five tree species at Banka range is *Shorea robusta* > *Madhuca indica* > *Mangifera indica* > *Terminalia bellerica* > *Acacia auriculiformis*. AGB of all the tree species at Banka and Bounsi is 2,196.29257 and 75.312 kg ha^{-1}, respectively. Likewise, BGB is recorded as 15.008 and 17.698 kg ha^{-1}, respectively for Banka and Bounsi range, therefore total biomass of two ranges are 78.875 and 93.011 kg ha^{-1}, respectively.

Total C stock at Banka and Bounsi range is 39.44 and 46.51 kg ha^{-1}, respectively where highest C stock is recorded for *Shorea robusta* in both the ranges (Banka – 7.65 kg ha^{-1}; Bounsi – 9.40 kg ha^{-1}) (Tables 3 and 4). Depending upon the growing stock and C stock, clustering of tree species was done and dendrogram (Figures 3 and 4) shows three clusters in both the ranges, which are different from the pattern for phytosociology. It was recorded that in Banka range, *Madhuca indica* and *Shorea robusta* formed Cluster 1 (Sapotaceae and

Name of species	SG (g cm^{-3})	SV (cm^3 ha^{-1})	AGB (g ha^{-1})	BGB (g ha^{-1})	TB (g ha^{-1})	C (kg Cha^{-1})	CO_2 equivalent (kg CO_2 ha^{-1})
Acacia auriculiformis	0.600	4,199.68	3,968.69	932.64	4,901.34	2.45	8.99
Acacia catechu	0.875	857.25	1,181.40	277.63	1,459.03	0.73	2.68
Acacia nilotica	0.780	42.80	52.58	12.36	64.94	0.03	0.12
Aegle marmelos	0.845	748.64	996.35	234.14	1,230.49	0.62	2.26
Albizia lebbeck	0.953	314.16	471.55	110.81	582.36	0.29	1.07
Anoegeissus latifolia	0.828	2,006.97	2,617.29	615.06	3,232.35	1.62	5.93
Anona squamosa	0.619	234.80	228.91	53.79	282.71	0.14	0.52
Artocarpus heterophyllus	0.600	120.40	113.78	26.74	140.52	0.07	0.26
Azadirachtaindica	1.086	384.24	657.23	154.45	811.68	0.41	1.49
Buchananialatifolia	0.458	1,455.44	1,049.88	246.72	1,296.60	0.65	2.38
Butea monosperma	0.465	2,196.56	1,608.70	378.05	1,986.75	0.99	3.65
Cassia siamea	0.746	2,966.11	3,485.03	818.98	4,304.01	2.15	7.90
Cochlospermum religiosum	0.270	4,492.38	1,910.38	448.94	2,359.32	1.18	4.33
Dalbergia sisso	0.669	769.49	810.80	190.54	1,001.33	0.50	1.84
Diospyros melanoxylon	0.678	630.48	673.26	158.22	831.48	0.42	1.53
Eucalyptus globulus	0.676	735.84	783.45	184.11	967.56	0.48	1.78
Ficus benghalensis	0.494	86.56	67.35	15.83	83.17	0.04	0.15
Gmelinaarborea	0.432	166.51	113.30	26.62	139.92	0.07	0.26
Holarrhena antidysenterica	0.445	201.00	140.88	33.11	173.98	0.09	0.32
Madhuca indica	0.619	9,001.56	8,775.84	2062.32	10,838.17	5.42	19.89
Mangifera indica	0.750	5,945.75	7,023.42	1,650.50	8,673.92	4.34	15.92
Mimusops elengi	1.000	208.40	328.23	77.13	405.36	0.20	0.74
Phyllanthus emblica	0.619	847.42	826.17	194.15	1,020.32	0.51	1.87
Schleichera oleosa	1.010	145.95	232.17	54.56	286.73	0.14	0.53
Semecarpus anacardium	0.991	508.50	793.68	186.51	980.19	0.49	1.80
Shorea robusta	0.700	11,239.81	12,391.89	2,912.10	15,303.99	7.65	28.08
Soyemida febrifuga	0.650	1,187.24	1,215.44	285.63	1,501.06	0.75	2.75
Syzygium cumini	0.669	302.23	318.45	74.84	393.29	0.20	0.72
Terminalia arjuna	1.189	767.33	1,436.97	337.69	1,774.65	0.89	3.26
Terminalia bellerica	1.169	3,424.00	6,304.18	1,481.48	7,785.67	3.89	14.29
Terminalia tomentosa	0.694	2,824.49	3,087.31	725.52	3,812.82	1.91	7.00
Ziziphus mauritiana	1.000	128.40	202.23	47.52	249.75	0.12	0.46
Total	23.58	59,140.40	2,196,292.57	15,008.69	78,875.48	39.44	144.74

