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WOOD DENSITY OF LOWER STRATUM TREES IN A SEMI-DECIDUOUS TROPICAL FOREST OF CAMEROON

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ABSTRACT

The lower forest stratum is often neglected in trees wood density studies. The aim of this study was to investigate wood density of lower stratum forest in a semi-deciduous rain forest of Cameroon. The data was collected from 30 random squares plots of 100m² and 200m. The wood density was assessed using immersion method. Wood samples were collected at three levels including: the base, the trunk and branches of trees. Measurement variables collected include the diameter, height and crown diameter. These variables were correlated to wood density using the Pearson coefficient. A total of 1498 samples from 136 tree species were collected. The wood density from these samples varied from 0.156 $g.cm^{-3}$ to 0.914 $g.cm^{-3}$, with an average of 0.561 $g.cm^{-3}$. ANOVA test showed that, wood density decreased significantly from 0.609 to 0.571 and then to 0.509 $g.cm^{-3}$ for the base, trunk and branches respectively. Interspecific analysis showed that wood density was significantly different between species (ANOVA, $p<0.001$). With respect of biological type, the mean wood density of 27 understory tree species (exclusively) found was 0.562 $g.cm^{-3}$. Wood density of 56 tropical forest tree species hitherto unknown in the literature were determined. The

Pearson correlation between measurement variables and wood density was close to zero; nevertheless, it varied in function of the tree species. This study suggested that more investigations of wood density of tropical forest trees should be conducted, particularly in the Congo Basin forests where an important diversity of medium and lower forest stratum trees is expected.

Contribution/Originality: This study contributes to the existing literature concerning wood density of lower stratum forest in semi-deciduous forest of Congo Basin for which limited information are available.

1. INTRODUCTION

The lower forest stratum, unlike the upper canopy, mainly includes young trees, shrubs, herbaceous plants, ferns, mosses, wildlife and microorganisms that grow below the crown of the woody stratum where sunlight is limited [1]. Although less investigated, this forest stratum is the most accessible in tropical forests. High humidity, reduce wind, specific plants and animals species which show adaptations to the specific microclimates created by limited sunlight are some common characteristics of this forest stratum ecosystem [2]. Tree species of this stratum are important for the forest dynamics and key drivers of its future, as they constitute the population from which future forest cover is recruited [3, 4]. Some plants species of this forest stratum only exist at their juvenile stage [2] with diameters not more than 10 cm [5]. Despite the diversity potential of this lower forest stratum, most of its parameters including wood density still little investigated in the Congo Basin forest [6] whereas, the contribution of the understory trees to carbon stock is moderate since the largest trees mostly contribute to the stocks [7] but this carbon can stay for long [8].

Several studies on carbon sequestration have been conducted in tropical forests, but few have focus on the carbon storage potential of species of lower stratum [5, 9] despite it critical role for the successful implementation of REDD+ (Reducing Emissions from Deforestation and Forest Degradation and carbon stocks). Chimi, et al. [9] pointed out that even if the species biomass in the lower stratum is low, their contribution to climate change mitigation should not be neglected. In addition, the implementation of REDD+ and carbon markets should be based on more realistic and effective values if the lower forest stratum is taken into account.

Estimating the woody carbon stock requires reliable knowledge of wood density of all plant components in the forest. By definition, the wood density is the mass of a wood per unit volume. Before the work of Henry, et al. [10] in Ghana, the importance of wood density to estimate the biomass and carbon contained in tropical trees has been raised by Chave, et al. [11]. It is therefore a key variable for estimating tree biomass. For an individual tree, the wood density differs between branches, trunk and base of the tree as well as radially within each of these tree levels, due to the radial growth [10, 12-15]. According to Nogueira, et al. [14] estimating the wood density of a tree without taking these intra and inter levels variations into account gives unsatisfactory results. Wiemann and Williamson [12] also pointed that, the wood density is an important indicator of the successional stage, succession and diameter class within a given forest or tree. Similarly, Djomo, et al. [15] showed variations in density of intraspecific wood. Thus, using the wood density of a large tree (large diameter) to estimate the biomass of a small tree (small diameter) of the same species might result to critical error [16]. Similarly, Le, et al. [17] underlined the influence of the tree architecture on the estimation of wood density. While knowledge of wood density of upper tree stratum are considerably increasing [15, 18] those of trees of lower stratum still little investigated. Determining the wood density of trees of this forest stratum, particularly in tropical forests represent an important contribution for the mitigation of the effects of climate changes.

This is particularly critical for the Central Africa tropical forests, due to its species richness [19]. Unfortunately, wood density of tree species in this forest still limited to the commercial trees species with trunk diameter above 10 cm [20]. This at the expenses of other tree species such those in the lower stratum with diameter less than 10 cm. Thus, knowledge on the wood density of the tree species in the lower stratum and that of the young woody trees in the canopy should provide better knowledge and reliability estimation of the forests carbon sequestration potential, therefore the implementation of the REDD+ process.

In Cameroon, where not less than 8,000 tree species have been identified [21] few studies wood density estimation have been conducted. This is also true to the entire Congo Basin forest, specifically for tree species of the lower stratum. However, Louis-Paul-Roger, et al. [5] showed that the undergrowth of Cameroon's semi-deciduous dense forests is very rich in terms of woody species. Thus, this study aimed was to expand knowledge on the wood density of tree species with diameter less than 10 cm in a semi-deciduous tropical rainforest of Cameroon. This work seek to answer the following questions: (i) Does the biological type of trees influence it wood density? (ii) Does the wood density of tree species of lower forest stratum vary vertically? (iii) Which correlations exist between wood density and measurement variable of the tree (diameter, height and crown diameter)?

