Carbon Stock Estimation In Secondary Forest And Gallery Forest Of Congo Using Allometric Equations

Romeo Ekoungoulou, Xiaodong Liu, Suspense Averti Ifo, Jean Joel Loumeto, Fousseni Folega

Abstract: The research was aimed to estimate the carbon stocks of above-and below-ground biomass in the secondary and gallery forest of Lesio-louna (Republic of Congo). The methodology of Allometric equations was used to measure the carbon stock of Lesio-louna natural forest. We were based precisely on the model II which is also called non-destructive method or indirect method of measuring carbon stock. We used parameters such as the Diameter at Breast Height (DBH) and wood density. The research was done with 6 circular plots each 1256m^2, with a distance of 100m between each plot, depending on the topography of the site of installation of these plots. The six studied plots were divided into two sites, which are: Inkou Forest Island (Secondary forest) and Blue Lake Forest (Gallery forest). Thus, in the 6 plots with 77 trees, there were three plots in Inkou Forest Island site and three plots in Blue Lake Forest site. The results of this study showed that the average carbon stock in 6 plots of the study was 130.9908333 t C /ha for above-ground biomass (AGB) and 30.78283179 t C /ha for below-ground biomass (BGB). In this forest ecosystem, the average carbon stock of AGB was more important in secondary forest compared to gallery forest with respectively 135.9763333 t C /ha against 126.0053 t C /ha. Also, the average carbon stock of BGB was higher in secondary forest (31.9544076 t C /ha) compared to gallery forest (29.61126 t C /ha). This study shows that the species density is higher in the secondary forest (3 plots with 44 trees) compared to the gallery forest (3 plots with 33 trees). This research indicates that, the forests component in the study area could appoint as an important carbon reservoir, and can also play a key role in climate change mitigation.

Keywords: Carbon stock, Secondary forest, Gallery forest, Above-ground biomass, Inkou forest island, Below-ground biomass, Blue lake forest.

1 INTRODUCTION

African countries in general and Congo in particular, have currently low Greenhouse Gas (GHG) emissions [20]. They are also the subject of carbon credit providers for the North and experience the first impacts of climate change [21-24].

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The forest plays a key role in the mitigation of this phenomenon by photosynthesis [21]. Globally, terrestrial ecosystems sequester annually 1.4 ± 0.7 P g1C.yr^{-1}, or 22.2% about the flux of fossil fuels [24]. The scope of the problem of Climate Change global response is clearly mentioned in the United Nations Framework Convention on Climate Change adopted at the World Summit on Sustainable Development called "Earth Summit held in Rio de Janeiro, Brazil in 1992 and the Kyoto Protocol adopted at the third session of the conference of the Parties in December 1997 in Kyoto, Japan [25]. Decisions which aimed at stabilizing concentrations of greenhouse gases in the atmosphere at a level which prevents dangerous interference with the global climate system were taken. Since the 13th Conference of the Parties (COP13) to the United Nations Framework Convention on Climate Change (UNFCCC) in Bali in 2007, the UNFCCC has progressively recognized the package of measures now known as REDD+, which stands for Reducing Emissions from Deforestation and forest Degradation, as well as the conservation and sustainable management of forests, and the enhancement of forest carbon stocks in developing country forests. At the COP16 in Cancun in 2010, REDD+ was officially incorporated into the UNFCCC's agreement on climate change. At COP17 in Durban in 2011, negotiators agreed on monitoring guidelines as safeguards for REDD+ implementation and on the means for developing estimates of emissions that would have occurred in the absence of REDD$^+$ [26]. Defining legally binding targets for reducing emissions Greenhouse Gas (GHG) emissions for developed countries during the period 2008-2011 was one of the issues [21]. This problem which focuses the attention of the international community following the combination of two factors, first, the IPCC [24] report that emissions of Greenhouse Gases (GHG) in the tropics represent between 20 and 25 % of carbon dioxide (CO_2) therefore retained Rainforest with "living trees" should be considered as a mitigation measure to reduce climate change. That is why the countries of the Congo Basin including the Republic of Congo have now grasped the importance of REDD (Reducing Emissions from Deforestation and Degradation) in the post-Kyoto targets and organize for their interests are recognized and taken into account [13-21]. Managing standing forests better, and expanding tree cover through socially- and environmentally-responsible reforestation and restoration, are cost- and time-effective strategies to conserve and enhance carbon stocks and mitigate climate change, as well as to facilitate adaptation. Integrating the + in REDD with carbon conservation in plant systems capitalizes on the potential of whole-of-landscape responses to climate change. Moreover, industrialized countries subject to the obligations of the Kyoto Protocol in reducing their anthropogenic GHG (Greenhouse Gas) purchase AAUs to other countries, or invest in emission reducing projects. They can under certain conditions be given another type of carbon credit [25]. Reference levels (RLs) and reference emission levels (RELs) are most commonly used as a business baselines to assess a country's performance in implementing REDD+ [25]. RLs are needed to establish a reference point or benchmark against which actual emissions (and removals) are compared. In fact, emissions reductions cannot be defined without having first agreed on the RL, which is therefore critical for gauging the effectiveness or forest carbon impact of REDD+ policies and activities. New research at CIFOR (Center for International Forestry Research) on a stepwise approach provides guidance on how countries with little data can begin to develop RL, and can improve their estimates as better data becomes available [16]. Faced with this situation, the quantification of carbon stocks and fluxes between the various reservoirs continental and aquatic ecosystems are currently a priority to the international community in general and the Intergovernmental Panel on Climate Change in particular. Finally they better predict the potential role of Congolese forest on the evolution of the atmosphere by greenhouse gas emissions and therefore climate change [20]. However, these studies have largely focused on the number of trees damaged [4-20]. The study of Pearson et al. [33] detailed the carbon impact, but not in the context of gap size or even volume of timber extracted. Thus, in the context of climate change, particular attention is given to carbon a major constituent of greenhouse gas emissions as mentioned by Chambers *et al*. [12] and Chave *et al*. [14]. The forest has a very important role in mitigating this phenomenon as mentioned by Hall [26]. But the assessment of carbon stocks in this ecosystem is not yet known satisfactorily for countries with this heritage can access the "carbon credit" which is another way to take advantage of the forest. Very little information exists in the field of forest carbon on the Congo [21]. However, there exist five (05) carbon reservoirs in a forest ecosystem: soil, plant debris (dead wood, dead roots, leaf litter), the air compartment (AGB), below-ground biomass (BGB), and herbaceous [2].In Congo, monitoring changes in carbon stocks serves as a method of assessing the impact of forest management activities, and also helps determine the role forest harvesting plays in the global carbon cycle [8]. To monitor logging impacts on carbon stocks in Republic of Congo, factors are required to link reported data or readily monitored components with the total carbon impact. The two most obvious factors for correlation are volume extracted (which is widely reported) and gap size (which can be determined remotely). Correlation factors can be created through an initial set of ground measurements. To our knowledge, only one study has created factors linking gap size or volume extracted with biomass damaged [35]. Many studies have examined logging and associated damage both in conventional and reduced impact scenarios [8]. The use of allometric regression models is a crucial step in estimating above-ground biomass (AGB), yet it is seldom directly tested [15]. Thus, the aim of this study is to estimate the carbon stock in secondary forest and gallery forest in Lesio-louna (Teke trays) area of Congo. So, the results of this research will be useful to the Congolese program about the carbon forest sequestration by MDDEFE-REDD+/WRI Project. Within the carbon market, the result of this study (carbon stock in Lesio-louna tropical rainforest) will allow the Republic of Congo to get the credit of carbon.

