EVALUATION OF THE FOREST STRUCTURE, DIVERSITY AND BIOMASS CARBON POTENTIAL IN THE SOUTHWEST REGION OF GUANGXI, CHINA

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Abstract. Evaluation and monitoring of forest structure, diversity, and biomass carbon dynamics are essential for effective forest biodiversity and carbon conservation. Using inventory data of 174 field plots with a size of 400 m^2, this study estimated the forest structure, species diversity, growing stock characteristics and biomass carbon of the South West Region of Guangxi Zhuang Autonomous Region of China. Our results showed that a total of 198 species belonging to 51 families, and 128 genera were found. The results of different diversity indices showed a greater species variation across the forest. Furthermore, different tree attributes were recorded for forest structure. In this regard, the mean tree height was 10.3 m, while the mean basal area was 5.94 $m^2\ ha^{-1}$. The mean growing stock volume was 104.14 $m^3 ha^{-1}$, and the average biomass carbon was 110.36 Mg ha^{-1}. Among the dominant species, the maximum importance value index (14.81%) and basal area (17.3 ± 3.03 $m^2\ ha^{-1}$) were recorded for *Pinus massoniana*. While the maximum growing stock volume (116.4 ± 20.2 $m^3\ ha^{-1}$) and biomass carbon (114 ± 18.3 Mg ha^{-1}) were found in the *Styrax subniveus*. Our results also highlighted that the basal area is a strong predictor of growing stock volume and biomass carbon compared to diameter and height. Moreover, the correlation between biomass carbon and diversity indices indicated a weak positive correlation, which provided the insight that high-value carbon- diversity forest can be achieved.

Keywords: *forest structure, biomass carbon, Tree diversity and density, carbon sequestration, carbon-diversity relation, Guangxi region*

Introduction

Forests are the largest contributors to territorial ecosystems on Earth and play a significant role in providing economic benefits as well as ecological services (Eckert, 2012; Meng et al., 2014). Forests are integral components of the global carbon cycle that take up and release a substantial amount of carbon (Wang et al., 2018). The regulation of atmospheric carbon concentration through forest carbon stock has been identified as a major political target to mitigate global climate change (Grassi et al., 2017). Forest ecosystems play an important role in the global carbon cycle (Li et al., 2017). While the estimation of carbon from forests brings an important understanding of global warming (Sierra et al., 2007). Globally, forests particularly tropical and sub-tropical forests are the center of biodiversity and carbon storage (Sullivan et al., 2017). About 60% of terrestrial

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photosynthesis takes place in the tropical forest (Field et al., 1998; Liu et al., 2015). This region has been recognized as a significant hotspot for global carbon source and sink and biodiversity (Bazzaz, 1998).

Over the past two decades, there has been a strong emphasis on the role of biodiversity in ecosystem properties, processes, and services to enhance carbon sequestration and storage (Naeem et al., 2009). Climate change and habitat loss are the two major components for the loss of global biodiversity (Thomas et al., 2013). Similarly, changes in the land use of forests are leading to emission sources of carbon (Matthews et al., 2014). Therefore, different incentives such as United Nation (UN) REDD + have emerged for the protection and conservation of high carbon and diversity areas (Robbins, 2016). The protection of forests for carbon and biodiversity depends on the relationship between biomass carbon and tree diversity. The positive relationship between biomass carbon and tree diversity would indicate synergies whereas a negative relationship would indicate difficult tradeoffs (Meng et al., 2014). However, in case of the absence of any relationship, the optimal solutions are required towards an understanding of the distribution of biomass carbon and biodiversity (Thomas et al., 2013).

The forest structure determines the functions of a forest; therefore, forest structure provides the fundamental bases for the formulation of forest management regime aimed at specific objectives (Warfield, 2006). Forests structural attributes such as stem density, growing stock volume, stand basal area, diameter, and tree height are the important variables for the management of forests (Meng et al., 2016). In addition, forest structural diversity, i.e., species diversity, tree size diversity, and position diversity, is more important to inform forest management (Corona, 2016). A notable example is structured-based forest management. Additionally, many authors documented the positive relationship between carbon sequestration and structural diversity (Noumi et al., 2018). Therefore, quick acquisition of forest structural variables, structural diversity indices, and forest carbon stocking is urgent for sustainable forest management.

The methods used to derive forest attributes include the conventional method and remote sensing method. National or regional forest field inventories data are also used for the measurement of different forest stand variables. In China, there are three major types of forest inventories including the national forest inventory, the forest management planning inventory, and the forest design operational inventory, which are used to derive such precedent forest attributes (Lei et al., 2009). However, regardless of the type of forest inventories, it is labour-cost, time-consuming and expensive.

In China, the researchers mainly focused on the measurement of carbon stock in different forest types (Dixon et al., 1994; Fang et al., 2007; Zhang et al., 2013). Similarly, forest structure and structural diversity have been documented by various authors (Meng et al., 2016). However, there is a lack of integrated information regarding the forest structure, species composition and diversity, and carbon dynamics. Therefore, the objective of our study is first to derive the forest attributes, including forest variables and forest structural diversity indices based on conventional forest inventory plots, mainly focused to answer the following questions: (1) what is the forest structure and the species diversity?; (2) how the carbon is distributed among the different diameter classes, among the tree height, mean diameter and basal area, and which attribute shaped the biomass carbon strongly; (4) what is the relationship of species diversity and biomass carbon?; (5) what is the status of structural attributes and biomass carbon potential of dominant tree species?

Materials and methods

Study area

The field statistics were obtained from the Experimental Center for Subtropical Forestry of the Chinese Academy of Forestry of Southwest of the Guangxi Zhuang Autonomous Region of China. The study site is the tropical research center situated in Pingxiang City (Píngxiáng Shì). The latitude and longitude extend from 21°57′ N to the 22°16′ N, 106°41′ E to 109°59′ E, respectively (*Fig. 1*). The area lies in the southern subtropical warm and semi-humid monsoon climate that is characterized by dry and wet season with a total mean annual precipitation ranging from 1200 to 1500 mm and annual evaporation is 1261-1388 mm. The relative humidity is 80-84%, with an average annual air temperature of about 20.5-21.7 °C, and ranges from minimum to maximum about 13 to 28 °C. The landscape is characterized by low mountain elevation ranging from 250-800 m and a slope range from 25 to 30%. The dominant parent rocks are granite, purple sand shale, and sandstone. The soil for the forest is developed by granite bricks and mostly red and purple in color (Kang et al., 2006; Meng et al., 2014; Ming et al., 2014). The natural vegetation includes the subtropical forest with a mixture of evergreen and deciduous species (Bruelheide et al., 2011). This region is rich in species diversity and the area is generally mixed but the dominant species of the forest vegetation are *Cunninghamia lanceolata*, *Magnoliaceae glanca, Illicium verum, Pinus massoniana, Betula alnoides, Castanopsis hystrix,* and *Quercus griffithii, Erythrophleum fordii*, *Castanopsis hystrix,* which are hardwood and have high economic value for timber (Lu et al., 1999; Bruelheide et al., 2011; Tang et al., 2012; Zhu et al., 2013).