2. MATERIAL AND METHODS

2.1. Study Area

This study was carried out in a moist tropical semi deciduous forest in Cameroon. The study area was located between the geographical coordinates of 3°20' and 3° 63' N and 13° 25' and 13° 85' E. The topography of this location is relatively flat with an altitude of 600 m. The soil is essentially lateritic; however, hydromorphic soils are present in river banks [22]. The climate is typically Guinean equatorial with four seasons: including two dry seasons (a long dry season from December to February and a short dry season from July to August) and two rainy seasons (a short rainy season from September to November and a long rainy season from March to June). The three major rivers found in this study area are the Dja, Nyong, Boumba and with minor rivers like Njo, Meh and Amp. This area belongs to the semi-deciduous rainforest [23]. The representative commercially valuable species of the flora are *Pterocarpus sayauxii*, *Triplochiton scleroxylon*, *Mansonia altissima*, *Terminalia superba*, *Entandophrama cylindricum*, etc.

2.2. Data Collection

Data was collected in 15 plots of 100 m^2 (10m × 10m) for trees with diameter below 5 cm and in 15 plots of 400 m^2 (20m × 20m) for trees with diameter between 5 and 10 cm [24]. Data collection was done exclusively on trees of the forest lower stratum with diameter < 10 cm. For each tree inventoried, vernacular or scientific names were recorded, specimens collected, pressed, impregnated with ethyl alcohol diluted at 70 °C and dried in the laboratory of Ecology and Systematics of the University of Yaounde 1. These specimens were then sent to the national herbarium of Yaounde to confirm the identification of trees species. For these trees, the reference level of diameter measurement was taken at 30 cm above the soil level [25]. Total height was measured directly on felled trees. For crown diameter, it was measured before the trees felled and was obtained from the average of two crown diameters measured along the North/South and East/West orientations. To estimate wood density, trees were felled using a machete or chainsaw depending on size. Samples having average weight of 38 g were then collected at the levels of tree breast height (base), trunk (approximately in the middle of the total stem height) and at one randomize branch. The samples were then labelled (names, numbers and plots number) and transported to the Laboratory of Ecology and Systematics at the University of Yaounde 1. A total of 1498 samples were collected at the base, trunk and branch levels from 502 trees and 136 species with diameter < 10 cm.

The water displacement method was applied for wood density determination [14]. So, the 1498 samples collected were used for the determination of the wood density in the study area. For each tree, these samples were collected at three (3) levels of the tree (base, trunk and branch of the tree). The green mass of each sample was directly measured in the field using a precision electronic balance. The green volume was calculated using immersion method. In fact, according to this method, a solid (samples collected in this study) immersed in water experiences an upward force equal to the mass of the water it displaces because the wood density of water is 1 g.cm-

³ at ambient temperature [26]. For the determination of volume, each green sample was fully immersed in water on a graduated cylinder and the mass of the displaced water read from the electronic balance calibrated [15]. These samples were oven dried in the laboratory at 105 °C [27] to obtain constant dry mass when after three consecutive mass times at regular intervals every 6 hours proofs it stability. In our earlier work we use this 6h interval between two mass measurements, because it is a standard in the UE to consider a 1% difference negligible between such measurements and a constant dry mass [28].

Only basic wood density was considered in this study; it was calculated using the following formula: wood density (ρ) = dry mass / green volume [13]. This formula concern each collected sample (base, trunk and branches of tree) for each tree. This formula is recommended for wood density determination and which could be applied for biomass estimation [27]. The wood density (ρ) of each tree was obtained by formula:

$\rho = \frac{\rho_{base} + \rho_{trunk} + \rho_{branche}}{3}$. The mean value of all these wood densities will be used to determine mean wood density of understory of study area. The formula used was:

$$\rho_{mean} = \frac{1}{N} \times (\sum \rho_{base} + \sum \rho_{trunk} + \sum \rho_{branches})$$

where N= the total number of understory trees sampled.

The literature review was done concerning the species to determine if the species found are exclusively understory or will be later shrubs or tree (those trees which constitute the higher stratum of the forest). For that, we have consulting the herbarium specimens (looking the descriptive card of each species), some's documents available like those of Quentin, et al. [29]; Tchouto, et al. [6].

2.3. Data Analysis

The software R (version 3.3.2) was used for data analysis. Looking at the Shapiro-Wilk test and graphics exploration showed that our data of wood density follows a normal distribution, parametric test of ANOVA was done to find out if significant difference exist between wood densities of different compartment of understory tree. Turkeys test was done to make a two by two comparison. Correlation between measurement variables of tree size such as diameter, total height and wood density was appreciated with the help of Pearson's correlation coefficient (r).

3. RESULTS

3.1. Average Density of Understory Species

The analyses of the 1498 samples of trees of the lower forest stratum (502 trees) collected showed that they belong to 136 species. The average wood density of trees of the study area was 0.561 g.cm^{-3}. According to vertical wood density variation, 502 samples were analysed at the base of tree with the densities varying from 0.110 to 1.147 g.cm^{-3} and an average of 0.609 g.cm^{-3}. A total of 503 samples were analysed at the trunks with densities ranging from 0.08 to 1.143 g.cm^{-3} and an average of 0.571 g.cm^{-3}, while 493 samples were analysed at the branch level with densities ranging from 0.08 to 1.142 g.cm^{-3} and an average of 0.508 g.cm^{-3} (Appendix 1).