2 Materials and Methods

2.1 Study Area

The study sites are located at Lesio-louna (14° E, 4° S), 140 km North East of Brazzaville in Teke Trays (Republic of Congo). Lesio-louna is in the Teke Trays of Republic of Congo, that is located in the sub-prefecture of Ngabe, the department of Pool in Republic of Congo (Fig. 1). Also, Lesio-louna (Fig. 1) is a wildlife reserve that extends over approximately 173.000 ha. Then, the Teke Trays are a wide range of trays starting from Republic of Gabon crossing Republic of Congo to the Democratic Republic of Congo. However, the average annual rainfall is 2100 mm (2006-2008) with a marked dry season from June to September and an annual average air temperature of 26°C [1]. The soil is a deep acidic sandy aerosol with clay content varying from 0.3 to 7.6% [2]. The area studied is dominated by forest groves at the Gallery Forest (GF) with many individuals of *Colletoecema dewevrei* (De Wild.) Petit. [Rubiaceae] and *Eriocoelum microspermum* (De Wild.) Radlk. [Sapindaceae] and a hill-slope forest clump (HF) dominated by *Musanga cecropioides* R. Br. [Urticaceae] and *Macaranga barteri* Mull.Arg. [Euphorbiaceae]. The height of the canopy was approximately 20-26 in Gallery forest and 15-21 m in Secondary forest [2].

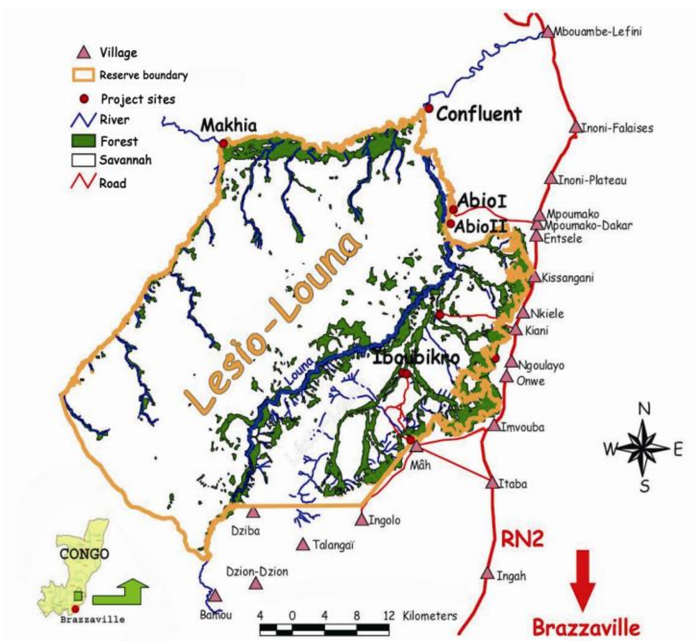

Fig. 1. Location of survey area

2.2 Data Collection

In this study, above ground biomass and carbon stocks of trees were estimated using allometric equations of Chave *et al*. [15], which are suitable for measurements of trees. For reasons of convenience, we estimated tree biomass based on the equations that relate biomass to diameter at breast height (DBH). Although the combination of diameter at breast height (DBH) and height is often higher than the diameter at breast height (DBH) alone, measuring the height of trees can be a lengthy operation and increase the cost of any monitoring program (Fig. 2). In addition, the databases for the trees around the world show that regression equations of biomass of the highest range and accuracy can be generated using only the diameter at breast height (DBH). During the measurements of this study, the height of the chest was 1.30 m above the ground for each tree [11].