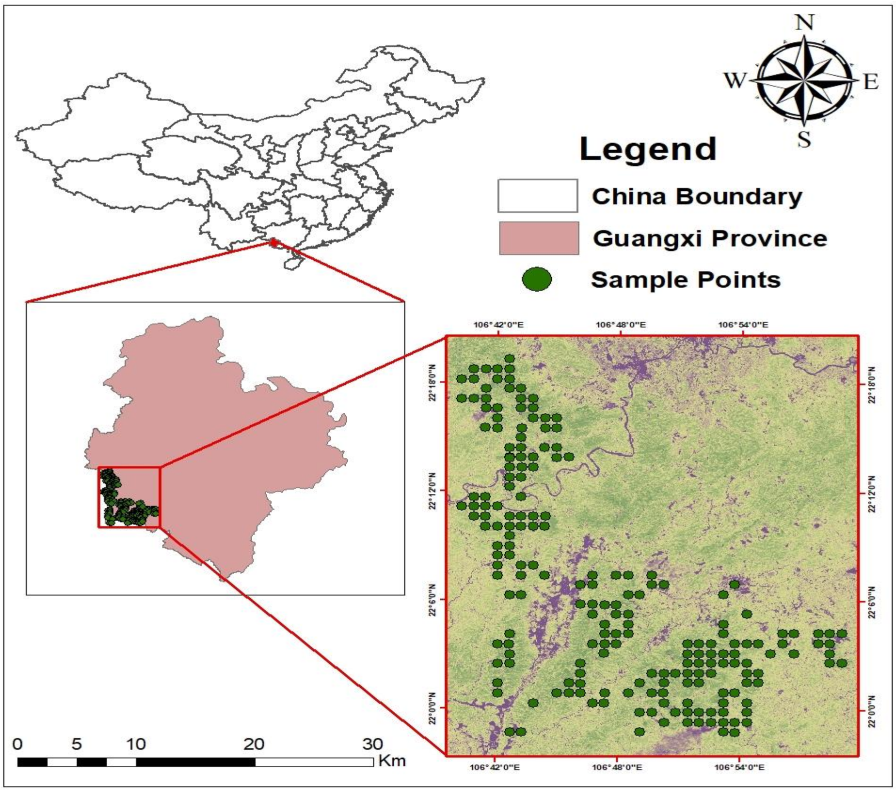

Figure 1. *Overview of the study area, the RapidEye satellite image in which the green circles represent the forest plots*

Research design and field inventory

For data collection, overall 174 sample plots were laid out in the forest. The size of each sample plot was 400 m^2. In each sample plot, the distance and bearing of each sample plot center were measured with each stem that was located within the radius of the circular plot, and each species was counted. The plant species were identified and their diameter at breast height (1.3 m from the above-ground) was recorded. On the basis of the size of the diameter, the classification was made. The values of stem density and relative stem density, basal area, and relative basal area and importance value index (IVI) were calculated for dominant plant species. The species diversity indices and height of the trees at the plot level were measured. From the height (m) and diameter (cm), the volume (m^3 ha^{-1}) of the tree was measured. The volume was converted into biomass (Mg ha^{-1}). From the biomass value, the carbon content was estimated using the Intergovernmental Panel on Climate Change IPCC (2007) (Change, 2007; Keenan et al., 2015) guidelines. Biomass was then summed across all the plots to obtain carbon stock (Mg ha^{-1}).

Data analysis

Based on the collected information at the plot level, the data was analyzed for the various structural attributes such as diameter, basal area, and density. The relative stem density, basal area, relative basal area, and the importance value index (IVI) were assessed using *Equations 1-3*.

$$\text{Relative density (RD)} = \frac{\text{Number of particular species}}{\text{Number of all species}} \times 100 \qquad \text{(Eq.1)}$$

$$\text{Relative basal area (RB)} = \frac{\text{Basal area of a particular species}}{\text{Basal area of all species}} \times 100 \qquad \text{(Eq.2)}$$

$$\text{Importance valur index (IVI)} = \frac{\text{RD} + \text{RB}}{2} \times 100 \qquad \text{(Eq.3)}$$

In order to compute the data for the description of the diversity, different community indices such as Shannon Wiener Diversity Index (SHI), Pielou Diversity Index (PI), and Simpson Diversity Index (SII) were used through *Equations 4-7*. (Magurran, 2013; Naidu and Kumar, 2016).

$$\text{SHI} = -\sum_{i=1}^{n} pi \cdot \ln(pi) \qquad \text{(Eq.4)}$$

$$\text{PI} = \frac{\text{SHI}}{\ln\text{ (S)}} \qquad \text{(Eq.5)}$$

where SHI is the Shannon Wiener Diversity Index and S is the total number of species across all samples in a dataset.

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$$\mathrm{SII} = 1 - \sum_{i=1}^{n} pi^2 \qquad \text{(Eq.6)}$$

Statistical Gini coefficient (GC) is one of the components of forest structure used for the distribution of tree diameter in a forest by the indicator of tree size variation (McElhinny et al., 2005). This was measured using *Equation 7:*

$$\mathrm{GC} = \sum_{t=1}^{n} (2t - n - 1)\mathrm{bat} / \sum_{t=1}^{n} ba(n-1) \qquad \text{(Eq.7)}$$

where *ba* is a basal area for the tree in rink *t* ($m^2\ ha^{-1}$), t is the rink from 1 to n number. Gini coefficient ranged from 0 to 1.

For biomass carbon estimation, we first calculated the volume of the tree (*Eq. 8*) then the volume was converted into biomass using the available regression models to estimate plant biomass (*Table 1*) (Wang et al., 2015; Du et al., 2015) The biomass was converted into carbon stock in the upper story vegetation using a conversion factor of 0.5 which indicates 50% of total plant biomass is equal to carbon stock (*Eq. 9*), this conversion factor has been used worldwide (Ahmad et al., 2019; Brown and Lugo, 1982; Xiao et al., 2003; Ahmad and Nizami, 2015).

$$Volume\ of\ tree = A \times H \times FF \qquad \text{(Eq.8)}$$

$$\text{Biomass carbon} = \text{Total biomass} * 0.5 \qquad \text{(Eq.9)}$$

***Table 1.** Allometric regression models used to estimate biomass*

S. No	Species	Model
1	Eucalyptus	$W_T = 0.138D^{2.436}$
2	Quercus	$W_T = 0.174D^{2.39}$
3	Hardwood	$W_T = 0.186D^{2.377}$
4	Softwood	$W_T = 0.104D^{2.53}$

W is the dry weight of different components while T shows the total dry weight of leaf, stem, branches, and roots