According to biological type of species recorded, 27 species found were exclusively understory and remain to this status during all their life (opposite to shrubs or canopy trees). For these understories trees, their mean wood density found was 0.562 (0.274-0.754) g.cm^{-3}. The mean wood density of small trees found which will be a shrub later according to their biological types (50 species) was 0.570 (0.224-0.750) g.cm^{-3}. For those which will be constitute the canopy later (59 species), their mean wood density was 0.552 (0.290-0.774) g.cm^{-3}. ANOVA test ($P>0.05$) have showed that there are not significant difference between these 3 biological types according to their mean wood density. If we consider exclusively species of this lower stratum found which their wood densities are available in the literature, the mean value of wood density of our tree found in the lower stratum was 0.550 g.cm^{-3} and those in the literature was 0.631 g.cm^{-3} (for those of the canopy or higher stratum); which represented a difference of the order of 14 %.

According to the literature reviewed on specific wood density for trees samples, this study allowed us to determine the wood density of 56 trees species which are unknown in the published data base. These included: *Pseudospondia microcarpa*, *Sorindeia grandifolia*, *Trichoscypha abut*, *Trichoscypha acuminata*, *Voacanga africana*, *Myrianthus preussii*, *Combretum paradoxum*, *Jollydora duparquetiana*, *Diospyros caniculata*, *Diospyros gabunensis*, *Diospyros hoyleana*, *Alchornea floribunda*, *Antidesma membranaceum*, *Drypetes chevaleri*, *Grossera macrantha*, *Maesobotrya barteri*, *Uapaca acuminata*, *Baphia pubescens*, *Calpocalyx dinklagei*, *Pterocarpus mildbraedii*, *Beilschmiedia obscura*, *Strychnos aculeata*, *Lepidobotrys staudtii*, *Strychnos barteri*, *Spathandra barteri*, *Trichilia gilgiana*, *Trichilia zewaldae*, *Penianthus camerunensis*, *Penianthus longifolia*, *Dorstenia africana*, *Strombosia chefferie*, *Treculia africana*, *Campylospermum elongatum*, *Heisteria parviflora*, *Olax latifolia*, *Aulacocalyx caudata*, *Bertiera breviflora*, *Bertiera racemora*, *Psychotria chalconeura*, *Rothmannia hispida*, *Zanthoxyllum buesgenii*, *Chytranthus angustifolius*, *Chytranthus atroviolaceus*, *Chytranthus carneus*, *Chytranthus gilletii*, *Trichilia welwitschii*, *Gambeya albida*, *Gambeya lacourtiana*, *Synsepalum longecuneatum*, *Chlamydocola chlamydantha*, *Rinorea batesii*, *Rinorea caudata* and *Rinorea longicuspis*. Between these species, 18 are exclusively understory, 25 are shrubs and 12 species trees of the upper stratum (Appendix 1).

Furthermore, wood densities of 19 genera were first reported in this study. These genera included: *Pseudospondia*, *Voacanga*, *Jollidora*, *Grossera*, *Maesobotrya*, *Lepidobotrys*, *Spathandra*, *Penianthus*, *Dorstenia*, *Treculia*, *Chytranthus*, *Gambeya*, *Chlamydocola*, *Asystasia*, *Bertiera*, *Cuviera*, *Euclinia*, *Leptonychia* and *Allexis* (Appendix 1).

3.2. Vertical Variation of Wood Density

The wood density decreased significantly from the base to the branches of the understory trees (ANOVA; p<0.000). ANOVA test showed a difference between wood densities at different levels of understory trees. The Turkey's test for the two by two comparison showed that whatever the tree compartment considered, there exist a significant difference. In general, average wood density decrease from 0.609 to 0.571 and then to 0.509 g.cm^{-3} respectively for the base, trunk and branches of each understory tree (Figure 1). According to each understory tree, Table 1 showed specific vertical variation of wood density.

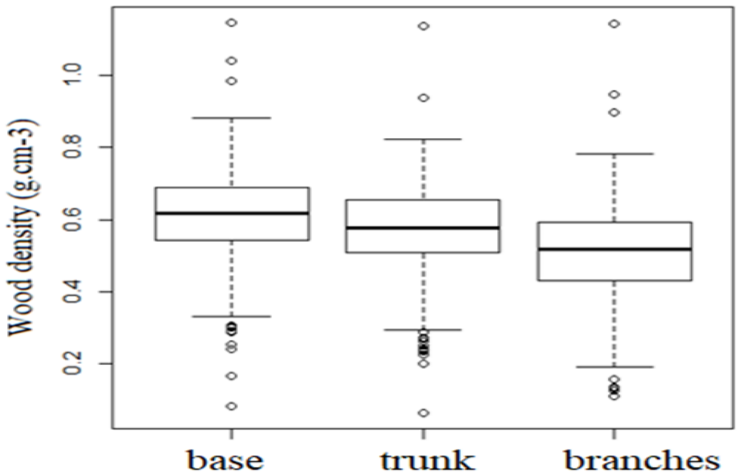

Figure-1. Vertical variation of wood density of the understory's tree compartments.

On the order hand, when we consider only the wood density of the base for trees obtained in this study area, we observed an overestimation of +8.6 % (with varied between 3.9 to 16.1% between species when we consider species with 10 individual (sample) or more); and when only wood density of trunk was considered, we observed also an overestimation of +1.8 % (0.4 – 8.1%). Contrarily, when only wood density of branches was considered, we observed an underestimation of -9.3 % (-23.7 – (-2.9%)).