Table 3.
Carbon stock estimation at Banka range

Notes: SG – specific gravity (g cm^{-3}); V – volume (cm^3 ha^{-1}); ABG – above ground biomass (g ha^{-1}); BGB – below ground biomass (g ha^{-1}); TB – total biomass (g ha^{-1}); C – carbon stock (kgC ha^{-1}); CO_2 equivalent (kg CO_2/ha)

Dipterocarpaceae family, respectively) while *Mangifera indica* and *Terminalia bellerica* formed Cluster 2 (Anacardeaceae and Combretaceae family, respectively). Rest of the tree species have similar association and formed cluster 3 that includes 28 species belonging to 17 families (Anacardiaceae, Annonaceae, Apocyanaceae, Bixaceae, Combretacaea, Ebenaceae, Fabaceae, Lamiaceae, Meliaceae, Mimosaceae, Moraceae, Myrtaceae, Phyllanthaceae, Rhamnaceae, Rutaceae, Sapindaceae and Sapotaceae). Similarly, in Bounsi range, *Eycalyptus globulus* and *Shorea robusta* formed two clusters, namely, Clusters 1 and 2, respectively and rest of the tree species formed cluster 3 that includes 23 tree species and 14 families (Anacardiaceae, Bixaceae, Combretaceae, Ebenaceae, Fabaceae, Lamiaceae, Malvaceae, Meliaceae, Moraceae, Myrtaceae, Rhamnaceae, Rutaceae, Sapindaceae and Sapotaceae).

4. Discussions

4.1 Forest structure

Abundance: frequency ratio recorded for Banka and Bounsi are 0.187 and 0.151, respectively depicting cluster distribution of trees (Figures 1 and 2). Although IVI is highest for *Shorea*

Name of species	SG ($g\ cm^{-3}$)	SV ($cm^3\ ha^{-1}$)	AGB ($g\ ha^{-1}$)	BGB ($g\ ha^{-1}$)	TB ($g\ ha^{-1}$)	C ($kg\ Cha^{-1}$)	CO_2 equivalent ($kg\ CO_2\ ha^{-1}$)
Acacia auriculiformis	0.600	2,584.16	2,442.03	573.88	3,015.91	1.51	5.53
Acacia catechu	0.875	264.88	365.04	85.78	450.82	0.23	0.83
Aegle marmelos	0.845	5.87	7.81	1.83	9.64	0.00	0.02
Albizia lebbeck	0.953	627.20	941.41	221.23	1,162.64	0.58	2.13
Anogeissus latifolia	0.828	316.00	412.10	96.84	508.94	0.25	0.93
Azadirachta indica	1.086	182.07	311.42	73.18	384.60	0.19	0.71
Bombax ceiba	0.329	355.20	184.06	43.25	227.31	0.11	0.42
Buchanania latifolia	0.458	546.13	393.95	92.58	486.53	0.24	0.89
Butea monosperma	0.465	4,849.29	3,551.50	834.60	4,386.10	2.19	8.04
Casia siamea	0.746	227.80	267.65	62.90	330.55	0.17	0.61
Cochlospermum religiosum	0.270	422.20	179.54	42.19	221.73	0.11	0.41
Diospyros melanoxylon	0.678	83.60	89.27	20.98	110.25	0.06	0.20
Eucalyptus globulus	0.676	32,893.80	35,022.03	8,230.18	43,252.21	21.63	79.29
Ficus benghalensis	0.494	2,474.00	1,924.90	452.35	2,377.25	1.19	4.36
Ficus racemosa	0.619	33.60	32.76	7.70	40.46	0.02	0.07
Madhucaindica	0.619	6,024.11	5,873.05	1,380.17	7,253.22	3.63	13.30
Mangifera indica	0.750	311.40	367.84	86.44	454.28	0.23	0.83
Schleichera oleosa	1.010	267.20	425.05	99.89	524.93	0.26	0.96
Semecarpus anacardium	0.991	59.87	93.44	21.96	115.40	0.06	0.21
Shorea robusta	0.700	13,789.00	15,202.37	3,572.56	18,774.93	9.39	34.42
Syzygium cumini	0.669	1,000.00	1,053.68	247.61	1,301.29	0.65	2.39
Tectona grandis	0.577	14.00	12.72	2.99	15.71	0.01	0.03
Terminalia arjuna	1.189	2,298.80	4,304.91	1,011.65	5,316.56	2.66	9.75
Terminalia tomentosa	0.694	1,630.20	1,781.89	418.74	2,200.63	1.10	4.03
Ziziphus mauritiana	1.000	46.00	72.45	17.03	89.48	0.04	0.16
Total	18.12	71,306.37	75,312.86	17,698.52	93,011.38	46.51	170.50