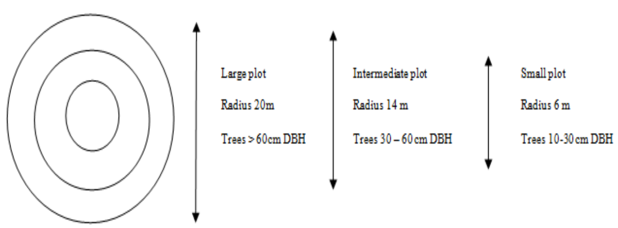

Fig. 2. Circular plot of diameter measurement at breast height (DBH) in forest ecosystem. The schematic diagram represents a sample plot consisting of three concentric circles.

This work was done with the use of the compass to know the North, South, East and West positions. Thus, measurements were made from the center of the plot to the North part, then from the center of the plot to the South part. Following was from the center of plot to the East part, followed from the center of plot to the West part. This work was repeated in all six (6) plots of our study area in Lesio-louna forest. Also, we used the GPS to meet the GPS waypoint of each plot, about a precision of the geographical position of each plot and the entire study area. So, GPS waypoints were observed in the center of each plot and the compass was used as the center of each plot of this tropical forest. However, when trees are labeled, the label and the aluminum nail must be placed 10 cm below the line of diameter at breast height (DBH) to avoid errors arising from bumps and other imperfections that may be found in the same place where the nail penetrates the tree [35]. For future inventories of the measurement will be made by measuring 10 cm of DBH above the nail. Aluminum nail should be planted deep enough to securely retain the label while leaving enough space to allow the tree to grow. If the objective is that the trees of the project area will be harvested later, the nail and the label must be placed at the base of the tree to avoid any accident involving chain saws and other equipment accidents. Each plot should contain a description of the method used for the next measurement to be carried out with efficiency and accuracy. Thus, the description of the approach used to measure trees of this study was incorporated into the data collection to allow measurements to be made with precision. The steps to follow were:

- Accurately locate the center of the plot (the use of GPS was used the method);
- As it was circular permanent plots had marks at the center and allocate a unique number to the plot. Experience has shown that the metal rods and PVC pipe work well for marking permanent plots;
- Starting with the North plot, measure DBH trees. Make a mark on the first shaft to indicate the start / end. Measure the chest height (1.3 m);
- After each tree, move in the clockwise direction to the next tree. If the plots should be measured again later, mark each tree using a numbered label and aluminum nail. It was necessary for us to save the tree species (scientific name). Each tree had a label with number and a scientific name well recorded;
- To allow an accurate count of regrowth (tree grows in the class of the smallest plot size), you must record the location of new trees each census over each nests plot;
- Occasionally trees are near the boundaries of the plots. Typically, plots are small (diameter is 40 m) and will be extrapolated to estimate the carbon in biomass per hectare. It is therefore important to carefully decide if a tree is in or out of the plot. If more than 50% of the shaft is inside the edges of the plot, the shaft is included. If more than 50% is outside the limits, the shaft is not excluded and is to be measured. It is exactly on the edge of the plot, choose whether inside or outside [34-35].

2.3 Measuring of Diameter at Breast Height of Trees

It's important that the diameter at breast height (DBH) tape is properly used to ensure the consistency of measurements made (Fig. 2). The following steps are to be respected:

- Make sure you have a bar or a pole with a length of 1.3 m to accurately measure line chest height on the tree. If there is none, using a large piece (2 cm of diameter) in better as reported by Pearson and Brown [35]. In turn, each member of the survey team should measure itself on the location of the breast height is 1.3m above the ground and rely on this site to determine where to put the meter tape;
- DBH tapes have a hook at the end. Push the hook into the bark of the tree and pull the tape to the right. DBH tape is always from the left and be pulled around the tree, even if the operator who takes action is a southpaw;
- When the tape is worn around the shaft and returns to the hook, the tape should be located above the hook. The tape should be upright and not upside down, the numbers must be in the correct reading order;
- If the tree is on a slope, always measure up the slope;
- If the shaft is tilted, the DBH tape should be worn according to the natural angle of the shaft, without taking into account the slope of the ground relative to the horizontal;
- If the tree has a fork at the chest level, take such action under the fork, and if that is not possible, consider that you are measuring two trees;

- If the tree is lying but still alive, then place the measuring stick down and measure at breast height as if the tree was standing. Trees are considered alive if they have green leaves;
- If a vine is growing on a tree to be measured, we do not cut the vine to clear a space to measure the diameter at breast height. If possible, move away from the vine trunk and drag the tape below. If the vine is too large to be removed from the trunk, we use the back of the ribbon and pull the front of the tree to assess the diameter of first hand. Cutting a vine should be the last option because in the long term with repeated measures taken, interfere with the natural dynamics of the plot eventually differentiate it from the surrounding forest. The same principle has to be respected for any other natural species found on a tree.

3 DATA ANALYSIS AND RESULTS

We used the model II of non-destructive method of Chave et al. [15], to measure the carbon stocks of above aground biomass in the study area (Inkou forest island and Blue Lake forest of Lesio-louna tropical area). Equation of Chave et al. [15] is a mathematic equation [15] to estimate the carbon stocks of aboveground biomass. Mokany's equation is a mathematic equation [29] to estimate the carbon stock of below-ground biomass.To calculate the carbon stock by using allometric equation of Chave *et al*. [15], we used two parameters, which are the wood density and DBH. Except allometric equations, the following software was used for statistical data processing: *SigmaPlot 10.0; SPSS 18.0* and *Microsoft Excel 10 as reported by* Richard *et al.* [36]. The *ArcGIS 10.0* software was used for geographical data processing. The study was made on 77 trees, with 6 plots of this forest ecosystem. The circle area of each plot is 1256 m^2 (Table 1). Then, the total above ground biomass of each tree in every plot was estimated using the following allometric equation:

$$AGB = \rho * expo\ (-1.239+1.980 \ln (DBH) + 0.207(\ln(DBH))^2 - 0.0281(\ln(DBH))^3)$$