3.3. Inter and Intraspecific Variation of Wood Density

For interspecific wood density variation, a highly significant difference was found between wood density according (ANOVA, $p<0.000$). This wood density varied according to tree species, from 0.156 $g.cm^{-3}$ for this individual *Pycnanthus angolensis* to 0.914 $g.cm^{-3}$ for one unknown species. In the context of this study, the intra-specific wood density variation is weak between individuals of same species; it varied between 0.007 - 0.165 $g.cm^{-3}$ according to the species.

3.4. Correlation between Diameter, Total Height and Wood Density

The arithmetic mean wood density of the trees showed no significant correlation with wood density and measurements variables of trees size (diameter, total height and crown diameter); in fact, Pearson's correlation coefficient showed that variation of measurements variables of tree size does not have any influence on the wood density. Thus, the correlation between diameter and wood density found was -0.04, that of total height and wood density was 0.006 and finally that of crown diameter and wood density was 0.03 Figure 2.

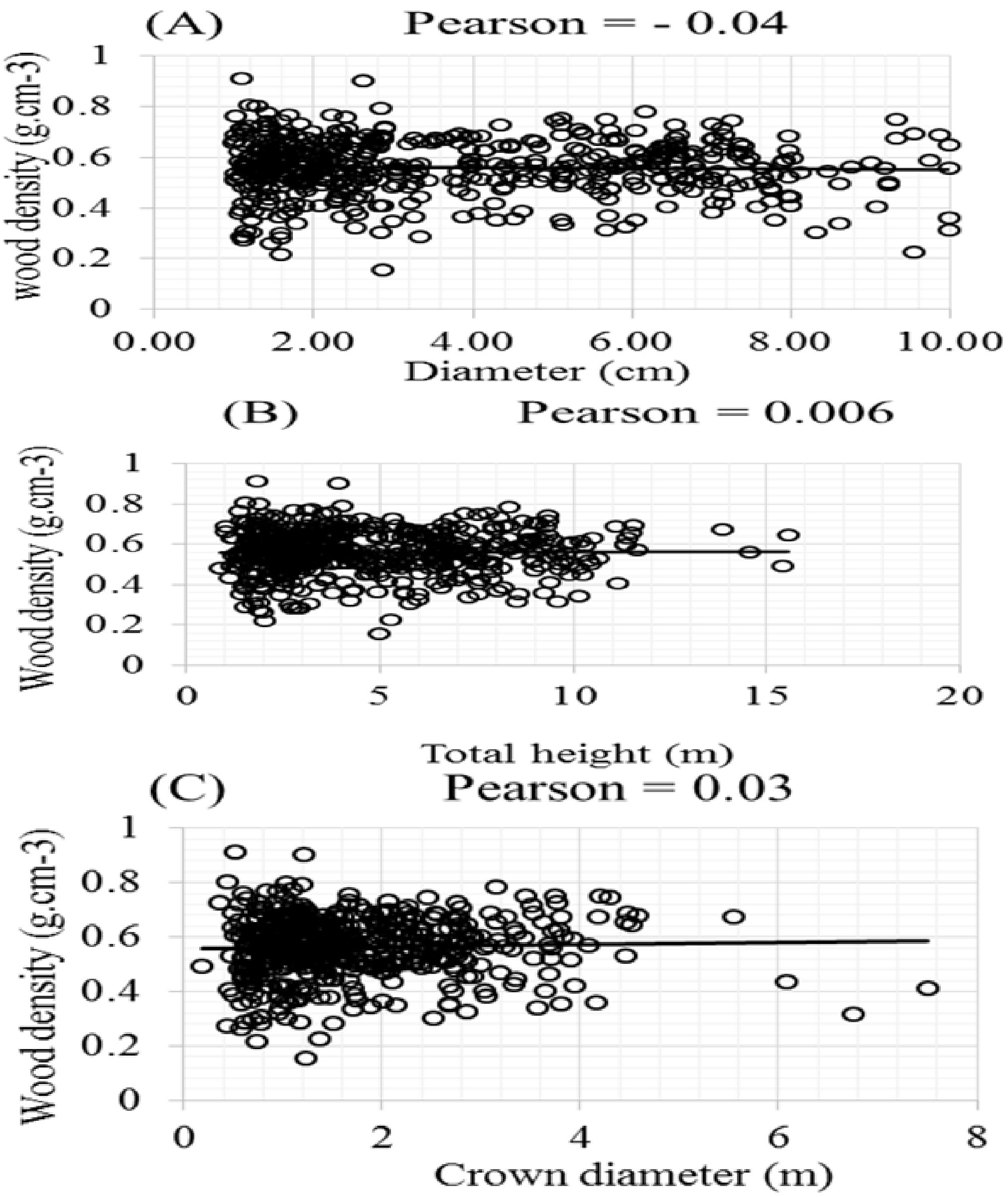

Figure-2. Correlation between wood density and diameter (A), total height (B), crown diameter (C).

However, this Pearson's correlation coefficient varied when we consider species separately. Like that, taking into account, the 5 species where more than 10 individuals was sample each, we observed that r varied between -0.095 to 0.658 for wood density and diameter of tree in function of the species. For total height and crown diameter, this correlation varied respectively to 0.256-0.571 and 0.03-0.713 respectively in function of species Table 1.

Table-1. Pearson's coefficient correlation (r) between wood density and measurement variables of trees size for 5 species most abundant in term of individual sample.

