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Original Research Article

Estimation of the Aerial Biomass of Trees with Non-Conforming Trunks (Foothills) of the Forests of the Congolese Central Basin by the Method Non-Destructive: Case of the YASIKIA Forests (Opala/Tshopo Province/DRC)

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Abstract

Summary: It is important to estimate the aboveground biomass and carbon stocks of trees with non-conforming trunks in the forests of the central Congolese basin to plan resource management and to assess the contribution of these forests in mitigating the effects of climate change and, this within the framework of conservation at the scale of a reserve, that for Measuring, Reporting and Verifying forest carbon stocks within the framework of national strategies for the reduction of greenhouse gas emissions linked Deforestation and Forest Degradation (REDD+). This study aimed to set up a protocol for estimating the aerial biomass and the corresponding carbon stocks of trees with particular architecture in the Yasikia forest. To succeed, a dendrometric study was carried out for all trees with non-compliant trunks. Dendrometric data were collected on 189 trees divided into 9 families and 20 species. The results of this study show that it is preferable to use the equivalent diameter for a good estimate of the biomass because taking the diameter at the end of the buttress or above, underestimates the quantity of biomass for a tree with a trunk not compliant. The equation used to estimate the woody biomass from different diameters was that of Brown *et al.*, (1989). The results of this study show that it is preferable to use the equivalent diameter for a good estimate of the biomass because taking the diameter at the end of the buttress or above, underestimates the quantity of biomass for a tree with a trunk not compliant. The equation used to estimate the woody biomass from different diameters was that of Brown *et al.*, (1989). The results of this study show that it is preferable to use the equivalent diameter for a good estimate of the biomass because taking the diameter at the end of the buttress or above, underestimates the quantity of biomass for a tree with a trunk not compliant. The equation used to estimate the woody biomass from different diameters was that of Brown *et al*., (1989).

Keywords: Woody biomass, carbon stocks, Nonconforming trunk, Yasikia forests.

1. INTRODUCTION

African forests, which represent 15% of the world's forest carbon stock (COMIFAC, 2005; Laporte *et al*., 2008), remain little studied (Vincke, 2011). Consequently, few data on the biomass of Central African forests are currently available and often scattered. Scientific knowledge is still insufficient and imprecise for many tropical species (Amsallem *et al*., 2004). It is therefore essential that research on these different aspects be promoted, in order to better plan the management and preservation of forest resources.

When collecting dendrometric data intended for the estimation of biomass, in practice, it is not the dbh that is measured directly, but the circumference C of the trunk of the tree at a height of 1.30 m, at with the help of a graduated flexible ribbon surrounding the trunk (Picard and Gourlet, 2008). The basal area of the tree is, by definition, the cross-sectional area of the trunk of the tree at 1.30 m in height, and is estimated from the circumference by the relation $S = C^2/4\pi$ (Picard and Gourlet, op.cit).

The equivalent diameter, De, is the diameter of a tree whose trunk would have a perfectly cylindrical shape and the same basal area as the subject tree. Thus: $De = C/\pi$.

It should be noted that, when the trunk of the tree has a cylindrical shape (conforming trunk), its dbh is identified with its equivalent diameter. But the more the shape of the trunk deviates from a cylinder, the greater the difference between the dbh and the equivalent diameter. For non-conforming trunks, especially those of buttressed or stilt-rooted trees, circumference measurement no longer makes sense. This is how the circumference is measured above buttresses according to the recommendations given by Clark *et al*., (2001). We are then led to measure the circumference no longer at 1.30 m in height, but at a sufficient height h for the trunk to regain a cylindrical shape.

The problem is that the basal area (and therefore the equivalent diameter) at a height h is lower than the basal area at 1.30 m (and therefore the dbh). This results in a systematic underestimation of the basal area and the biomass of trees with non-compliant trunks.

Indeed, in the central Congolese basin, several species of trees often have buttresses, kinds of more or less flattened expansions, with a vertical side adhering to the trunk and another horizontal superimposed on large tracing roots thus forming winged shoulders. at the base of the shaft (Puig, 2001). These are flattened roots that rise high enough on the trunk that they appear strangled (Quentin, 2011). Among the buttresses there are shoulders and serifs. The shoulders are slightly marked upright buttresses and the footings are poorly developed buttresses formed by connections of the large roots at the base of the trunk (Dany, 2010).