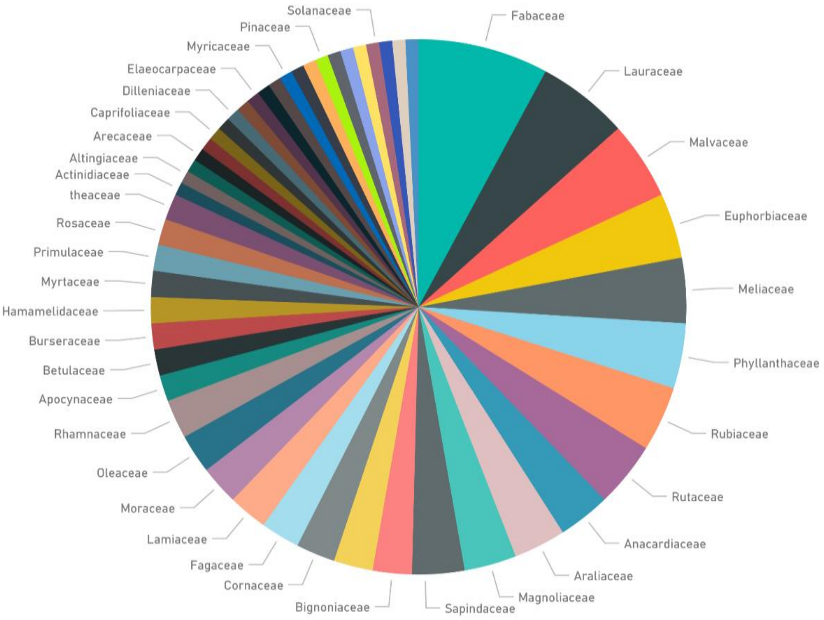
Statistical analysis

R package vegan was used for the calculation of the diversity indices (Team, 2013; Muneer et al., 2019) The variation in tree diameter, tree height, stem density, basal area, and biomass and carbon stock in the respective diameter classes (class-1 (5-11 cm), class-2 (12-16 cm), class-3 (17-28)) were determined by analysis of variance (ANOVA) using Statistix 8, version 8.1). Regression models were developed to study the relationship of tree height, diameter, and basal area with volume and biomass carbon by using Origin 2018. The correlation between respective diversity indices and biomass carbon was carried out using different correlation analyses such as the linear regression, Pearson correlation, and Spearman rank correlation.

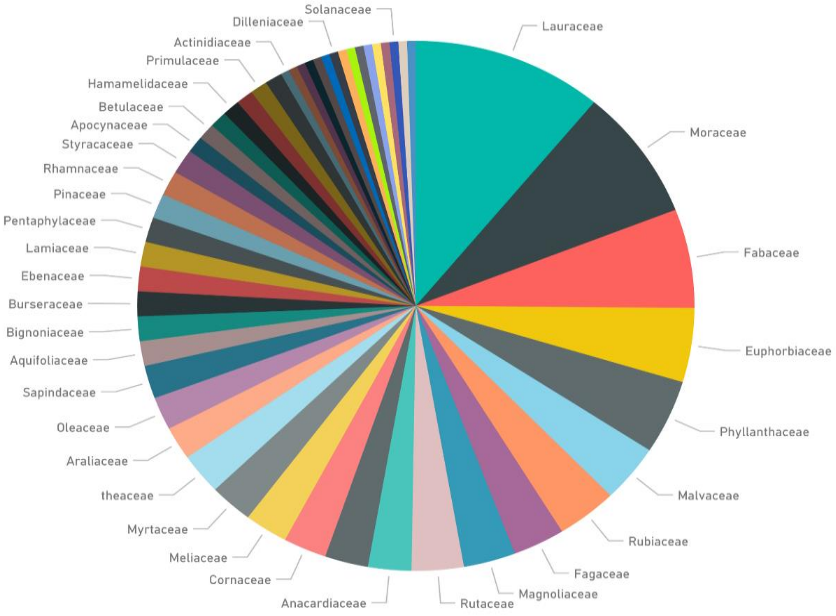
Results

Forest structure and species diversity

The results of the present study revealed that in this region 128 genera (*Fig. 2a*) and 198 species (*Fig. 2b*) belonging to 51 families were found. Among the 51 plant families, the highest number of genera i.e., 10, 7, 6, and 5 were found in *Fabaceae*, *Lauraceae*, *Malvaceae*, and *Rubiaceae* respectively. While the highest number of species were found in family Lauraceae, Moraceae and Fabaceae about 22, 16, and 12 respectively. Family Phyl*lanthaceae* and *Euphorbiaceae* each consisting of 5 genera and 9 species. In contrast, 16 families consisting of single genus and species.



(a) No. of the genus in respective families



(b) No. of species in respective families

Figure 2. *The relative contribution of the number of genera (a); and number of species (b) belonging to their respective families*

Regarding the species diversity at the plot level, it showed that SHI varied between 0 to 2.67 with a mean value of 1.034, while the SII varied between 0 and 1 with a mean value of 0.478. The PI value was found at the range of 0 and 1 with a mean value of 0.582 and the GC was in the range of 0 and 1 with a mean of 0.384 (*Fig. 3*). For more detail see *Appendix* (*Table A1*).

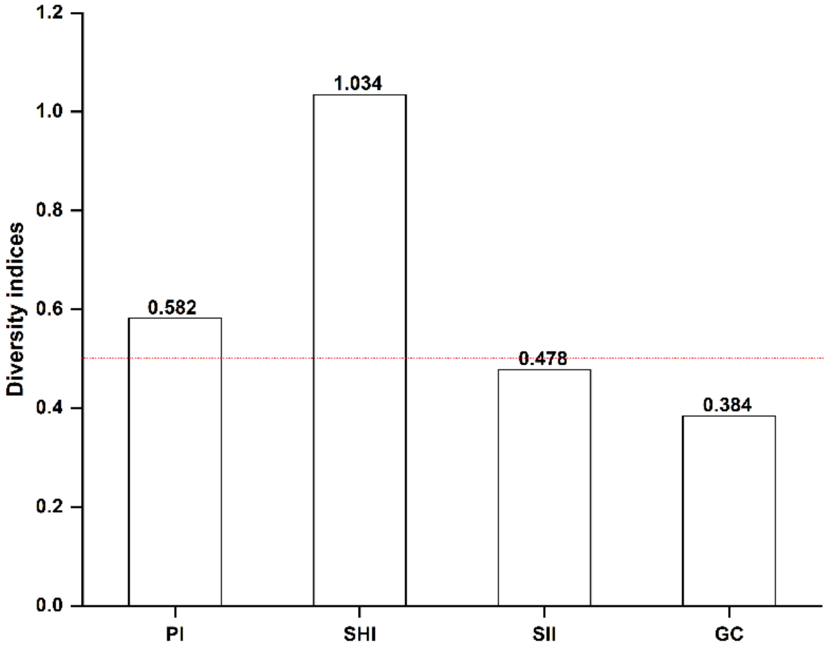


Figure 3. *Diversity indices for all sampling plots*

Growing stock characteristic and biomass carbon

This study revealed that in the tropical forest of Pingxing city, the average diameter varied significantly between the different diameter classes. The highest mean diameter was recorded in class-3, while the lowest was found in class-1. The significant higher value for the height was found for class-3 and the lowest was recorded in class-1. The average mean height was 10.3 ± 3.0 m. Mean density varied between 592.13 ± 280.24 to 955.70 ± 538.66 (trees ha^{-1}). A statistically lower stem density was recorded in the diameter class-1 compared to class-2 and class-3. While, the value of the basal area, stem volume, total tree biomass, and biomass carbon were recorded significantly higher in the class-3, while these were significantly lower in class-1 (*Table 2*).