Species	Diameter	Height	Crown diameter
Diospyros gabunensis	0.658	0.571	0.713
Garcinia epunctata	-0.095	0.256	0.031
Rinorea batesii	0.481	0.577	0.457
Tabernaemantana crassa	0.425	0.320	0.0690
Voacanga africana	0.364	0.469	0.442

4. DISCUSSION

4.1. Average Wood Density

In contrast to other studies in wood density, this focused on wood density of trees species of the lower forest stratum (especially those with diameter <10 cm) which are mostly neglected in forest studies. The results of the wood density varied between 0.156 and 0.914 g.cm^{-3} with an average of 0.561 g.cm^{-3}; found in this study area was close to those found by other authors in tropical forests. It is the case of Djomo, et al. [15] who found in the semi-deciduous forest of East Cameroun that wood density varied from 0.295 to 0.912 g.cm^{-3} with an average of 0.561 g.cm^{-3}; those of Day, et al. [30] in Central African tropical rain forest who found that wood density range from 0.211 to 0.981 g.cm^{-3}, the results of Fayolle, et al. [28] showed that wood density varied from 0.284 to 1.152 g.cm^{-3} with an average of 0.630 g.cm^{-3} in a dense rainforest of South-west Cameroon, and Henry, et al. [10] in the dense wet-evergreen forest of Ghana found that wood density varied from 0.110 to 1.010 g.cm^{-3} with an average of 0.590 g.cm^{-3}. It was the same results in accordance with the variation of wood densities available in global wood density where it varied from 0.08 to 1.39 g.cm^{-3} for 8411 individual tree samples in the world forest. Indeed, the average wood density found in this study was close to those (0.58 g.cm^{-3}) of Chave, et al. [11] in the tropical forests. According to Fearnside [13] the average wood density found was lower than the 0.700 g.cm^{-3} found in tropical Amazonian forests. For this reason, wood densities in moist tropical forests of Africa are lower than those of tropical Amazon rainforests [10]. Phytogeographical, ecological or environmental factors as well as plant ecophysiology could explain these variations [14, 31].

However, the mean wood density of one site could also be function of its species diversity. Taking for example a site where trees which are typically lightweight, are more abundant in a site, a large number of these trees species and according to their fast-growing, may be responsible for the low mean density in this area; this is particularly true for pioneer species which are especially qualified to low wood density. For Muller-Landau [32] pioneer species have low density while emerging species have inter-mediate density and sub-canopy slow-growing species have high density. Level of light in forest had an effect on the average wood density of area. Ramananantoandro, et al. [33] have showed that mean wood density decrease with the shade level (high for nomad light species (e.g. understory species that can growth in the shadows of the other trees) and high for semi-shade tolerance (canopy)). These observations which could be adopted in our context when we consider our 3 biological types are not far to those of this authors.

4.2. Inter and Intraspecific Wood Density

Inter specific wood density found in our study area varied from 0.156 g.cm^{-3} for *Pycnanthus angolensis* to 0.914 g.cm^{-3} for an unidentified species. Parametric test showed that wood density varied significantly with the tree species. Some authors like Bastin, et al. [7]; Henry, et al. [10] obtained similar results. Environmental condition and ecophysiological aspects such as climatic zones, humidity, age, illumination and rapid growth, soil fertility, etc.

are among the factors which could explain interspecific wood density [12, 14, 16, 34]. Morphological or anatomical factors might also be taken into consideration. Some species for example are qualified for low density because their morphological characteristics favours rapid growth while others are qualified as high density due to their slow growth. Structural characteristics of low and high wood density trees determined their defence against physical damage, predators and pathogenic agents. Within an ecosystem for example, wood density can be used as an indicator of ecological succession stages [12]. For this reason, pioneer species are less dense.

Molto, et al. [35] in accordance with the results of this study expressed that, although small, intra-specific wood density variation should not be neglected. In fact, for the same species, the wood density could vary as a result of the environment or disturbance level [33]. Considering the fact that our study was carried out exclusively on one site, the intra-specific variation found on whatever species was low (0.007 - 0.165 $g.cm^{-3}$) and not significantly different.

4.3. Vertical Variation of Wood Density

ANOVA test showed a high significant difference between wood densities of the base, trunk and branches; this was also the case for the comparison two by two according to Turkey's test. For Henry, et al. [10] within the same species and the same tree, wood density vary (decrease) between different organs including roots, along the stem, the branches and leaves. Thus, as in several studies [8, 10, 12, 14, 15, 36, 37] the wood density variation increase vertically along the tree. Ecophysiological aspects relate to the tree species could be the origin of this variation [16].

Considering this vertical variation of wood density the wood density collected at one point or one compartment of the tree could not represent that of the entire tree in order to avoid its overestimation. Nevertheless, this overestimation probably vary with the tree species and anatomic characteristics. Imprecisions in samples collection especially for the trunk and branches can also explain this variation. The results from this study were similar to those of Nogueira, et al. [14]; Djomo, et al. [15]. However, in some cases, these authors mentioned that wood density could decrease vertically if the base of the tree is subjected to wood rot or degradation.

4.4. Correlation between Wood Density and Measurement Variables of Trees

Globally, the arithmetic mean wood density of trees of lower forest stratum was not correlated to measurement variables of trees size and Pearson correlation coefficient found was approximately zero. Previous studies have confirmed this point of view especially with tree diameter and total height [14, 33, 34] but according to our literature research, there are no study that underline the influence of crown diameter increase on the wood density variation. However, for this correlation in function of each species, this observation was contrary. In this context, we have selected the 5 most abundant species in term of their individual sample and the results showed that base of the tree species, the Pearson's correlation coefficient between wood density and measurements variables of trees size could be up than 0.5 (e.g. *Diospyros gabunensis*). This mean that, correlate wood density with measurement variables of trees size with accounting for between – species differences are known to be important [37].