The vegetation of Yasikia, on the other hand, is a mix of evergreen forests, including large tracts of "monodominant" forests of Gilbertiodendron dewevrei and "mixed" forests in which no species is dominant, but certain Caesalpinioid legumes, such as Julbernardia seretii (De Wild) J. Leonard and Cynometra alexandri CH Wright, are very abundant (Makana *et al*., 2001). When a stand contains many trees with non-conforming trunks, it is the stand's biomass and basal area that are underestimated (Estimated biomass < Observed biomass).

From the above, it can be seen that the diameter is one of the most used main input variables (Gnangle, 2012) and can be the source of several uncertainties (errors of estimation) on the estimation of biomass and the contribution of the forests of the central Congolese basin in general and even for those of Yasikia to the global carbon cycle. Gnangle (2012) points out that for an evergreen forest the aerial biomass is concentrated in the trunks. Although the measurement of buttresses is difficult (terrain + calculation) (Matieu, 2013 in Dany, 2010), it is imperative that the biases and inconsistencies for the feet of trees with buttresses which present mechanical constraints be elucidated.

To mark out this fact, three questions were asked.

1. What is the structure of a stand of non-conforming trunk trees in one hectare?
2. What are the amounts of aboveground biomass and carbon stocks resulting from girth captures at different heights of trees with nonconforming trunks?
3. What effect do the different measurements made on a tree with a non-compliant trunk (D1.30; Dfc and Dfc+30) have on the estimation of the biomass?

To these questions, the corresponding hypotheses are formulated as follows:

1. Due to their large root expansions, trees with non-conforming trunks are largely those with large diameters and low relative density in a one-hectare plot.
2. Taking into account the particularity of these feet, the amounts of aerial biomass and carbon stocks of trees with non-conforming trunks are higher than those found in the literature.
3. Given that these trees do not have a cylindrical trunk, the different Circumference measurements (C1.30; Cfc and Cfc+30) cause a variation thus causing an underestimation of the equivalent biomass of trees with non-conforming trunks.

In this regard, this study aims to implement a protocol for estimating the aboveground biomass of trees with non-conforming trunks constituting the stand.

Specifically:

1. Analyze the structure of the stand of non-conforming trunk trees in Yasikia forests.
2. Estimate aboveground biomass and carbon stocks specifically for this architectural class of trees.
3. Analyze the variations in biomass caused by the different measurements made on trees with non-conforming architecture in the forests of Yasikia.

2. METHODOLOGY

2.1. Study site

This study was carried out in the Yasikia forest located in the central basin of the Congo basin, south of the city of Kisangani, in the Democratic Republic of Congo in the Province of Tshopo, Territory of Opala. It extends between the equator at 1° north latitude and between ~1° and 25° east longitude.

The topography of the area is gentle, with occasional hills including small stretches of shallow rocky ground.

The soils in this region are derived from Precambrian granitic rock and can be classified into the ferralitic order that dominates most of the Congo Forest

Basin (Brady 1990 in Dany, 2010). They are generally very deep, uniform in texture, and lacking distinct horizons from ~3 cm to 150 cm depth. These soils have a sandy to sandy-clayey texture. They are acidic and poor in nutrients, particularly phosphorus and nitrogen (Makana *et al*., 2001).

The description of the dense forests of Yasikia links it to the Guinean-Congolese region (White, 1981 and 1986). The inventory work carried out in these forests shows that most of the forests are characterized by the floristic procession dominated by Scorodophloeus zenkeri Harms.

1.2 Methodological approaches

1.2.1. Delimitation, inventory and identification

After a field prospection which made it possible to locate the interesting forest blocks, undisturbed and having presented favorable conditions for the installation of the devices. A total of 48 plots have been defined and materialized on the ground. They have a square shape (25 x 25m) in a total area of 3 ha; due to 16 plots per hectare. For each hectare, we drew four main lines to delimit a plot with nylon strings and nine (9) secondary lines equidistant by 10 m and perpendicular to the main lines for the grid of the plot. The identifications of the species initiated in the field were verified both by comparison with the reference specimens kept in the herbaria of the National Herbarium of Yangambi. In addition, we used the flora and botanical works concerning tropical Africa and the catalog of vascular plants in the districts of Kisangani and Tshopo Lejoly *et al*., 2010.