For unidentified species, we applied the mean wood density for each plot weighted, by the number of trees from each species [35]. The general equation for the rainforests was chosen [15]:

$$AGB\ (kg) = \rho * exp\ (-1.239+1.980 \ln (D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

For example, one of our study's trees from the plot1 in Inkou Forest Island (secondary forest) had a DBH of 40.3 cm (Table 1). The scientific name of this tree is *Musanga cecropioides* (Urticaceae).Then, 40.3 cm is well within the maximum diameter at breast height for this equation, which is reliable up to 148 cm.

$$AGB\ (kg) = \rho * exp\ (-1.239+1.980 \ln (D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$$

$\rho = 0.05 g\ cm^{-3}$

$D = DBH = 40.3 cm$

$$AGB\ (kg) = \rho * exp\ (-1.239+1.980 \ln (DBH) + 0.207(\ln(DBH))^2 - 0.0281(\ln(DBH))^3)$$

The biomass of this *Musanga cecropioides* is 211.5 kg, so 0.2115t. Then, to determine the carbon quantity of this tree (*Musanga cecropioides*), we divided the biomass obtained by two [6-35]. So, the carbon stock estimation of this *Musanga cecropioides* from plot1 is 0.1057 t C.

To estimate the carbon stock of the below-ground biomass (BGBC), we used the equation from Mokany *et al.* [29]. The equation from Mokany *et al*. [29] is as follows:

$Y = 0.235 * AGB$ if $AGBC > 62.5$ t C/ha (1)

$Y = 0.205 * AGB$ if $AGBC \leq 62.5$ t C/ha (2)

So, *Y*= *BGBC*= Below-ground biomass carbon (t C /ha)

(1) $BGBC = 0.235 * AGB$ if $AGBC > 62.5$ t C/ha

(2) $BGBC = 0.205 * AGB$ if $AGBC \leq 62.5$ t C/ha

Table 1. Distribution of the carbon stock and area state in Lesio-louna natural forest

Plots	Forest Type	Nb. Trees	AGB[b]	BGB[c]	Nest Area[d]	Site	Average DBH[a]	Area State
P1	Secondary forest	14	137.914	32.4098172	1256	Inkou forest island	30.75	Normal
P2	Secondary forest	19	147.404	34.639853	1256	Inkou forest island	30.98	Normal
P3	Secondary forest	11	122.611	28.8135527	1256	Inkou forest island	42.01	ecosystem disturbance by fire
P4	Gallery forest	11	096.722	22.7297033	1256	Blue lake	24.49	Normal
P5	Gallery forest	11	153.274	36.0192979	1256	Blue lake	40.38	Normal
P6	Gallery forest	11	128.020	30.0847666	1256	Blue lake	41.91	Swamp

a: diameter at breast height (cm,), b: carbon stock of above-ground biomass (t C/ha), c: carbon stock of below-ground biomass (t C/ha), P: Plot, d: Nest area (in m^2)

3.1 Floristic and Specific Diversity

This study was realized in two sites of Lesio-louna in Congo, which are: Inkou Forest Island and Blue Lake Forest. Concerning trees sampling in this Lesio-louna forest, we used the DBH$\geq$10 cm because this tropical rainforest is not quite young as suggested by some authors [18-23]. The stems less than 10 cm would be measured in a forest quite young [20]. However, this study was done with 6 circular plots each 1256m^2, so 20m of radius by plot (Fig. 2). Thus, in six plots, three plots are in the secondary forest, precisely in Inkou Forest Island and three plots in the gallery forest. Three plots of secondary forest include 44 trees measured during the study. Also, other 3 plots are in the Blue Lake Forest (gallery forest). During the study, 44 trees of the Blue Lake Forest were measured. The total number of trees measured in this study for the study area was 77 trees (Fig. 3). The 77 trees in study area are the trees with DBH$\geq$10cm [5-22]. For the distribution of trees by diameter class, we observed in the study area: 31 trees for the diameter class 10-30cm, 36 trees for the diameter class 30-60cm and 10 trees for the diameter class > 60cm. We obtained the high number of trees in the diameter class 30-60 which is precisely in plot 2 with 13 trees (Table 2).

Table 2. Distribution of trees in six plots of the study area (Inkou Forest Island and Blue Lake Forest) by diameter class

Plot	TC_1	TC_2	TC_3	Total
Plot1	8	5	1	14
Plot2	6	13	0	19
Plot3	2	6	3	11
Plot4	8	3	0	11
Plot5	5	3	3	11
Plot6	2	6	3	11
T	31	36	10	77

T: Total of trees; TC_1: Number of trees with diameter class 10-30cm of DBH; TC_2: Number of trees with diameter class 30-60cm of DBH; TC_3: Number of trees with diameter class >60cm of DBH.

Overall, the diameter class 30-60cm has a high number of trees (36 trees), followed by diameter class 10-30cm (31 trees) and diameter class > 60cm with 10 trees (Table 2). In 6 plots of this study forest, the plot 2 has the highest number of trees (19 trees), followed by plot 1 (14 trees) and other plots with 11 trees each. The secondary forest has more trees (44 trees) with respect to the gallery forest with 33 trees (Figure 4).

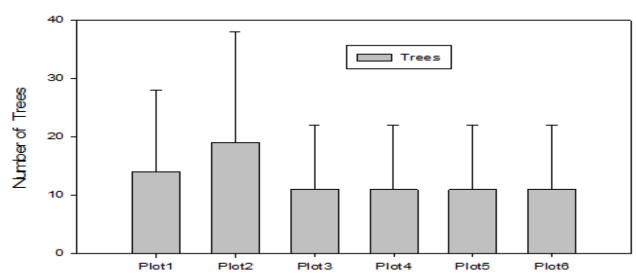

Fig. 3. Total number of trees in six plots of study area: Gallery forest (Blue Lake Forest) and Secondary forest (Inkou Forest Island) by plot.