Notes: SG – specific gravity ($g\ cm^{-3}$); V – volume ($cm^3\ ha^{-1}$); ABG - above ground biomass ($g\ ha^{-1}$); BGB – below ground biomass ($g\ ha^{-1}$); TB – total biomass ($g\ ha^{-1}$); C – carbon stock ($kg\ Cha^{-1}$); CO_2 equivalent ($kg\ CO_2$/ha)

Table 4. Carbon stock estimation at Bounsi range

robusta but the values are lower than the values recorded for Doon Valley at Western Himalaya (Gautam *et al.*, 2008; Mandal and Joshi, 2014) and other tropical forests (Ganguli *et al.*, 2016). The species diversity index value in our study is comparable to Eastern Ghats, which is much higher than the value in our study (Reddy *et al.*, 2008; Ganguli *et al.*, 2016) and consistent with studies made by Saklani *et al.* (2018).

Correlation between biomass and volume of growing stock depicts dependency of total biomass on growing stock volume (Banka: $R^2 = 0.9269$, Bounsi: $R^2 = 0.9943$) where dbh and height are the predictor for volume of tree individuals. Positive correlation was also observed between volume, biomass, basal area of tree species with carbon stock (Banka range: $R^2 = 0.9269$ for Volume-C stock; $R^2 = 1$ for total biomass-C stock and $R^2 = 0.647$ for basal area-C stock; and Bounsi range: $R^2 = 1$ for volume, biomass and basal area with C stock). However, sometimes specific gravity of trees also contributes to the biomass; therefore the pattern for total biomass differs from volume pattern of tree species at Banka range (specific gravity of *Cochlospermum religiosum* is $0.270\ g\ cm^{-3}$ that caused the lowering of AGB than *Acacia auriculiformis* and *Terminalia bellerica* at Banka range). Similar studies on biomass and C storage at Sathanur Reserve Forest of eastern ghats and Asola Bhatti Sanctuary in Northern Aravalli hills showed positive correlation between biomass and C storage where highest storage was contributed by *Albizia amara* and *Anogeissus pendula*, respectively (Kushwaha *et al.*, 2014; Salunkhe *et al.*, 2016; Jhariya, 2017). The C stock in our study shows lowered value, which is comparable to the values estimated

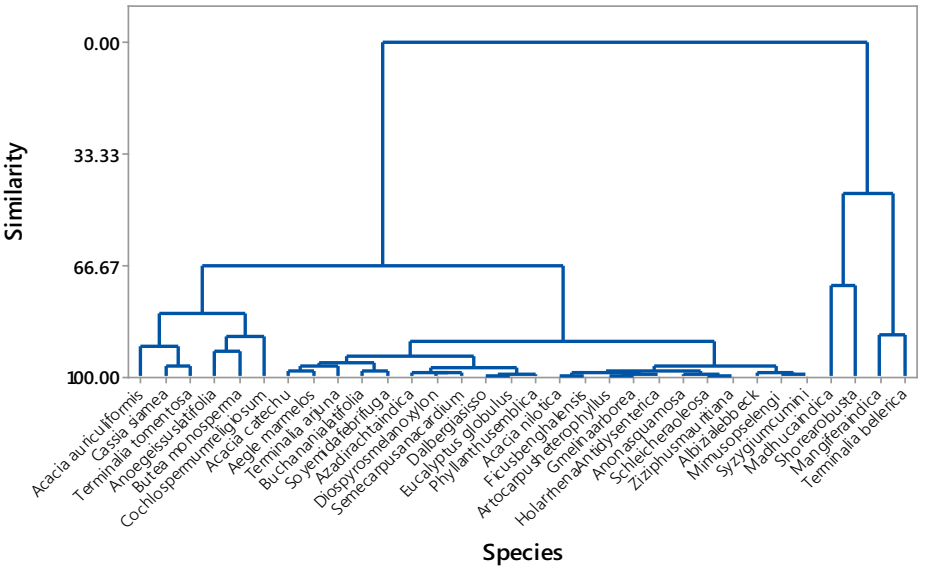

Figure 3.
Dendrogram showing clustering of tree species with respect to growing stock and C stock for similarity analysis at Banka range