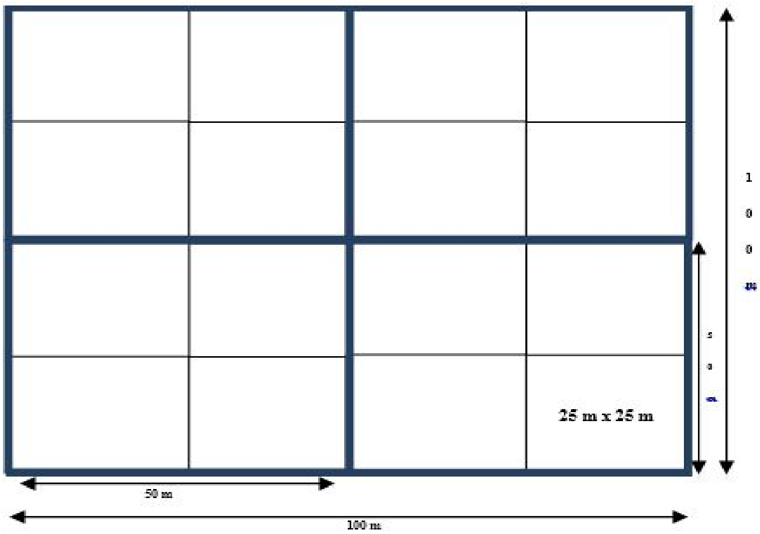

Figure 1: Representation of the sampling device

After the establishment of two devices of one hectare each, any woody plant erected with a diameter greater than 10 cm and having buttresses at 1.30 m were measured, identified and assigned a particular number which allows its identification in the field. Thus each label bears a unique number formed of three digits. The numbers are assigned according to the columns of the plots from south to north or from east to west depending on the layout of the plot, and inside the plot following a well-defined order and the circumference was measured according to three methods:

- Measurement of the circumference of the trunk at 1.30 m in height at the level of the buttresses using a specific tape, the dbh;
- Measurement of the circumference of the trunk at a height h above the buttresses using a specific tape, the dbh;
- Measurement of the circumference at +30 cm from the end of the buttresses.

Tree height, which is an important variable for biomass predictions, is rarely performed because it requires additional effort (Quentin, 2012). For a good number of forest inventories, it is predicted by a model linking it to its diameter. In the context of the present study, it was measured using a VERTEX IV for all the trees.

2.2.2. Analysis and data processing:

a) Predictive circumference model

The variable which interests the forester and which is difficult to measure on a tree with a non-conforming trunk is the equivalent circumference (Ceq) at 1.30 m. On the other hand, the variables that are easy to measure are:

The circumference at 1.30 m ribbon stretched on the buttresses (C130)

The circumference above the buttresses, where the trunk becomes cylindrical again (Cfc)

The circumference measurement height at which the trunk becomes cylindrical again (h)

In order to estimate the equivalent circumference, we sought to adjust a model predicting

this Ceq according to the explanatory variables which are the circumference at 1.30 m (C130), the circumference above the buttresses (Cfc) and the circumference at a height (h). The model to be fitted was given by the average of three circumferences:
Ceq = (C130 + Cfc+Cfc+30)/3 …………….. [1]

Where,

C130 = Circumference at 1.30m on the foothills
Cfc = Circumference at the end of the buttresses
Cfc+30 = Circumference at +30cm from the end of the buttresses

b) Analysis of the structure

After having obtained the equivalent circumference, variable which made it possible to calculate the basal area (ST) of the stand studied and to establish the diameter distribution of the stems in classes of diameter of 10 cm? The ST is expressed in m²/ha, and the formula for the ST of a tree is noted small (g) = (ð × d2)/4 [2]. The basal area of a stand is noted as large (G) and represents the sum of the small (g) of all the trees that make up this stand (Pardré and Bouchon, 1988). It is therefore expressed in square meters per hectare (m2/ha). In the context of this study, the equivalent diameter was used.