Table 2. *Growing stock characteristics and biomass carbon of the forest in different diameter classes*

Diameter class (cm)	**Mean diameter (cm)**	**Height (m)**	**Density (ha^{-1})**	**Basal area (m^2 ha^{-1})**	**Volume (m^3 ha^{-1})**	**Biomass (Mg ha^{-1})**	**Carbon stock (Mg ha^{-1})**
Class-1	9.63±0.21c	7.77±0.22c	592±280.2b	8.84±0.75c	43.55±3.90c	51.54±4.50c	25.77±2.27c
Class-2	14.30±0.17b	10.35±0.22b	888.7±378.6a	17.81±0.96b	114.21±7.39b	119.27±7.24b	59.63±3.62b
Class-3	19.95±0.40a	13.06±0.40a	955.7±538.6a	21.19±1.37a	154.68±11.71a	160.27±12a	80.13±6a
Mean	14.62±2.98	10.3±1.52	812.17±111.75	15.94±3.68	104.14±32.47	110.36±31.70	55.17±15.84

The regression relationship of the basal area, diameter, and height with the volume and biomass carbon is presented in *Table 3* and *Figure 4*. The results of the analysis revealed that the basal area had a highly positive correlation with volume and biomass carbon. In contrast, a weak correlation was observed for diameter with volume and biomass carbon. Furthermore, the correlation of height with volume and biomass carbon was also found weak. These findings clearly explained that the basal area is the best predictor of growing stock and biomass carbon compared to stem diameter and tree height.

The relationship between diversity indices and biomass carbon is given in *Table 4*. It showed the positive but very weak correlation for all indices i.e., Pearson correlation, linear regression, and Spearman rank correlation.

Table 3. *Regression analysis between the basal area with volume and biomass carbon, diameter with volume, and biomass carbon and height with volume and biomass carbon*

	Relationship type	Equation	R^2	y0	A	P
Basal area vs volume	f = y0 + a*x	V = y0 + a*x	0.92	-91.91	7.75	< 0.0001
Basal area vs biomass carbon	f = y0 + a*x	BMC = y0 + a*x	0.91	-6.88	3.87b	< 0.0001
Diameter vs volume	f = y0 + a*x	BMC = y0 + a*x	0.40	-48.06	10.45	< 0.0001
Diameter vs biomass carbon	f = y0 + a*x	V = y0 + a*x	0.38	-40.49	10.35	< 0.0001
Height vs volume	f = y0 + a*x	V = y0 + a*x	0.50	-48.06	10.45	< 0.0001
Height vs biomass carbon	f = y0 + a*x	BMC = y0 + a*x	0.36	-40.49	10.35	< 0.0001

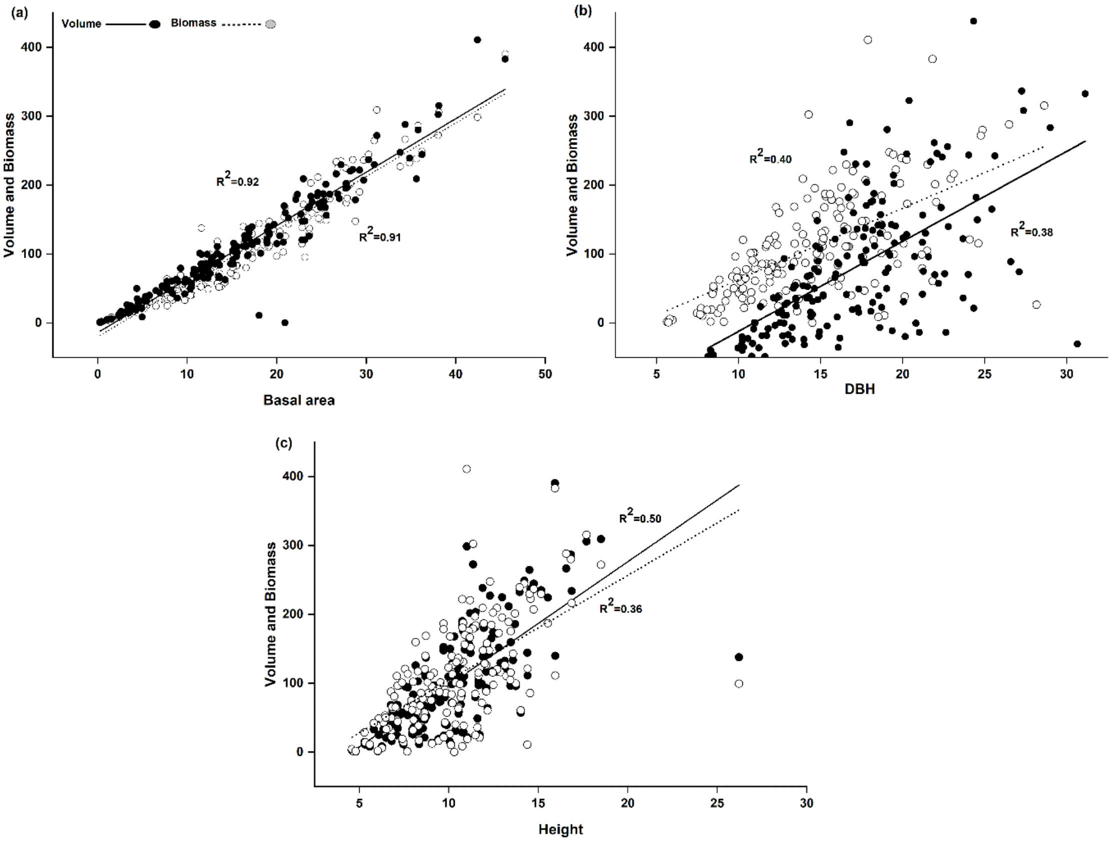


Figure 4. *Forest attributes showing the correlation between; (a) volume and biomass with basal area; (b) volume and biomass with DBH; (c) volume and biomass with height*

Table 4. *Relationship between diversity indices and biomass carbon*

Diversity indices	Pearson correlation		Linear regression (R^2)		Spearman rank correlation	
	PV	P	R^2	P	SRV	P
SII	0.14	0.0624	0.020	0.062	0.136	0.073
SHI	0.15	0.039	0.024	0.039	0.191	0.0.011
PI	0.102	0.0179	0.01	0.0150	-0.001	0.011
GC	0.29	0.000	0.088	0.000	0.299	0.000
MDI	0.17	0.0242	0.029	0.0242	0.163	0.0316

SII (Simpson Diversity Index), SHI (Shannon Wiener Diversity Index), PI (Pielou Diversity Index), GC (Gini coefficient)

Structural attributes, growing stock and biomass carbon of the dominant species

The results of various structural attributes, like stem density, basal area, relative stem density, relative basal area and importance value index (IVI) for individual dominant tree species (12) are given in *Table 5*. The results revealed that among the different dominant species, the highest stem density, basal area, relative stem density, relative basal area, and importance value index (IVI) were recorded for *Pinus massoniana.* Regarding growing stock characteristics, its maximum mean diameter was found for *Illicium verum* followed by *Styrax subniveus*, while the mean height was found the highest for *Styrax subniveus*, *Illicium verum.* The maximum growing stock volume and biomass carbon was observed for *Pinus massoniana* followed by *Manglietia hainanensis* (*Table 6*).