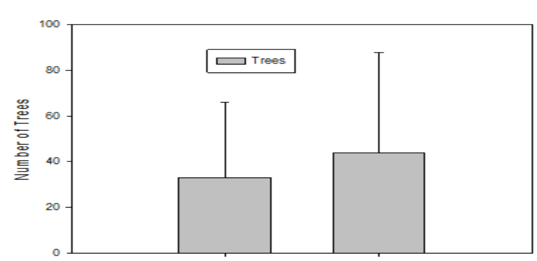

Fig. 4. Number of trees in Gallery forest (Blue Lake Forest) and Secondary forest (Inkou Forest Island).

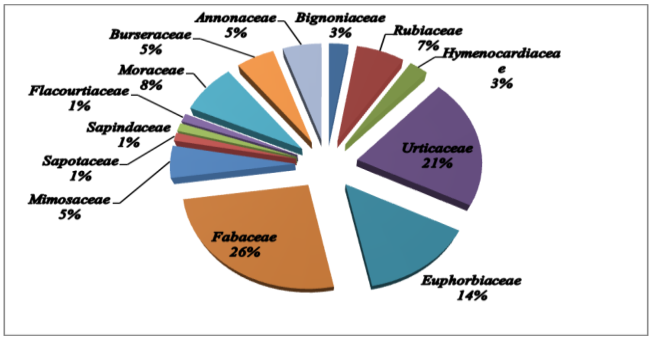

Fig. 5. Frequency of Specific Spectra Families

This study shows that in this forest there are 77 species distributed in 13 families (Table 4). The family of Fabaceae (20 species or 26% of frequency) contains the greatest number of species, followed by the family of Urticaceae with 16 species 21% of frequency. The family of Euphorbiaceae has a frequency of 14% with 11 species (Figure 5). For other families: Moraceae have 6 species; Rubiaceae 5 species; Burceraceae, Annonaceae and Mimosaceae (4 species for each); Hymenocardiaceae and Bignoniaceae (2 species for each); Sapotaceae, Flacourtiaceae and Sapindaceae have one species for each.

3.2 Biomass and Carbon Assessment

Figure 6 shows that, the carbon stock is higher in above ground biomass (130.9908333 t C / ha) compared to below ground biomass (30.78283179 t C / ha). Also, the figure 7 shows that, the average of above-ground biomass carbon (135.9763333 t C / ha) is higher in the secondary forest compared to the gallery (126.0053 t C / ha). The average of below-ground biomass carbon was respectively in secondary forest (Inkou Forest Island) 31.9544076 t C/ha and in gallery forest (Blue Lake Forest) 29.61125594 t C /ha (Figure 8). The stock of carbon is higher in the secondary forest compared to the gallery forest as mentioned by Gorte [19]. The total carbon in the gallery forest was 466.8497678 t, and in secondary forest 503.792223 t. We found that in these natural forests, the total carbon stock (AGBC+BGBC) of secondary forest is high with respect to the total carbon stock (AGBC+BGBC) of the gallery forest as mentioned by Barnes et al. (1998). In this studied tropical forest, the plot 5 (153.274 t C / ha) has the highest carbon stocks (Fig. 9) while the plot 4 contains lesser stocks of carbon (96,722 t C / ha). The Plot 4 and the plot 5 are all in the gallery forest.

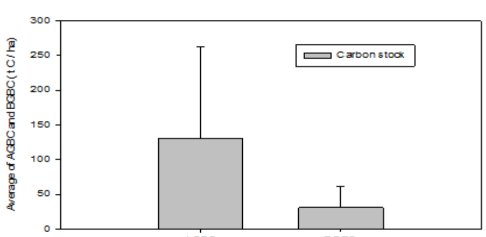

Fig. 6. Average of carbon stock of above-ground biomass (AGB) and below-ground biomass (BGB) in study area (AGBC= above ground biomass carbon; BGBC= below ground biomass carbon).

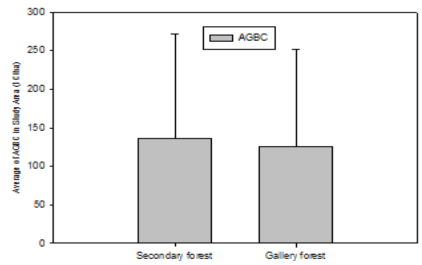

Fig. 7. Average of carbon stock of above-ground biomass in Secondary forest (Inkou Forest Island) and Gallery forest (Blue Lake Forest). AGBC: above-ground biomass carbon.

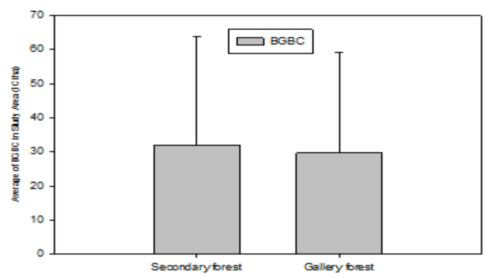

Fig. 8. Average of carbon stock of below-ground biomass in Secondary forest (Inkou Forest Island) and Gallery forest (Blue Lake Forest). BGBC: below-ground biomass carbon.