The distribution or distribution of individuals by classes is of great interest in forest management because it is an expression of stand structure. It also reflects the reaction of the latter to ecological conditions. This distribution will be made by class of dbh, crown diameter, total height and bole height. All the trees thus distributed according to the different classes, will be represented by histograms on the basis of their frequency. It was about the distribution by classes of individuals or numbers.

c) Calculation of densities

$$Density\ (m^2/ha) = \frac{\sum_{i=1}^{n} \pi \frac{Di^2}{4} (m^2)}{Superficit\ of\ site\ (ha)} \text{ ……… [3]}$$

With i an integer which varies from 1 to n number of stems
Di: diameter at breast height (1.30m) of i stem

d) Above-ground biomass estimation and allometric equations

In the case of the present study, we have precisely the total aboveground biomass of a tree (AGB) from the allometric equation of Brown *et al.*, (1989) taking into account density and diameter
AGBest = Exp (-2.134+2.53ln(D2) [4] (Brown *et al.*, 1989)

e) Carbon stock estimate

Estimation of carbon stock in the forest depends on knowledge of dry aboveground biomass (Vieira *et al.*, 2008). It has been reported that the carbon contained in the dry biomass of a tree is 50% (Brown, 1997; Houghton *et al.*, 2001; Baker *et al.*, 2004; Chave *et al.*, 2005; Lewis *et al.*, 2009).

For our study, the amount of Carbon Dioxide (CO2) that would be emitted into the atmosphere if all buttress trees in the plot – sample were cut down and burned completely can be calculated as follows: AGB x 0.5 [5].

Where: AGB = The total dry and living aboveground biomass in the sample plot; 0.5= conversion factor.

3. Presentation of the results obtained

In this part, we calibrate the results obtained in two parts. The first focuses on the distribution of individuals into families according to the diametric structure and the second will relate to the estimation of aerial AGB and carbon stocks.

1.1. Structure

In order to determine the type of forest in which the inventory was carried out, we carefully analyzed four (4) parameters (density of families, basal area, density of trees in plots and diameter distribution).

1.2. Relative density of families

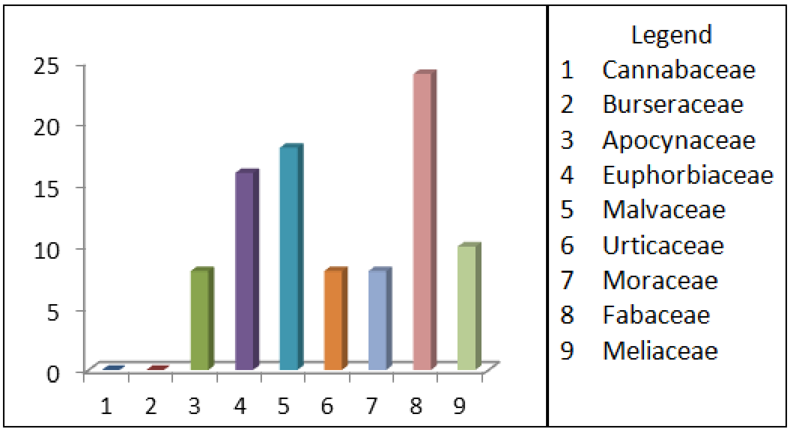

Figure 2: Distribution of families in the waves.

It is important to note that this observation comes from three hectares made in the natural forest of Yasikia. This figure shows that the Fabaceae (75%) form the family with the highest relative diversity. It plays a major role at the level of each structural group, whether in terms of density or dominance.

In short, we can say that the species belonging to the Fabaceae family are the most diversified and arranged of the foothills for the case of our study.

Basal areas according to diameter classes

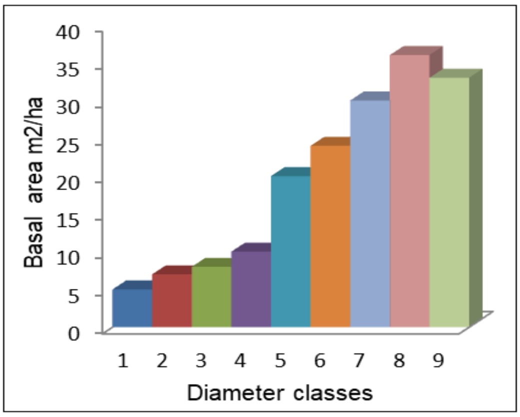

Figure 3: Representation of basal area by diameter class

Reading this figure shows the distribution of basal areas according to diameter classes. It seems necessary to us to specify that on this histogram, the classes of diameter range from [10 -20 cm] to [90 -100 cm]. The classes [80 - 90 cm] and [90 - 100cm] occupy the largest proportion of basal areas in our plots, followed by those of average diameter [70 - 80 cm].