Theoretically, tree diameter increase with tree age. This could explain the high Pearson correlation coefficient observed for some species when correlation wood density measurements variables of tree size specific to one species was performed. Nevertheless, Baker, et al. [36] and De Castro, et al. [16] have showed also that for the same species, wood density varied with the age. However, according to the point of view which suggests that increasing tree diameter correlates with tree age increases, we did not find a correlation between increasing diameter and wood density when all data set was take into account without distinction between species.

Considering exclusively trees whose wood densities are available in the literature, the comparison their correspondence with those of lower forest stratum in this study (for the same species) showed a difference to the order of 14 %. In fact, the mean wood density of our lower stratum trees was 0.550 $g.cm^{-3}$ and that of the literature about these trees was 0.631 g.cm^{-3}. This information confirmed the increase in wood density with the diameter of tree [16]. In this context, Woodcock and Shier [38] found that small-diameter trees have lower density than larger trees. In addition, this authors found different mean wood densities in plots of different successional stages, with lower density in young successional stages.

5. CONCLUSION

This study presented an important the contributions of knowledge of lower forest stratum trees wood density, inter and intraspecific variations and the influence of measurement variables of trees size on wood density. The interspecific wood density of the tree species was significantly different. An over and underestimation of wood densities in the order of +8.6 %, +1.8 % and -9.3% respectively when only wood density was measured at the base, the trunk and branches of trees. However, measurement variables of trees size have effect on wood density only for some species when they are taken separately. According to trees with available wood densities in literature, the mean wood density of our lower forest stratum found confirm the fact that increase in wood density goes with the age of trees. In the tropical forest, wood density is a key variable for the estimation of tree biomass because it reduces uncertainty in estimates of carbon stocks, and this study has permitted to make available wood density of 136 trees lower forest stratum of East Cameroon amongst which were 56 species not available in the literature.

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Appendix-1. Wood density of 136 understory tree species inventoried in semi deciduous forest. N: number of understory trees sampled; " / " represented understory trees species which data about their wood density is missing in the literature.

Species	Families		Measure wood density				Literature wood density	
		N	base	trunk	branches	average	global	references
Understory								
Aidia micrantha	Rubiaceae	3	0.817	0.763	0.683	0.754	0.663	[18] extratropical
Alchornea floribunda	Euphorbiaceae	2	0.624	0.575	0.510	0.570	/	
Allexis sp.	Ulmaceae	10	0.635	0.576	0.488	0.566	/	
Bertiera breviflora	Rubiaceae	1	0.625	0.692	0.250	0.522	/	
Bertiera racemora	Rubiaceae	1	0.565	0.564	0.322	0.484	/	
Bertiera sp.	Rubiaceae	1	0.626	0.622	0.648	0.632	/	
Campylospermum elongatum	Ochnaceae	3	0.751	0.682	0.656	0.696	/	
Campylospermum spp.	Ochnaceae	5	0.717	0.688	0.613	0.672	/	
Canthium sp.	Rubiaceae	1	0.616	0.561	0.525	0.567	/	
Combretum paradoxum	Combretaceae	1	0.621	0.585	0.353	0.520	/	
Memecylon sp.	Melastomataceae	1	0.664	0.658	0.543	0.622	/	
Myrianthus preussii	Cecropiaceae	3	0.482	0.381	0.240	0.368	/	
Penianthus camerunensis	Menispermaceae	1	0.535	0.495	0.466	0.499	/	
Penianthus longifolia	Menispermaceae	1	0.635	0.532	0.471	0.546	/	
Psychotria chalconeura	Rubiaceae	1	0.436	0.261	0.125	0.274	/	
Psychotria sp.	Rubiaceae	2	0.632	0.613	0.546	0.597	/	
Rinorea batesii	Violaceae	14	0.641	0.621	0.585	0.613	/	
Rinorea caudata	Violaceae	1	0.463	0.452	0.368	0.428	/	
Rinorea longicuspis	Violaceae	1	0.786	0.678	0.543	0.669	/	
Rothmania sp.	Rubiaceae	5	0.550	0.625	0.572	0.582	/	
Rothmania urcelliformis	Rubiaceae	2	0.599	0.574	0.537	0.570	0.538	[18] extratropical
Rothmannia hispida	Rubiaceae	2	0.601	0.594	0.521	0.572	/	
Strychnos aculeata	Loganiaceae	1	0.645	0.765	0.588	0.666	/	
Strychnos barteri	Loganiaceae	2	0.647	0.586	0.545	0.593	/	
Strychnos sp.	Loganiaceae	2	0.652	0.644	0.592	0.629	/	
Tabernaemantana crassa	Apocynaceae	16	0.534	0.494	0.351	0.460	0.550	[18]
Voacanga africana	Apocynaceae	13	0.511	0.512	0.454	0.492	/	
Shrub								
Anthonotha lamprophylla	Fabaceae	4	0.612	0.559	0.535	0.569	0.780	[39]
Anthonotha sp.	Fabaceae	7	0.634	0.602	0.528	0.588	0.652	[18]
Antidesma membranaceum	Euphorbiaceae	1	0.729	0.697	0.652	0.693	/	
Asystasia sp.	Acanthaceae	1	0.519	0.471	0.381	0.457	/	
Aulacocalyx caudata	Rubiaceae	1	0.561	0.625	0.533	0.573	/	
Carapa sp.	Meliaceae	2	0.631	0.625	0.510	0.589	/	
Chlamydocola chlamydantha	Malvaceae	1	0.506	0.395	0.369	0.423	/	
Chytranthus angustifolius	Sapindaceae	7	0.607	0.699	0.644	0.650	/	
Chytranthus atroviolaceus	Sapindaceae	2	0.655	0.655	0.596	0.635	/	
Chytranthus carneus	Sapindaceae	2	0.659	0.653	0.511	0.608	/	
Chytranthus gilletii	Sapindaceae	1	0.704	0.692	0.583	0.660	/	
Chytranthus sp.	Sapindaceae	6	0.606	0.572	0.460	0.546	/	
Cola acuminata	Malvaceae	1	0.532	0.528	0.514	0.524	0.508	[18]
Combretum spp.	Combretaceae	4	0.562	0.555	0.449	0.522	0.791	[18]
Cuviera sp.	Rubiaceae	1	0.722	0.736	0.593	0.684	/	
Diospyros caniculata	Ebenaceae	1	0.706	0.653	0.660	0.673	/	