The results of the percentage distribution of different growing stock characteristics that include diameter, height, density, basal area, volume, and biomass carbon are given in *Table 7*. The results depicted that *Illicium verum* share a maximum percentage for diameter, while the highest percentage value for height was recorded for *Styrax subniveus*, for stem density, basal area, and biomass shared highest percentage value by *Pinus massoniana,* similarly, for volume the maximum percentage value was recorded for *Styrax subniveus*.

Table 5. *Structural attributes of the dominant species*

Species	Stem density ha^{-1}	Basal area m^2 ha^{-1}	Relative stem density	Relative basal area	IVI %
Illicium verum	266.25 ± 35.69	6.2 ± 1.09	8.82	5.36	7.09
Pinus massoniana	442.37 ± 31.9	17.3 ± 3.03	14.66	14.95	14.81
Cunninghamia lanceolata	291.39 ± 58.4	7.13 ± 1.67	9.66	6.16	7.91
Saurauia tristyla	265.6 ± 63.9	6.8 ± 0.87	8.80	5.94	7.37
Manglietia hainanensis	262.5 ± 151.5	11.8 ± 8.4	8.70	10.23	9.47
Styrax subniveus	233.3 ± 10.5	13.6 ± 1.8	7.73	11.82	9.77
Liquidambar formosana	129 ± 12.9	5.2 ± 0.77	4.27	4.51	4.39
Acacia confusa	253.57 ± 89.7	11.5 ± 5.7	8.40	9.03	8.71
Castanopsishystrix	277.2 ± 49.7	7.7 ± 1.88	9.19	6.66	7.92
Cyclobalanopsismyrsinifa	216.66 ± 30	10.77 ± 5.47	7.18	9.29	8.24
Quercus griffithii	205 ± 40.62	8 ± 3.93	6.79	6.96	6.88
Schima superb	175 ± 42	10.53 ± 3.9	5.80	9.09	7.44

Table 6. *Growing stock characteristics and biomass carbon of dominant tree species*

Species	Mean diameter (cm)	Height (m)	Volume (m^3 ha^{-1})	Biomass (Mg ha^{-1})	Carbon stock (Mg ha^{-1})
Illicium verum	31.85 ± 15	16.9 ± 8.2	31.3 ± 6.3	47 ± 8.8	23.5 ± 4.4
Pinus massoniana	21.7 ± 0.6	13.5 ± 0.9	99.6 ± 7	106.5 ± 6.8	53.2 ± 3.4
Cunninghamia lanceolata	13.21 ± 0.92	9.6 ± 0.53	50.2 ± 12.6	52.4 ± 13.3	26.2 ± 11.6
Saurauia tristyla	18.2 ± 2.15	10.4 ± 1.37	44 ± 7.5	53.4 ± 8	26.7 ± 4
Manglietia hainanensis	17.19 ± 4.7	12.36 ± 2.8	96 ± 36.1	96 ± 80.3	48 ± 40.1
Styrax subniveus	25.34 ± 2	17.1 ± 1.5	116.4 ± 20.2	114 ± 18.3	57 ± 9.1
Liquidambar formosana	20.9 ± 1.6	12.1 ± 0.5	35.8 ± 5.8	43.2 ± 7.3	21.6 ± 0.7
Acacia confusa	17.8 ± 2.34	11.8 ± 0.8	77.5 ± 38.6	69.8 ± 13.6	34.9 ± 6.8
Castanopsis hystrix	17.4 ± 0.98	12.8 ± 0.6	55.9 ± 14.4	56.4 ± 14.1	28.2 ± 7
Cyclobalanopsismyrsinifa	22.11 ± 4.73	14.80 ± 2.24	86.53 ± 48.11	87.47 ± 48.45	43.73 ± 24.22
Quercus griffithii	18.63 ± 3.11	12 ± 1.76	60.13 ± 34.24	63.66 ± 33.49	31.83 ± 16.74
Schima superba	23.75 ± 2.03	14 ± 1.4	78.1 ± 26.5	94.9 ± 41.2	47.4 ± 20.6

Table 7. *Percentage contribution in growing stock characteristics and biomass carbon of the dominant tree species*

Species	DBH	Height	Density	Basal area	Volume	Biomass	Carbon stock
Illicium verum	12.80	10.71	8.82	5.36	3.80	5.31	5.31
Pinus massoniana	8.73	8.56	14.66	14.95	12.08	12.03	12.03
Cunninghamia lanceolata	5.31	6.12	9.66	6.16	6.09	5.92	5.92
Saurauia tristyla	7.32	6.63	8.80	5.94	5.34	6.04	6.04
Manglietia hainanensis	6.91	7.81	8.70	10.23	11.63	10.86	10.86
Styrax subniveus	10.19	10.82	7.73	11.82	14.11	12.88	12.88
Liquidambar formosana	8.41	7.70	4.27	4.51	4.35	4.88	4.88
Acacia confusa	7.39	7.65	8.40	9.03	8.56	7.89	7.89
Castanopsis hystrix	7.01	8.13	9.19	6.66	6.79	6.38	6.38
Cyclobalanopsismyrsinifa	8.89	9.36	7.18	9.29	10.48	9.88	9.88
Quercus griffithii	7.49	7.62	6.79	6.96	7.29	7.19	7.19
Schima superba	9.55	8.90	5.80	9.09	9.47	10.73	10.73

Discussion

The tropical forest that covers only 7-10% of the earth's land surface, is the hotspot for carbon storage and biodiversity (Bonan, 2008). and stores a significant part of global carbon and biodiversity (Poorter et al., 2015) In this study, we examined different structural attributes, species diversity and biomass carbon of the tropical forest in Guangxi Zhuang Autonomous Region of China. Our results reported a total of 198 species belonging to 51 families. Among the different families, family *Lauraceae* was the richest family with respect to the number of species followed by family *Moraceae* and *Phyllanthaceae*. The mean values of different diversity indices (*Fig. 2*) showed a greater variation in species across the forest. Similarly, at the plot level, the variation in the values of diversity indices pinpoints the diverse nature of the forest. The results of a number of species in this study are consistent with the results of the Dinghushan tropical forests of China (Ostertag et al., 2014). In comparison, our results fall in the acceptable range of species numbers (192-240) and families (46-50) reported from the tropical forest in different regions of Colombia, Sri Lanka and Thailand. However, our results represent a higher number of species and families with respect to the tropical forest of different region of Taiwan, Puerto Rico, Brazil, India, and USA, while a lower species and family numbers with respect to the tropical forest in different regions of Malaysia, Ecuador, Thailand, Cameroon, and the Republic of Cango (Ostertag et al., 2014). The average stem density in this study area varies from 50 to 2525 with a mean value of 812.17 ± 111.75, this value of stem density is greater from the reported value of the tropical forest of Mudumalai, India, but lower from the reported values across the tropical forest. The mean basal area (15.94 m^2 ha^{-1}) and biomass carbon (110.36 ± 31.70) of this study fall in the range of mean basal area and biomass carbon across the regions as reported in the previous study (Ostertag et al., 2014).