Density of trees with non-conforming trunks and the basal area by species in the plots

A total of 189 trees were sampled on three plots of one hectare each (57 trees for plot 1; 65 trees for plot 2 and 67 trees for plot 3). These 189 feet are divided into 20 different species. They have been identified and measured, they are divided into 14 genera and 9 families.

For all the species inventoried, the density as well as the different basal areas of each species are given in Table 1 below.

Table 1: Density and basal areas of inventoried species

Species	**Families**	**Densities (N.ind/ha)**	**STeq (m²/ha)**	**STfc (m²/ha)**	**STfc+30 (m²/ha)**
Alstonia boonei	Apocynaceae	5	3.830	2,850	2.657
Canarium schweinfurthii	Burseraceae	0.6	0.345	1.002	0.541
Celtis mildbraedii	Cannabaceae	2	0.073	0.070	0.065
cola altissima	Malvaceae	0.5	0.250	0.177	0.164
Dialium pentandrum	Fabaceae	1.04	0.445	0.399	0.542
Ficus mucus	Moraceae	0.8	0.26	0.091	0.087
Guibourtia demeusei	Fabaceae	0.5	0.030	0.028	0.027
Hunteria congolana	Apocynaceae	0.5	0.041	0.300	0.015
Julbernardia seretii	Fabaceae	13.5	8. 240	7.917	5.691
Khaya anthotheca	Meliaceae	0.5	0.154	0.144	0.138
Lovoa trichilioides	Meliaceae	0.5	0.293	0.290	0.273
Milicia excelsa	Moraceae	2	0.176	0.135	0.222
Musanga cecropioides	Urticaceae	0.4	0.234	0.122	0.602
Piptadeniastrum africanum	Fabaceae	0.56	0.325	0.267	0.255
Pterocarpus soyauxii	Fabaceae	0.5	0.135	0.108	0.106
Pterygota bequaertii	Malvaceae	0.6	0.055	0.065	0.034
Ricinodendron heudelotii	Euphorbiaceae	0.5	0.653	0.433	0.402
Scorodophloeus zenkeri	Fabaceae	34	29.666	20.962	17.390
Tragia tenuifolia	Euphorbiaceae	0.5	0.521	0.345	0.210
Treculia africana	Moraceae	0.5	0.601	0.411	0.467
Total		**63.00**	**46.027**	**36.12**	**29.89**

From the analysis of Table 1, it follows that the tree density in the three hectares of this part of the Yasikia forests is 63 individuals per hectare. The species Scorodophloeus zenkeri appears as the one with a high density (34 individuals per hectare). It is followed by the species Julbernardia seretii (13.5 individuals per hectare) and Alstonia boonei (5 individuals per hectare) while the other species have low densities in the three plots. Taking into account different measurement points, these trees occupy on average 46.027m²/ha for the equivalent diameter, 36.12 m²/ha for the diameter taken at the end of the foothills and 29.89m²/ha for the diameter at +30cm of buttresses.

Tree diameter distribution

Figure 5 shows the number of stems by diameter class.

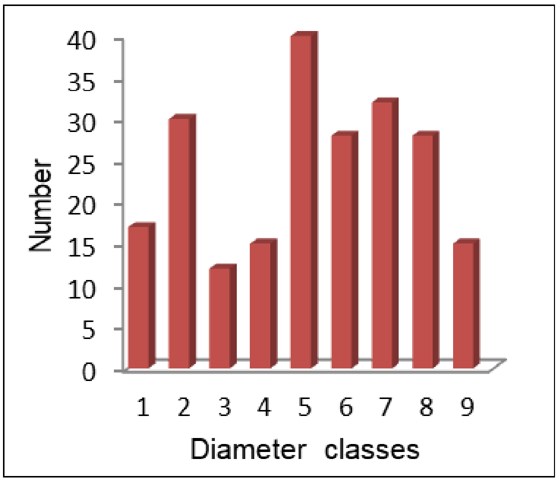

Figure 4: Diameter distribution of trees with non-compliant trunks in the plot

Figure 5 above illustrates densities as a function of diameter classes. It should be noted that trees with non-compliant trunks are more represented in diameter classes 2,5,6,7 and 8. The shape of the bars allows us to say that this structure is in the shape of a "Bell", with many trees of average size.