Diospyros gabunensis	Ebenaceae	11	0.666	0.638	0.575	0.626	/	
Diospyros hoyleana	Ebenaceae	4	0.669	0.642	0.655	0.655	/	
Dorstenia africana	Moraceae	1	0.694	0.688	0.563	0.648	/	
Drypetes chevaleri	Euphorbiaceae	2	0.705	0.642	0.651	0.666	/	
Drypetes grossweileri	Euphorbiaceae	2	0.688	0.695	0.613	0.665	0.669	[18]
Drypetes spp.	Euphorbiaceae	27	0.661	0.566	0.580	0.602	0.630	[39]
Euclinia sp.	Rubiaceae	1	0.733	0.724	0.714	0.724	/	
Euphorbia sp.	Euphorbiaceae	1	0.252	0.224	0.198	0.224	/	
Ficus sp.1	Moraceae	1	0.722	0.682	0.667	0.690	/	
Ficus sp.2	Moraceae	2	0.475	0.469	0.427	0.457	/	
Grewia sp.	Tiliaceae	1	0.431	0.327	0.337	0.365	/	
Grossera macrantha	Euphorbiaceae	2	0.688	0.562	0.436	0.562	/	
Guarea sp.	Meliaceae	10	0.370	0.415	0.373	0.384	/	
Heisteria parviflora	Olacaceae	1	0.806	0.693	0.753	0.750	/	
Jollydora duparquetiana	Combretaceae	1	0.510	0.515	0.500	0.508	/	
Lasiodiscus mannii	Rhamnaceae	5	0.582	0.579	0.532	0.564	0.389	[15]
Lepidobotrys staudtii	Lepidobotryaceae	1	0.535	0.512	0.474	0.507	/	
Leptonychia sp.	Malvaceae	3	0.548	0.517	0.475	0.524		
Maesobotrya barteri	Euphorbiaceae	1	0.530	0.512	0.480	0.507	/	
Maesobotrya sp	Euphorbiaceae	5	0.569	0.559	0.477	0.535	/	
Olax latifolia	Olacaceae	1	0.561	0.542	0.438	0.513	/	
Oxyanthus speciosus	Rubiaceae	7	0.672	0.633	0.568	0.624	0.525	[18]
Polyathia suaveolens	Annonaceae	10	0.569	0.539	0.509	0.537	0.695	[18]
Sorindeia grandifolia	Anacardiaceae	1	0.607	0.508	0.506	0.540	/	
Spathandra barteri	Melastomataceae	2	0.701	0.682	0.668	0.684	/	
Strombosia chefferie	Moraceae	1	0.704	0.547	0.459	0.570	/	
Treculia africana	Moraceae	2	0.557	0.540	0.476	0.525	/	
Trichilia gilgiana	Meliaceae	2	0.545	0.521	0.530	0.532	/	
Trichilia heudellotii	Meliaceae	9	0.581	0.544	0.479	0.538	0.439	[18]
Trichilia rubescens	Meliaceae	8	0.648	0.586	0.494	0.577	0.487	[15]
Trichilia sp.	Meliaceae	9	0.654	0.610	0.493	0.586	/	
Trichilia welwitschii	Meliaceae	1	0.614	0.589	0.421	0.541	/	
Trichilia zewaldae	Meliaceae	1	0.660	0.443	0.340	0.481	/	
Xylopia sp.	Annonaceae	1	0.814	0.657	0.667	0.713	/	
Trees								
Albizia adianthifolia	Fabaceae	4	0.714	0.660	0.573	0.654	0.510	[18]
Albizia zygia	Fabaceae	1	0.558	0.403	0.515	0.492	0.494	[18]
Anonidium mannii	Annonaceae	6	0.406	0.372	0.374	0.384	0.291	[18, 39]
Baillonnella toxisperma	Sapotaceae	1	0.683	0.671	0.529	0.628	0.725	[18]
Baphia pubescens	Fabaceae	1	0.595	0.654	0.629	0.626	/	
Baphia sp.	Fabaceae	1	0.583	0.536	0.533	0.551	/	
Beilschmiedia obscura	Lauraceae	1	0.616	0.607	0.530	0.584	/	
Calpocalyx dinklagei	Fabaceae	10	0.741	0.637	0.583	0.654	/	
Canarium schweinfurthii	Burseraceae	1	0.586	0.539	0.412	0.512	0.402	[18]
Celtis adolfi-friderici	Ulmaceae	3	0.585	0.468	0.461	0.504	0.684	[18]
Celtis Mildbraedii	Ulmaceae	4	0.599	0.720	0.510	0.610	0.640	[18]
Celtis tessmanii	Ulmaceae	5	0.689	0.629	0.538	0.618	0.656	[18]
Celtis zenkeri	Ulmaceae	2	0.621	0.551	0.509	0.561	0.608	[18]
Coelocaryon preussii	Myristicaceae	9	0.509	0.410	0.340	0.413	0.495	[18]
Cylicodiscus gabunensis	Fabaceae	1	0.625	0.533	0.500	0.553	0.790	[18]
Dacryodes buettneri	Burseraceae	3	0.642	0.586	0.562	0.597	0.513	[18]
Dacryodes sp.	Burseraceae	2	0.574	0.519	0.430	0.508	/	
Dalium sp.	Fabaceae	6	0.661	0.694	0.619	0.635	/	
Desbordesia glaucescens	Irvingiaceae	2	0.801	0.780	0.729	0.770	0.915	[18]
Enantia chlorantha	Annonaceae	2	0.427	0.357	0.360	0.381	0.295	[15]
Eribroma oblongum	Malvaceae	3	0.320	0.327	0.223	0.290	0.638	[18]
Erythrophleum	Fabaceae	4	0.664	0.662	0.620	0.649	0.872	[18]