Stock is a key parameter for forest management as well in measuring biomass carbon of forest (Ahmad et al., 2019; Somogyi et al., 2008). Globally, national forestry inventories data are used for assessing forest growth. The FAO used national forest inventory data for global forestry statistics (FAO, 2010). In measuring forest growing stock and biomass carbon, tree height and diameter are the key components. Most of the volume tables are based on the height and diameter of a tree (Ahmad et al., 2019). But these tables represent the individual tree measurement. However, individual tree measurement is a time-consuming process that needs more financial and physical efforts. Therefore, there is a need for direct measurement of growing stock volume and biomass carbon. In this study, we test the scope of the tree height, diameter and basal area for the direct measurement of a tree growing stock volume and biomass carbon. The results that whether tree height, tree diameter, and basal area are in the best predictor of growing stock volume (GSV) and biomass carbon are presented in *Table 3*. The results in the table showed a strong positive correlation with the growing stock volume and biomass carbon with a coefficient of determination (R^2) value of 92 and 91, respectively. In the case of diameter, growing stock and biomass carbon relationship, there is a positive correlation, but the value of R^2 (0.40 and 0.38) represents a weak relationship compared to the basal area (*Fig. 3*) Similarly, height based growing stock volume and biomass carbon relationship also revealed a positive correlation, but not as strong as basal area based. These results clearly suggest that the basal area is the best predictor of growing stock volume and biomass carbon. Basal area is widely used in assessing forest growing stock and biomass carbon in the tropical wet and dry forest (Balderas Torres and Lovett, 2012).

Globally conservation measurements are emerging for forest biodiversity conservation with carbon management. The UN REED + policy helping in the establishment of safeguard areas with a high carbon stock and storage potential (Robbins, 2016). The potential of these safeguards areas for biodiversity and carbon conservation depends on the relationships between carbon and species diversity (Robbins, 2016). A positive correlation of species diversity indicates a potential interaction, while a negative would indicate “difficult trade-offs” (Gardner et al., 2012). Furthermore, the absence of any relationship would suggest different solutions for the establishment of safeguards areas (Thomas et al., 2013). Our present findings contrast with the reported positive diversity-biomass relationship (Cavanaugh et al., 2014). That tropical forests are positively but weekly correlated with species diversity in Asia. This presence of a weekly positive relationship indicates the driving mechanisms of diversity-carbon relationships are scale-dependent or could be due to the environmental variations acting at a larger scale (Chisholm et al., 2013).

Conclusion

Assessing forest structural attributes, species diversity, growing stock characteristics, and biomass carbon is fundamental for effective forest carbon and biodiversity management. The results of the analysis of 174 field plots showed that the forest in the Guangxi region of China showed great variation in species diversity. The finding indicates that the forest vegetation had a large carbon mitigation potential. The basal area based growing stock and biomass carbon relationships highlighted that basal area is the best predictor for growing stock volume and biomass carbon compared to tree height and diameter. Thus, we suggest the use of the basal area for direct measurement of growing stock volume and biomass carbon to reduce both the financial and physical efforts. The positive but weak relationship of diversity indicates that a high carbon and biodiversity conservation forest can be achieved, that needs a further small scale and large-scale research. Our findings concluded that the forest of the Guangxi region, South China has not only a greater diversity but also has greater carbon mitigation potential.

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Data availability. The data used to support the findings of this study are available from the corresponding author upon request.

Conflict of interests. The authors declare that they have no conflict of interests.

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APPENDIX

Table A1. *Diversity indices data for all plots*

Plot No	Pielou's evenness	Shannon DI	Simpson	GINI Coefficient
1	0.576217	0.63304	0.349030471	0.366572
2	0.476463	0.766838	0.3488	0.28923
3	0.776771	1.076833	0.581446311	0.535711
4	0.287086	0.315396	0.139917695	0.277387
5	0.841636	1.93794	0.812071331	0.609881
6	0	0	0	0
7	0	0	0	0
8	0.748555	1.86009	0.75308642	0.533193
9	0.292665	0.524385	0.215251487	0.320634
11	0.968632	1.884871	0.840236686	0.622295
12	0.946395	1.039721	0.625	0.595755
13	0.906895	2.326139	0.880941603	0.529475
14	0.830451	1.726875	0.773175542	0.731258
15	0.468996	0.325083	0.18	0.25371
16	0.738021	1.436122	0.680272109	0.583156
17	0.668946	1.469825	0.664940828	0.442352
19	0.626512	1.219137	0.535147392	0.410751
20	0.827407	1.33166	0.6875	0.566102
21	0.431854	0.695042	0.396431722	0.304012
22	0.936304	2.245159	0.88	0.454053
24	0.452351	0.728032	0.36294896	0.311519
25	0.825631	1.814098	0.772727273	0.536075
27	0.521172	0.722498	0.37037037	0.283177
28	0.745657	1.033701	0.578125	0.293181
29	0.511688	0.709351	0.382271468	0.425373
30	0.69625	1.120571	0.545	0.473322
31	0.83875	2.151352	0.831020408	0.616176
34	0.777132	1.789411	0.77318641	0.659339
36	0.804497	1.76766	0.786703601	0.547489
37	0.872494	2.362757	0.867346939	0.640003
39	0.760738	2.109213	0.804664723	0.600097
40	0.867726	2.156218	0.853177502	0.606399
42	0.900092	2.495584	0.896333182	0.548714
44	0.344913	0.478151	0.217687075	0.428515
46	0.647978	1.347433	0.59833795	0.480582
47	0.733691	0.806042	0.527089073	0.580547
48	0.725226	1.593484	0.687277051	0.525282