1.3. Aboveground woody biomass estimates and carbon stocks

In this study, the biomass and carbon stocks of 189 trees, belonging to 20 species, were obtained for each diameter measurement point and according to the allometric equation of Brown *et al*., 1989.

a) Biomass by species and diameter classes

In order to estimate the biomass of the plots of our study, the equation of Brown et al. 1989 was used. This equation showed that the biomass content of trees with a non-conforming trunk is 472.54 T/ha when the equivalent diameter is obtained. While when the diameter was just measured at the end of the foothills, the biomass obtained is 338.23T/ha and so when the diameter is taken at +30cm from the end of the foothills, the biomass is 246.36T/ha.

b) Biomass function and diameter distribution

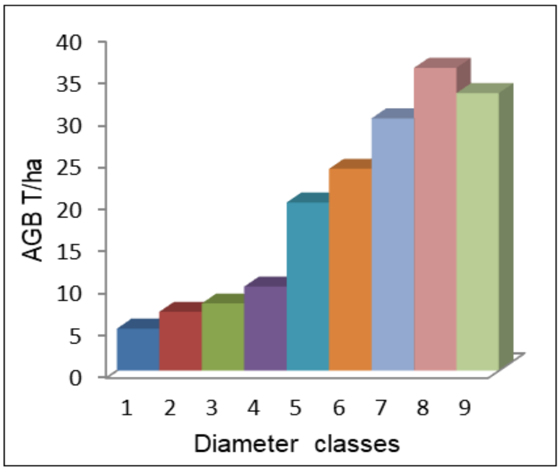

Figure 5: Biomass according to tree diameter classes

In view of this histogram, it appears that the greatest biomass is observed on large trees. We also note that the proportion of biomass for each diameter class in Figure 6 above is more significant in the diameter classes [50 – 60cm]; [70 – 80cm]; [80 – 90cm] and [90 – 100cm]. They represent on average 80% of the total AGB.

It should be noted that Brown (1997) and Puig *et al*., (1990) confirmed that "the amount of tree biomass increases with diameter".

2. Correlation study between AGB and basal area

For the plots of our study, we observe a proportional relationship between the AGB and the basal area.

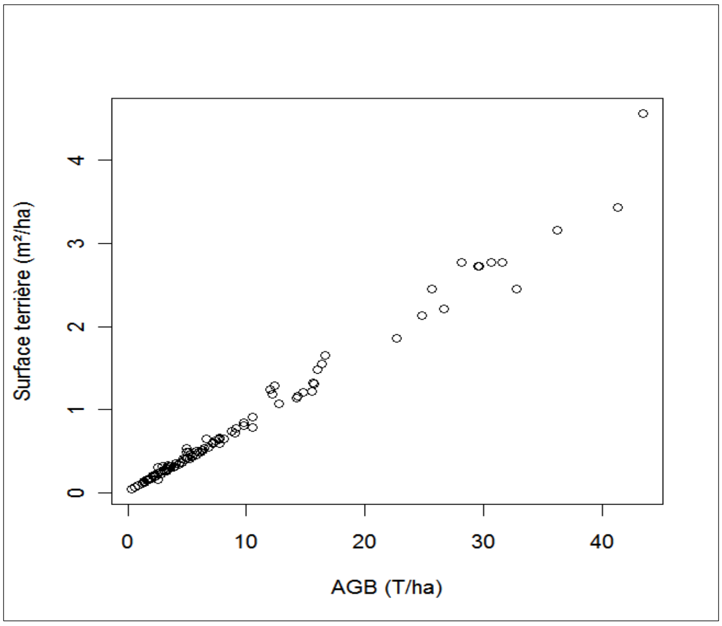

Figure 6: Correlation between AGB and basal area

We find that the highest value of AGB corresponds to the highest value of basal area and similarly the lowest value of AGB corresponds to the lowest value of basal area. This correlation is strong and positive (r=0.991; p-value= 2.2e-16). The proportion of biomass for each diameter class in the figure above shows that the aerial biomass of large buttressed trees (>50cm) represents on average 80% of that of the total AGB.