ivorensis								
Gambeya albida	Sapotaceae	3	0.548	0.555	0.483	0.529	/	
Gambeya lacourtiana	Sapotaceae	1	0.521	0.497	0.438	0.485	/	
Garcinia epunctata	Clusiaceae	12	0.671	0.649	0.571	0.630	0.843	[18]
Garcinia mannii	Clusiaceae	1	0.580	0.431	0.352	0.454	0.824	[18]
Garcinia sp.	Clusiaceae	3	0.551	0.499	0.437	0.496	/	
Heisteria sp.	Olacaceae	1	0.986	0.618	0.628	0.744	/	
Irvingia gabonensis	Irvingiaceae	4	0.691	0.664	0.586	0.647	0.775	[18]
Irvingia grandifolia	Irvingiaceae	1	0.605	0.610	0.500	0.572	0.800	[18]
Irvingia sp.	Irvingiaceae	1	0.795	0.778	0.750	0.774		[18]
Kigelia africana	Bignoniaceae	1	0.396	0.354	0.323	0.358	0.564	[18]
Lannea welwitschii	Anacardiaceae	1	0.349	0.419	0.364	0.377	0.405	[18]
Pachyelasma tessmannii	Fabaceae	1	0.687	0.627	0.583	0.633	0.738	[18]
Pausinystalia macroseras	Rubiaceae	3	0.698	0.656	0.510	0.621	0.588	[18]
Penthacletra macrophylla	Fabaceae	1	0.743	0.622	0.597	0.654	0.841	[18]
Petersianthus macrocarpus	Lecythidaceae	6	0.567	0.474	0.417	0.489	0.667	[18]
Picralima nitida	Apocynaceae	2	0.651	0.563	0.392	0.535	0.775	[18]
Piptadenistrum africanum	Fabaceae	3	0.711	0.561	0.587	0.620	0.607	[18]
Pseudospondias microcarpa	Anacardiaceae	1	0.348	0.352	0.242	0.314	/	
Pterocarpus mildbraedii	Fabaceae	1	0.492	0.447	0.401	0.447	/	
Pterocarpus soyauxii	Fabaceae	4	0.636	0.520	0.416	0.524	0.658	[18]
Pycnanthus angolensis	Myristicaceae	3	0.422	0.329	0.237	0.329	0.409	[18]
Staudtia kamerunensis	Myristicaceae	2	0.586	0.583	0.396	0.558	0.797	[18]
Strombosia grandifolia	Olacaceae	1	0.625	0.667	0.522	0.604	0.825	[18]
Strombosia pustulata	Olacaceae	5	0.677	0.653	0.624	0.651	0.830	[18]
Synsepalum longecuneatum	Sapotaceae	1	0.797	0.789	0.703	0.763	/	
Tessmania africana	Fabaceae	1	0.646	0.596	0.526	0.590	0.824	[18]
Tricalysia sp.	Rubiaceae	2	0.658	0.563	0.507	0.576	/	
Trichoscypha abut	Anacardiaceae	1	0.571	0.471	0.407	0.483	/	
Trichoscypha acuminata	Anacardiaceae	2	0.669	0.582	0.421	0.598	/	
Trichoscypha sp.	Anacardiaceae	1	0.693	0.644	0.462	0.599	/	
Triplochyton scleroxylon	Malvaceae	2	0.573	0.434	0.397	0.468	0.335	[18]
Uapaca acuminata	Euphorbiaceae	1	0.611	0.568	0.480	0.553	/	
Uapaca guinensis	Euphorbiaceae	3	0.592	0.549	0.397	0.513	0.612	[18]
Uapaca heudellotii	Euphorbiaceae	2	0.616	0.591	0.500	0.569	0.614	[18]
Uapaca paludosa	Euphorbiaceae	7	0.618	0.532	0.501	0.535	0.652	[18]
Uapaca sp.	Euphorbiaceae	4	0.605	0.599	0.475	0.560		
Zanthoxyllum buesgenii	Rutaceae	1	0.581	0.529	0.556	0.555	/	
Unknow species (N=26 species)		65	0.592	0.571	0.509	0.557		