4 Discussion and Conclusion

Allometric equations are an essential tool for understanding the storage of carbon in tropical forests [26-28].This study shows that the species density is higher in the secondary forest compared to the gallery forest. The study was done with 6 circular plots each 1256m^2, so 20m of radius by plot. Thus, the study was conducted in secondary forest and gallery forest of Lesio - louna area and 77 trees species were recorded in this study area. Trees species recorded in this study are represented in 13 families: 44 species in the secondary forest and 33 species in the gallery forest. In this forest ecosystem, the family of Fabaceae has the higher species number (frequency of 26%, with 20 species) has many species, followed by Urticaceae (16 species). Plot 2 is richest species (19 species), 6 species in the diameter class 10 -30cm, 13 species in the diameter class 30 -60 cm and no species in the diameter class > 60 cm. In plot five, 11 species are recorded: 5 species are in the diameter class 10 -30 cm, 3 species in the diameter class 30 -60cm, 3 species in the diameter class > 60cm. With only 11 species, this plot 5 has the higher carbon stock which is 153.274 t C / ha for above-ground biomass (AGB). Instead, the plot 2 with 19 species, contains only 147.404 t C / ha of carbon stock for above-ground biomass (AGB). It is mean; species number is not the only parameter which determines the trees carbon stock.

Table 3. Carbon stocks (t C/ha) of AGB and BGB in six plots of study area (Lesio-louna forest)

Plots	FT	TT	ABGC	BGBC	CT
Plot1	SF	14	137.914	32.4098172	170.3238
Plot2	SF	19	147.404	34.639853	182.0439
Plot3	SF	11	122.611	28.8135527	151.4246
Plot4	GF	11	96.722	22.7297033	119.4517
Plot5	GF	11	153.274	36.0192979	189.2933
Plot6	GF	11	128.020	30.0847666	158.1048

FT: Forest type; TT: Total of trees; CT: Carbon total (t C/ha); AGBC: Above-ground biomass carbon (t C/ha); BGB: Below ground biomass carbon (t C/ha); SF: Secondary forest; GF: Gallery forest.

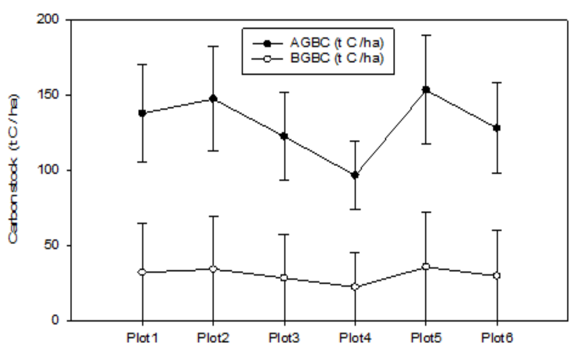

Fig. 9. Carbon stock (t C/ha) of above-and below-ground biomass in secondary forest (Inkou Forest Island) and gallery forest (Blue Lake Forest) by plot.

Breugel *et al*. [4] about the estimating carbon stock in secondary forests determined that a common method to quantify carbon stocks in forests is the use of allometric regression models to convert forest inventory data to estimates of aboveground biomass (AGB). The use of allometric models implies decisions [14-15] on the selection of extant models or the development of a local model, the predictor variables included in the selected model and the number of trees and species for destructive biomass measurements. They has assess uncertainties associated with these decisions using data from 94 secondary forest plots in central Panama and 244 harvested trees belonging to 26 locally abundant species. AGB estimates from species-specific models were used to assess relative errors of estimates from multispecies models [10]. To reduce uncertainty in the estimation of plot AGB, including wood specific gravity (WSG) in the model was more important than the number of trees used for model fitting. However, Breugel *et al*. [4] had found that, decreasing the number of trees increased uncertainty of landscape-level AGB estimates substantially, while including WSG had limited effects on the accuracy of the landscape-level estimates. The results of the study from Djomo *et al*. [17] about Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa, shows that the using only diameter as input variable, the mixed-species regression model estimates the aboveground biomass of the study site with an average error of 7.4%. Adding height or wood density did not improve significantly the estimations. Using the three variables together improved the precision with an average error of 3.4%. For general allometric equations tree height was a good predictor variable. The best pan moist tropical equation was obtained when the three variables were added together followed by the one which includes diameter and height. This study provides diameter breast height relationships and wood density of 77 trees. The pan moist tropical equation developed by Chave *et al.* [15], estimates total aboveground biomass across different sites with an average error of 20.3% followed by equations developed in the present study with an average error of 29.5%. However, about our study, the average carbon stock for above-ground biomass (AGB) in secondary forest (135.9763333 t C / ha) was higher than in gallery forest (126.0053 t C / ha). Also, the average carbon stock for below-ground biomass (BGB) in secondary forest (31.9544076 t C / ha) was higher than in the gallery forest (29.61126 t C / ha). In this study, we found that the carbon stock is in large quantities in the secondary forest compared to the gallery forest [4-5]. We deduce that, the quantity or carbon stock for AGB + BGB in a study plot is still not affected by the number of species in this plot. Thus, the stock of carbon (AGB + BGB) in a studied plot is influenced by biological type of species that constitute this study plot (Table 3). The results of this work show that, plots dominated by species of the family of Fabaceae contain a high carbon stock compared to others families studied as mentioned by Breugel *et al*. [4]. *Millettia laurentii* (Fabaceae) of plot 1 in Inkou Forest Island has a higher DBH (80 cm) among the 77 species in our study area (Table 4). But the plot 1 is in secondary forest and that *Millettia laurentii*, contains 137.914 (t C / ha) of carbon stock for above-ground biomass (AGB) and 32.40981721 t C / ha for below-ground biomass (BGB). For cons, the plot 5 which is in the gallery forest, has the most dominant of carbon stock (153.274 t C /ha for AGB) compared to the others studied plots (Figure 9). Table1 shows that in this study, the area state of Plot1, Plot2, Plot4 and Plot5 are normal, but the area state of Plot3 is an ecosystem disturbance by fire and the area state of Plot6 is a swamp. The works of Holdaway *et al*. [27] about the propagating uncertainty in plot-based estimates of forest carbon stock and carbon stock change, indicate that Plot-to-plot variation was the greatest source of uncertainty, amounting to 9.1% of mean above-ground carbon stock [4] estimates (201.11 MgC ha^{-1}). Propagation of the measurement error and model uncertainty resulted in a 1% increase in uncertainty (0.1% of mean stock estimate). Carbon change estimates (mean - 0.86 MgC ha^{-1} y^{-1}) were more uncertain, with sampling error equating to 56% of the mean, and when measurement error and model uncertainty were included this uncertainty increased by 35% (22.1% of the mean change estimate). For carbon change, the largest sources of measurement error were missed/double counted stems and fallen coarse woody debris [9]. Table 4 shows that the DBH trees vary from one plot to another and the carbon stock of above-ground biomass (AGB) and below-ground biomass (BGB) varies from plot to plot. The gallery forest has a low stock with respect to the secondary forest because the gallery forest is a forest that contains species that store less carbon. Also, the Blue Lake Forest is a gallery forest that has plenty of water, the undergrowth is thick, the litter of the forest is also thick and the hills of Mâh village prevent the growth of these trees. Furthermore, Inkou Forest Island is located on the hill and the growth of trees in this forest is normal because the sun light penetrates normally. This has an important secondary forest because it's a carbon stock forest of Fabaceae. Fabaceae has species which have the ability to fix atmospheric nitrogen by the presence of nodules that are in their root. Furthermore, undergrowth of Inkou Forest Island (secondary forest) is clearing (ventilated) and the litter is thick.