3. Talks

3.1. Plot size and methods

Plant organic matter is mainly produced by photosynthesis. Part of the production corresponds to an increase in biomass, harvestable by humans or by other consumers. Another part is usable by the vegetation for its own needs. The study we conducted in the field allowed us to evaluate the biomass for a specific category of vegetation trees. We do not know the optimal size of a forest production study plot in terms of biomass; this should be the subject of further research.

For our study, we worked on three plots of 10000m² (100 x 100m), i.e. 1 ha each. Studies by Poore (1968) showed that a plot of 2 to 4 ha was necessary to obtain a representative sample of a relatively homogeneous forest. Dany (2010) confirmed that there is an upper limit to the size of the plots since large areas increase diversity and no longer represent the same type of forest studied.

The study on the evaluation of the biomass must be done on a primary forest which has not yet undergone any human disturbance. For this evaluation, the classic method consists in cutting and weighing each organ of the tree. This method can only be applied in a forest in full exploitation. Our study being carried out in an undisturbed primary forest, we opted for the possible non-destruction of the structure of the forest and as an alternative, we used strings instead of layons to delimit our plots.

3.2. Stand structure

a) Density and diameter distribution

The density obtained in our different plots is on average 63 trees with non-compliant trunks/ha. This density only concerns trees with a particular status and cannot be reconciled with the values generally found in certain tropical forests in the world in the literature. ((HERTEL *et al*., 2009; GROENEVELD *et al*., 2009; Antin, 2009; LODHIYAL *et al*., 2009; ANONYMOUS, 2009; in CULMSEE *et al*., 2010). Stem density increases with increasing diameter classes (Table 1). Nevertheless, these results corroborate those found in the forests of the Ivindo National Park and the Ipassa Nature Reserve in Masuku in Cameroon by QUENTIN

(2011) who found a density of 51.5 trees with non-conforming trunk (buttress)/ha LOKE *et al*., (2015) obtained 50.5 trees with trunk with buttresses/ha in the forest of Epulu.

The study of the diameter distribution in our three plots shows that the individuals of small sizes are less numerous. Therefore, there would be no need to argue with the assumption of ROLLET (1971) in CULMSEE (2010) that "In a natural forest, tree diameters conform to an exponential distribution. So it is quite interesting to note that for trees with a non-conforming trunk, through our three study plots, this hypothesis does not correspond: there are many trees of large diameter and very few of small diameter. . LOKE et al. (op. cit.) have also pointed this out. This allows us to confirm our first hypothesis that trees with non-conforming trunks are largely those with large diameter and low relative density in a plot. It should be noted that based on this observation, this site meets the criterion of an undisturbed forest. To better support this idea, it is interesting to observe the proportion of AGB and basal area classes ≥ 50 cm.

b) The basal area

In the literature, we have found that the basal area of several 1 ha plots in tropical rainforests in some countries of the world is between 30.7m²/ha and 45.75m²/ha. However, our results show basal area values significantly higher than those observed in many forests around the world. For all of our three plots, the total equivalent basal area is 46.027m²/ha, while the trees with non-conforming trunks are only a procession of trees in a plot. It should be mentioned that the basal area of the trees covered by this study increases with increasing diameter classes.

3.3. Total Biomass

Our study provides the most accurate estimate of total AGB currently available for trees with nonconforming trunks in the central Congolese basin at Yasikia. A general conclusion is that in these very satisfactory forests settling about 472.54 T/ha for trees with non-conforming trunks on average for the study site. In Epulu, LOKE *et al*., (2015) obtained 469.770 T/ha. Note that this estimate was made using an improved allometric model (BROWN *et al*., 1989) to estimate tree biomass.

Our AGB results for the study plots do not correspond to the values obtained in the literature following the attribution of a special status to trees with non-compliant architecture. This allows us to confirm our second hypothesis stipulating that the quantities of AGB and carbon stocks of trees with non-conforming trunks are higher than those found in the literature.