49	0.786988	1.636496	0.71	0.47807
51	0	0	0	0
54	0.454262	0.813927	0.357659435	0.307899
56	0.723376	1.164229	0.6176	0.590368
58	0.372013	0.408698	0.196428571	0.226294
60	0.889231	2.280832	0.879501385	0.654842
61	0.276195	0.191444	0.090702948	0.15473
63	0.795854	2.041325	0.810657596	0.481883
65	0.832941	2.136452	0.843621399	0.572395
66	0.798255	1.43028	0.693333333	0.378562
67	0.766563	1.765076	0.737777778	0.413766
69	0.735509	0.509816	0.328180737	0.228401
70	0.864974	0.950271	0.56	0.137444
72	0.787629	1.813583	0.765868887	0.566309
73	0.371232	0.257319	0.132653061	0.084405
74	0.507101	1.054487	0.543905325	0.543927
75	0.73553	1.431275	0.674556213	0.567012
76	0	0	0	0
78	0.733595	1.180676	0.618923611	0.442309
80	0.860361	1.78907	0.806922661	0.674427
81	0.907208	2.570314	0.90877915	0.475267
83	0.811527	2.01657	0.796398892	0.586654
85	0.587947	1.222602	0.555785124	0.340998
86	0.266765	0.184907	0.08677686	0.385625
89	0.617059	0.677909	0.380622837	0.611744
90	0.941735	1.034601	0.62244898	0.38662
91	0.700221	1.362566	0.615702479	0.504637
94	0.272253	0.438174	0.181061394	0.396852
95	0.920325	1.649	0.780023781	0.526034
96	0.832378	1.339661	0.702947846	0.654079
97	0.873002	1.698783	0.763888889	0.572947
98	0.730985	1.520041	0.682926829	0.540197
99	0	0	0	0
100	0.802405	0.881532	0.5546875	0.596741
102	0	0	0	0
104	0.806027	2.002903	0.810249307	0.608665
106	0.381982	0.41965	0.207346939	0.468058
107	0.624889	1.119651	0.577609519	0.479489
110	0.681422	1.693271	0.725525098	0.512811
111	0.852664	1.963331	0.8096	0.640489
112	0.511614	0.995554	0.457593688	0.517096
115	0.650624	0.714783	0.453217956	0.285847
117	0.943511	2.673167	0.92	0.345099
119	0.593279	0.822459	0.422476587	0.401978
122	0.864737	1.39174	0.71875	0.247757
123	0.773601	1.608657	0.703703704	0.495338

124	0	0	0	0
125	0.543564	0.37677	0.21875	0.316422
127	0.908304	0.997874	0.6016	0.629252
128	0	0	0	0
129	0	0	0	0
130	0.567163	1.103647	0.497781065	0.385753
132	0.422001	0.292508	0.156734694	0.22161
134	0.620731	1.112201	0.524005487	0.497316
135	0.548065	1.066486	0.482103725	0.500377
136	0	0	0	0
137	0.717905	1.783926	0.697530864	0.484719
138	0.349642	0.626474	0.25462963	0.221132
139	0.556331	0.89538	0.42	0.434019
141	0.33729	0.233792	0.1171875	0.422432
142	0.608003	1.18312	0.549886621	0.341771
143	0	0	0	0
144	0.31969	0.514521	0.218490305	0.269218
145	0.824467	1.898405	0.806692773	0.329984
146	0.716323	1.890418	0.758494031	0.312573
147	0.782252	1.084432	0.594104308	0.456489
149	0.925863	1.017164	0.609418283	0.288092
151	0.882344	2.192543	0.865051903	0.588248
152	0.595906	0.65467	0.364197531	0.393768
153	0.858567	1.976923	0.8128	0.517908
154	0	0	0	0
155	0	0	0	0
157	0.421596	0.46317	0.229968311	0.210259
159	0.709446	0.983501	0.566162571	0.503001
161	0	0	0	0
162	0	0	0	0
164	0.559809	1.164091	0.594674556	0.536746
165	0	0	0	0
166	0.81752	0.898137	0.556213018	0.136753
167	0	0	0	0
168	0.383255	0.531304	0.242222222	0.561176
169	0.663489	1.188813	0.587890625	0.466275
170	0	0	0	0
171	0.952522	2.193262	0.879904875	0.608873
173	0.758818	1.577917	0.72543618	0.499811
174	0.905713	0.995027	0.592592593	0.441657
175	0.824044	1.975971	0.821037253	0.406082
176	0.607773	0.978173	0.467120181	0.464165
177	0.92062	1.011404	0.611111111	0.505057
178	0.447075	0.491162	0.257785467	0.445699
179	0.718373	0.789213	0.519395135	0.408087
180	0.735509	0.509816	0.328180737	0.261715

181	0.392378	0.431071	0.210059172	0.30596
182	0.685776	1.426031	0.637777778	0.478157
185	0.304221	0.334221	0.1504	0.240211
186	0.921628	2.122127	0.861602497	0.514186
187	0.921185	1.277034	0.693877551	0.699302
189	0.856326	1.78068	0.798353909	0.56952
191	0.515273	0.566086	0.291666667	0.324354
192	0	0	0	0
193	0.670877	1.079735	0.524691358	0.340699
194	0.233584	0.323816	0.130165289	0.280499
195	0.910864	1.63205	0.786703601	0.465055
196	0.717438	1.840192	0.783068783	0.666519
197	0.371232	0.257319	0.132653061	0.235044
198	0.304221	0.334221	0.1504	0.407337
200	0.845351	0.585953	0.396694215	0.693085
204	0	0	0	0
205	0.68567	0.753286	0.492438563	0.39043
206	0.704575	1.262429	0.611570248	0.44649
207	0	0	0	0
208	0.258019	0.178845	0.083175803	0.184031
209	0.818289	1.88418	0.7936	0.442242
211	0.303375	0.210283	0.102264427	0.236289
212	0.447814	0.620802	0.322845805	0.26649
213	0.795886	1.103332	0.597505669	0.492705
214	0.871049	1.56071	0.75	0.562479
215	0.782992	0.542729	0.357290298	0.283409
216	0.751085	1.729436	0.73	0.522164
218	0.568724	1.106685	0.51808021	0.146053
219	0.48689	0.534903	0.289704142	0.394593
220	0.767199	1.595346	0.72702332	0.301114
221	0.643968	1.153835	0.61257687	0.657433
222	0	0	0	0
224	0.918296	0.636514	0.444444444	0.357069
225	0.23494	0.420956	0.158333333	0.302133
226	0.315914	0.347067	0.16	0.384589
227	0.319337	0.221348	0.109220752	0.295215
229	0.646823	1.34503	0.60375	0.272159
230	0	0	0	0
231	0.736734	1.32005	0.655749377	0.084467
232	0.850594	1.655179	0.756944444	0.335953
233	0.854071	2.367989	0.862140775	0.583625
234	0.51972	0.836456	0.428571429	0.557649
235	0.594604	0.956979	0.464285714	0.34051
236	0.222285	0.154076	0.068877551	0.393967
237	0.558449	1.161261	0.51041047	0.302074