Table 4. Distribution of species in secondary forest (Inkou Forest Island) and gallery forest (Blue Lake Forest) of Lesio-louna area

Species*	Family	FT	Plot	DBH
Artocarpus ultilis	Moraceae	GF	Plot5	21.6
Artocarpus ultilis	Moraceae	GF	Plot6	31.4
Bursera simaruba	Burseraceae	GF	Plot4	50.9
Bursera simaruba	Burseraceae	GF	Plot5	73
Bursera simaruba	Burseraceae	GF	Plot5	37.1
Bursera simaruba	Burseraceae	GF	Plot6	29.8
Caloncoba welwitschii	Flacourtiaceae	GF	Plot4	18.3
Colletoecema dewevrei	Rubiaceae	SF	Plot1	15.5
Colletoecema dewevrei	Rubiaceae	SF	Plot2	19.5
Eriocoelum macrocarpum	Sapindaceae	GF	Plot4	15.3
Ficus deltoidea	Moraceae	GF	Plot4	17.7
Hymenocardia ulmoides	Hymenocardiaceae	SF	Plot1	17
Hymenocardia ulmoides	Hymenocardiaceae	SF	Plot3	40.4
Macaranga barteri	Euphorbiaceae	SF	Plot1	11.8
Macaranga barteri	Euphorbiaceae	SF	Plot1	23.1
Macaranga barteri	Euphorbiaceae	SF	Plot1	21.4
Macaranga barteri	Euphorbiaceae	SF	Plot1	31.4
Macaranga barteri	Euphorbiaceae	SF	Plot1	45.1
Macaranga barteri	Euphorbiaceae	SF	Plot2	12.2
Macaranga barteri	Euphorbiaceae	SF	Plot2	31.7
Macaranga barteri	Euphorbiaceae	SF	Plot2	39.5
Macaranga barteri	Euphorbiaceae	SF	Plot2	31.2
Macaranga barteri	Euphorbiaceae	SF	Plot2	21.5
Macaranga barteri	Euphorbiaceae	GF	Plot6	10.3
Markhamia sessilis	Bignoniaceae	SF	Plot1	18.3
Markhamia sessilis	Bignoniaceae	SF	Plot1	12.3
Millettia laurentii	Fabaceae	SF	Plot1	49.4
Millettia laurentii	Fabaceae	SF	Plot1	51.8
Millettia laurentii	Fabaceae	SF	Plot1	80
Millettia laurentii	Fabaceae	SF	Plot3	15.5
Millettia laurentii	Fabaceae	SF	Plot3	36.6
Millettia laurentii	Fabaceae	SF	Plot3	31.1
Millettia laurentii	Fabaceae	SF	Plot3	28.7
Millettia laurentii	Fabaceae	SF	Plot3	38.2
Millettia laurentii	Fabaceae	SF	Plot3	71.7
Millettia laurentii	Fabaceae	SF	Plot3	65.5
Millettia laurentii	Fabaceae	SF	Plot3	62.7
Millettia laurentii	Fabaceae	GF	Plot4	22
Millettia laurentii	Fabaceae	GF	Plot4	28.1
Millettia laurentii	Fabaceae	GF	Plot4	11.1
Millettia laurentii	Fabaceae	GF	Plot5	20.9
Millettia laurentii	Fabaceae	GF	Plot6	60.4
Millettia laurentii	Fabaceae	GF	Plot6	63.1
Millettia pinnata	Fabaceae	GF	Plot4	41.9
Millettia pinnata	Fabaceae	GF	Plot6	32
Millettia pinnata	Fabaceae	GF	Plot6	56.2
Millettia pinnata	Fabaceae	GF	Plot6	65.7
Musanga cecropioides	Urticaceae	SF	Plot1	13.1
Musanga cecropioides	Urticaceae	SF	Plot1	40.3
Musanga cecropioides	Urticaceae	SF	Plot2	41.4
Musanga cecropioides	Urticaceae	SF	Plot2	41.2
Musanga cecropioides	Urticaceae	SF	Plot2	31.9
Musanga cecropioides	Urticaceae	SF	Plot2	39.2
Musanga cecropioides	Urticaceae	SF	Plot2	35.8
Musanga cecropioides	Urticaceae	SF	Plot2	31.1
Musanga cecropioides	Urticaceae	SF	Plot2	31.6
Musanga cecropioides	Urticaceae	SF	Plot2	21.4
Musanga cecropioides	Urticaceae	SF	Plot2	29.2
Musanga cecropioides	Urticaceae	SF	Plot2	34.5
Musanga cecropioides	Urticaceae	SF	Plot2	32.4
Musanga cecropioides	Urticaceae	SF	Plot2	52.3
Musanga cecropioides	Urticaceae	GF	Plot4	12.2
Musanga cecropioides	Urticaceae	GF	Plot5	29.4
Omphalocarpum elatum	Sapotaceae	SF	Plot3	39.1
Oxyanthus speciosus	Rubiaceae	SF	Plot2	11.2
Oxyanthus speciosus	Rubiaceae	GF	Plot5	84.3
Pentaclethra eetveldeana	Mimosaceae	SF	Plot3	32.7
Pentaclethra eetveldeana	Mimosaceae	GF	Plot6	30.6
Pentaclethra eetveldeana	Mimosaceae	GF	Plot6	44.4
Piptadeniastrum africanum	Mimosaceae	GF	Plot5	26
Treculia africana	Moraceae	GF	Plot4	21.1
Treculia africana	Moraceae	GF	Plot4	30.8
Treculia obovoidea	Moraceae	GF	Plot5	17.3
Xylopia aethiopica	Annonaceae	GF	Plot5	40.7
Xylopia aethiopica	Annonaceae	GF	Plot5	33.4
Xylopia aethiopica	Annonaceae	GF	Plot5	60.5
Xylopia aethiopica	Annonaceae	GF	Plot6	37.2