In our three plots, tall trees (≥ 60 cm DBH) represent 80% of aboveground biomass. It should be confirmed that in tropical forests, large trees are inevitably the dominant element of aboveground biomass. This was also confirmed by LOKE *et al*., (2015) in Epulu.

4.1. Biomass and different measurements

The figure below presents the comparative situation of different measurements made on a tree with a non-compliant trunk with the estimate of the biomass.

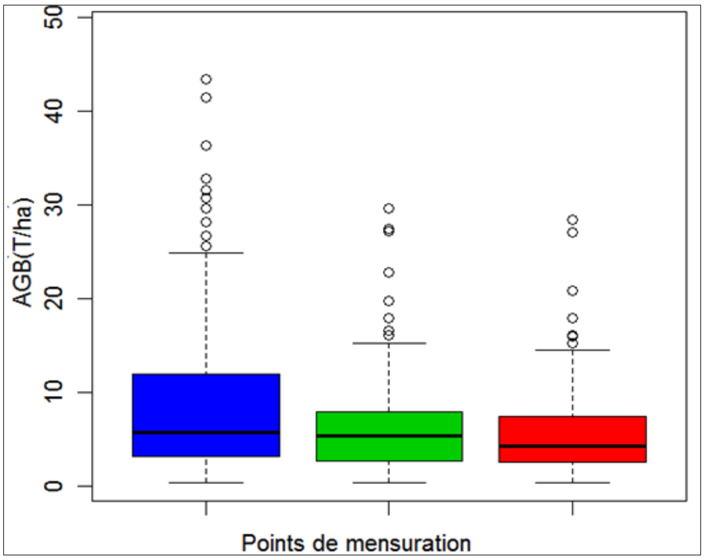

Figure 7: AGB per measurement point (Deq, Dfc and Dfc+30)

Using a single allometric equation (BROWN *et al*., 1989), we tried to apply it to different measurement points of Diameter. After comparing these three AGBs, we found that there are large variations between the AGB calculated from Deq, Dfc and Dfc+30. After analysis of variation, we found a large heteroscedasticity between variables (AGBeq > or ≠ de AGBfc > or ≠ AGBfc+30) with P-value= 2.2e-16; dl=98; α=0.1. The P-value being lower than the threshold, these three AGB are significantly different.

This allows us to confirm our last and third hypothesis according to which the different Circumference measurements (C1.30, Cfc and Cfc+30) cause a variation thus causing an underestimation of the equivalent biomass of trees with non-conforming trunks. To that,

4. Conclusion and perspectives

In this study, we elucidated an accurate estimate of aboveground woody biomass and carbon stocks by the non-destructive method of trees with buttresses of the Yasikia forest using the three-modality circumference measurement (1.30m on buttresses, Fin buttresses at a height h and 30cm from the end of the buttresses) and the density of the wood.

The three hypotheses put forward were all confirmed and the assigned objectives were achieved insofar as we were able to obtain their structure and an estimate of the appropriate AGB for this procession of trees.

This allows us to conclude that the Pantropical model developed by BROWN et al. (1989), seems to be the most appropriate for this work. However, researchers FOSTER et al. (2002) specified that no statistical procedure makes it possible to decide without ambiguity which model is the best.

By comparing the values of the basal area (varying from 0.066 to 46.027 m2/ha) and the density (on average of 63 trees with non-compliant trunks per hectare) of our three study plots with data from the literature: 35.4 m2/ha for the basal area and 476 trees per hectare for the density according to CULMSEE *et al*., (2010) in Indonesia, we have evidence that Yasikia forests show exceptional structure.

Regarding aboveground biomass and carbon stocks, our estimates are different from those found in the literature and this is justified by the prediction of equivalent diameter. This biomass varies according to the diameter measurement point.

Outlook

Taking into account the interest of this study and its importance on a planetary scale; certain recommendations were retained:

- Some plots deserve to be retraced in order to avoid huge margins of error on the measurements of the trees.
- The estimate of the aboveground biomass should be carried out by attributing to buttress trees (or other epiphytes, lianas, ferns, palms, with stilt roots) a particular status making it possible to obtain the equivalent circumference.
- Upstream of management projects for these forests, carbon stock quantification would be needed to quantify potential carbon gains or losses in the Yasikia Forest.

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