Table A2. *Forest structure with respect to family, genera and species*

	Family	Genera	Species
1	Actinidiaceae	Saurauia	*Saurauia tristyla*
2	Altingiaceae	Liquidambar	*Liquidambar formosana*
3	Anacardiaceae	Choerospondias, Pistacia, Rhus, Toxicodendron	*Choerospondias axillaris, Pistacia chinensis, Rush chinessis, Toxicodendron vernicifluum, Toxicodendron succedaneum*
4	Apocynaceae	Stropanthus, Rauvolfia	*Stropanthus divaricatus, Rauvolfia verticillata*
5	Aquifoliaceae	Ilex	*Ilex godajam, Ilex hainanensis, Ilex chinensis*
6	Araliaceae	Tetrapanax, Schefflera, Heteropanax, Aralia	*Tetrapanax papyrifer, Schefflera octophylla, Heteropanax fragrans, Aralia chinensis*
7	Arecaceae	Caryota	*Caryota ochlandra*
8	Betulaceae	Ostrya	*Ostrya japonica*
9	Bignoniaceae	Oroxylum, Redermachera, Dolichandrone	*Oroxylum indicum, Redermachera sinica, Dolichandrone sinica*
10	Borginaceae	Cordia	*Cordia dichotoma*
11	Burseraceae	Garuga, Canarium	*Garuga floribunda, Canarium pimela, Canarium album*
12	Cannabaceae	Trema	*Trema dielsiana, Trema cannabina, Trema tomentosa*
13	Caprifoliaceae	Lonicera	*Lonicera chrysantha*
14	Cornaceae	Cornus, Aphanamixis, Alangium	*Cornus capitata, Aphanamixis grandifolia,* *Alangium feberi, Alangium kurzi*
15	Cupressaceae	Cunninghamia	*Cunninghamia lanceolata*
16	Dilleniaceae	Dillenia	*Dillenia indica*
17	Ebenaceae	Diospyros	*Diospyros kaki, Diospyros saxatilis, Diospyros morrisian*
18	Elaeocarpaceae	Elaeocarpus	*Elaeocarpus sylvestri*
19	Euphorbiaceae	Aleurites, Vernicia, Glochidion, Macaranga, Mallotus	*Aleurites montana, Vernicia fordii, Vernicia montana, Glochidion hirsutum, Macaranga denticulata, Mallotus barbatus, Mallotus japonicus, Mallotus paniculatus, Mallotus philippensis*
20	Euphorbioideae	Sapium	*Sapium sebiferum, Sapium discolor*
21	Fabaceae	Acacia, Adenanthera, Albizia, Calliandra, Dalbergia, Erythrophleum, Leucaena, Millettia, Mimosa, Pithecellobium	*Acacia confusa, Adenanthera pavonina, Albizia julibrissin, Albizia odoratissima, Calliandra brevipes, Dalbergia odorifera, Erythrophleum fordii, Leucaena leucocephala, Millettia speciosa, Mimosa sepiaria, Pithecellobium clypearia, Pithecellobium lucidum*
22	Fagaceae	Castanea, Castanopsis, Quercus	*Castanea mollissima, Castanopsis fargesii, Castanopsis hystrix, Quercus griffithii, Quercus linn*
23	Hamamelidaceae	Mytilaria, Rhodoleia	*Mytilaria laosensis, Rhodoleia championii*
24	Hypericaceae	Cratoxylum	*Cratoxylum cochinchinense*
25	Lamiaceae	Gmelina, Tectona, Clerodendrum	*Gmelina chinensis, Tectona grandis, Clerodendrum ervatamioides*

26	Lauraceae	Actinodaphne, Phoebe, Neolitsea, Machilus, Litsea, Lindera, Cinnamomum	*Actinodaphne pilosa, Actinodaphne angustifolia, Phoebe zhennan, Phoebe bournei, Neolitsea sericea, Machilus chinensis, Machilus pauhoi, Machilus pingii, Machilus velutina, Litsea cubeba, Litsea glutinosa, Litsea monopetala, Litsea elongata, Litsea forrestii, Litsea panamonja, Litsea pungens, Litsea yunnanensis, Lindera glauca, Cinnamomum bodinieri*
			Cinnamomum camphora, Cinnamomum cassia,
			Cinnamomum Tonkinense
27	Magnoliaceae	Tsoongiodendron, Manglietia, Michelia, Liriodendron	*Tsoongiodendron odorum, Manglietia glanca,*
			Manglietia hainanensis, Michelia alba, Michelia macclurei, Liriodendron chinense
28	Malvaceae	Microcos, Sterculia, Helictercs, Hibiscus, Excentrodendron, Bombax	*Microcos paniculata, Sterculia lanceolata, Sterculia nobilis, Helictercs angustifolia, Hibiscus mutabilis, Excentrodendron hsienmu, Bombax malabaricum*
29	Meliaceae	Chukrasia, Cipadessa, Melia, Khaya, Aphanamixis	*Chukrasia tabularis, Cipadessa cinerascens, Melia azedarach, Khaya senegalensis, Aphanamixis polystachya*
30	Moraceae	Artocarpus, Broussonetia, Ficus	*Artocarpus hypargyreus, Broussonetia kaempferi, Broussonetia papyrifefera, Ficus altissima, Ficus auriculata, Ficus esquiroliana, Ficus hispida Ficus oligdon, Ficus ruyuanensis, Ficus hirta, Ficus irisana, Ficus microcarpa, Ficus orthoneura, Ficus racemosa, Ficus tinctoria*
31	Myricaceae	Myrica	*Myrica rubra*
32	Myrtaceae	Eucalyptus, Syzygium	*Eucalyptus robusta, Eucalyptus urophylla, Eucalyptus fordi, Syzygium cumini, Syzygium hainanense*
33	Oleaceae	Olea, Ligustrum, Fraxinus	*Olea europaea, Ligustrum compactum, Ligustrum quihoui, Fraxinus chinensis*
34	Paeoniaceae	Paeonia	*Paeonia suffruticosa, Paeonia delavayi*
35	Pentaphylaceae	Eurya	*Eurya groffii, Eurya ciliata, Eurya japonica*
36	Phyllanthaceae	Antidesma, Phyllanthus, Bischofia, Bridelia, Glochidion	*Antidesma bunius, Antidesma celebicum, Antidesma fordii, Phyllanthus emblica, Bischofia javanica, Bischofia polycarpa, Bridelia tomentosa, Bridelia stipularis, Glochidion puberum*
37	Pinaceae	Pinus	*Pinus massoniana, Pinus elliottii, Pinus caribaea,*
38	Poaceae	Bambusa	*Bambusa rutila*
39	Primulaceae	Ardisia, Maesa	*Ardisia japonica, Maesa japonica*
40	Rhamnaceae	Ziziphus, Sageretia, Hovenia	*Ziziphus jujuba, Sageretia theezans, Hovenia acerba*
41	Rosaceae	Crataegus, Pyrus	*Crataegus pinnatifida, Pyrus calleryana*
42	Rubiaceae	Canthium, Catunaregam Wendlandia, Psychotria, Pavetta	*Canthium horridum, Catunaregam spinosa, Wendlandia tinctoria, Wendlandia uvariifolia, Psychotria rubra, Pavetta arenosa, Pavetta hongkongensis*
43	Rutaceae	Citrus, Clausena, Zanthoxylum, Tetradium, Evodia	*Citrus reticulata, Clausena excavata, Zanthoxylum avicennae, Tetradium glabrifolium, Evodia lapta, Evodia trichotoma*
44	Sapindaceae	Acer, Sapindus, Litchi, Dimocarpus	*Acer momo, Sapindus mukorossi, Litchi chinensis, Dimocarpus longan*

45	Schisandraceae	Illicium	*Illicium verum*
46	Simaroubaceae	Brucea	*Brucea javanica*
47	Solanaceae	Solanum	*Solanum erianthum*
48	Staphyleaceae	Staphylea	*Staphylea forrestii*
49	Styracaceae	Styrax	*Styrax subniveus, Styrax tonkinensis, Styrax officinalis*
50	Symplocaceae	Symplocos	*Symplocos cochinchinensis*
51	Theaceae	Schima, Camellia	*Schima argentia, Schima superba, Schima wallichii, Camellia japonica, Camellia oleifera*