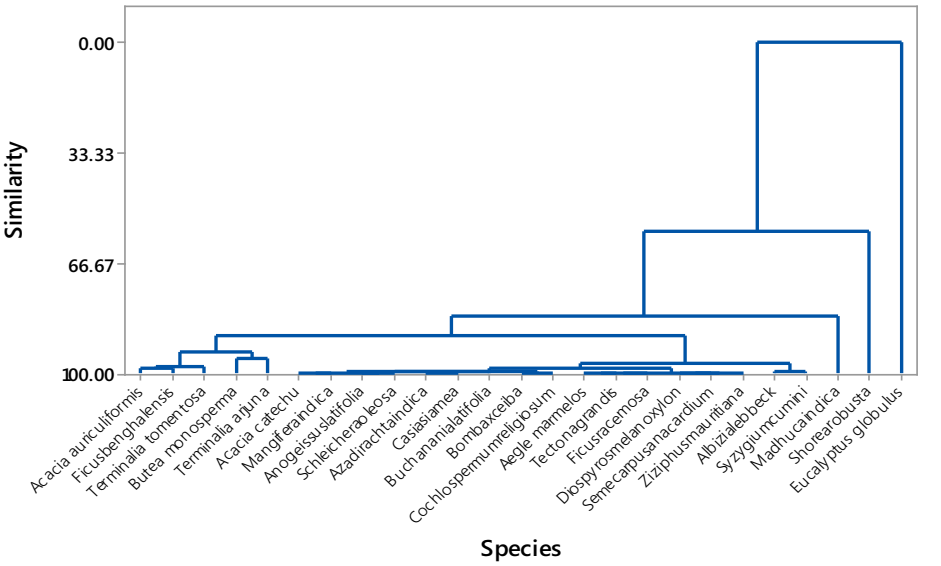

Figure 4.
Dendrogram showing clustering of tree species with respect to growing stock and C stock for similarity analysis at Bounsi range

at Garhwal Himalaya (Mahato *et al.*, 2016) and Manipur (Thokchom and Yadava, 2017) and Tripura (Banik *et al.*, 2018) while the values are similar to the C stock estimated for North East India (Singh *et al.*, 2016). Lowered biomass in our study is relatively due to presence of young trees having <10 cm dbh, small bole size and often anthropogenic disturbances such as lopping and grazing, prevailing in the area caused removal or lowering of biomass, which

is similar with study at tropical deciduous forest of Madhya Pradesh, India (Salunkhe *et al.*, 2016; Dar *et al.*, 2019). However, Prevalence of edaphic factors with poor soil depth and soil structure is also responsible for low above ground biomass.

4.2 Carbon sequestration potential

With respect to the C stock recorded for all the trees enumerated in Banka and Bounsi range have potential to sequester 144.74 kg CO_2 ha^{-1} (or 0.15 *t* CO_2 ha^{-1}) and 170.50 kg CO_2 ha^{-1} (or 0.17 *t* CO_2 ha^{-1}), respectively. Therefore, extrapolating the amount of C stock and CO_2 sequestered in the total forest area enumerated it is about 51.8 *t* ha^{-1} and 194.25 *t* CO_2 at Banka range and 12.56 *t* ha^{-1} and 45.9 *t* CO_2 at Bounsi, respectively. The amount of C sequestered is much lower than compared to other tropical forests of North Western Ghats (Mandal and Joshi, 2014; Patel *et al.*, 2015; Salunkhe *et al.*, 2016; Banik *et al.*, 2018; Dar *et al.*, 2019). Lowered amount is contributed by lowered C stock, which indeed depends upon dbh and volume, which acts as an important indicator for C stock in trees. However, the dominant tree species S*horea robusta* solely contributes to about 19% and 20% of total C stock of enumerated area at Banka and Bounsi forest range, respectively.

5. Conclusions

The study illustrates forest structure and pattern of distribution of trees in the area, which also determines the biomass and carbon stock pattern in the study area. From the survey, it is evident that most of the forest area is degraded and many of the area are restored through plantation and afforestation programs. Coppice Sal (*Shorea robusta*) is noticed in most of the forest area under two ranges and the forest undergoes its secondary successional stage supports the restoration of forests through afforestation. However, the prevalence of high biotic pressure in different pockets of the study area accompanied with edaphic factors causes reduced survival rate of recruited plants in terms of recruitment, growth and establishment. Lowered growing stock volume accompanied by lowered biomass is subjected to decreased C stock value compared to other forests of tropics, which is due to the presence of maximum trees under dbh class <10 cm. However, the valuation of these forests (area enumerated only) in terms of C sequestration (for present year of C stock estimation) applying international price @ US$13 t^{-1} CO_2 is estimated as US$2,525.25 and US$596.70 for Banka and Bounsi range, respectively. Therefore, these forests have potential to act as carbon sink but proper management and protection is required for young trees along with habitat restoration and biodiversity conservation of the entire forest ranges.

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