*No.: Number of Label; *: Scientific name of tree; DBH: Diameter at breast height (cm); FT: Forest type; SF: Secondary Forest; GF: Gallery Forest.*

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References
[1] ANAC, ''Situation Météorologique Nationale'', Rapport annuel de l'agence nationale de l'aviation civile. Agence Nationale de l'Aviation Civile (ANAC), Unpubliched, Pp. 64, Republic of Congo, 2010.

[2] Anonymous, ''Annual report of Lesio-louna Project (Rapport annuel du projet Lesio-louna)''. Ministry of sustainable devlopment, Forest economy and Environment (Ministère de Développement Durable, de l'Economie Forestière et de l'Environnement), *The Aspinall foundation*, pp.55, Congo, Brazzaville, 2011.'

[3] V. B. Barnes, et al., Forest ecology. Fourth edition, pp. 774, USA, 1998.

[4] V. M. Breugel et al., Estimating carbon stock in secondary forests: Decisions and uncertainties associated with allometric biomass models, Elsevier, Forest Ecology and Management, pp. 1648–1657, 2011.

[5] S. Brown, A. Gillespie, and A. E. Lugo, Biomass estimation methods for tropical forest with applications to forest inventory data. Forest Science Vol. 35, pp. 881–902, 1989.

[6] S. Brown, Estimating biomass and biomass change of tropical forests: a primer UN FAO Forestry Paper 134, http://www.fao.org/docrep/W4095E/W4095E00.htm. Pp.55, 1997.

[7] S. Brown et al., Application of Multispectral 3-Dimensional Aerial Digital Imagery for Estimating Carbon Stocks in a Tropical Pine Savanna. Report to the Nature Conservancy Conservation Partnership Agreement, pp. 22, 2004.

[8] S. Brown et al., ''Impact of selective logging on the carbon stocks of tropical forests'': Republic of Congo as a case study. Winrock International. Deliverable 6 to USAID, Cooperative Agreement No. EEM A-00-03-00006-00, pp. 21, 2005.

[9] S. Brown, Creating a virtual tropical forest from three-dimensional aerial imagery to estimate carbon stocks, Ecological Applications, pp.13, 2005.

[10] K. P. Burnham and D.R. Anderson, ''Model selection and inference'', A practical information–theoretic approach, Second edition, Springer, Berlin, Heidelberg, Germany. 2002.

[11] S. Cai, X. Kang, L. Zhang, Allometric models for aboveground biomass of ten tree species in northeast China, Ann. For. Res. 56(1): 105-122, 2013.

[12] J.Q. Chambers et al. Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest, Forest Ecology Management, Vol. 152, pp. 73–84, 2001.

[13] J. Chave, B. Riera, and M.A. Dubois, Estimation of biomass in a neotropical forest of French Guiana: spatial and temporal variability. *Journal of Tropical Ecology* 17:79–96, 2001.

[14] J. Chave et al., Error propagation and scaling for tropical forest biomass estimates. Philosophical Transactions Royal Society B 359, 409–420, 2004.

[15] J. Chave et al., Tree allometry and improved estimation of carbon stocks and balance in tropical forests, Oecologia 145: 87–99, 2005.

[16] CIFOR, Forests and climate change mitigation. Center for International Forestry Research. Key research finding, pp.2, 2012.

[17] N. A. Djomo et al., Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa, Forest Ecology and Management, 260:1873–1885, 2010.

[18] E. Alvarez et al., Tree above-ground biomass allometries for carbon stocks estimation in the natural forests of Colombia, Forest Ecology and Management, 267: 297–308, 2012.

[19] W.R. Gorte, Carbon Sequestration in Forests, Congressional Research Service, Natural Resources Policy, Report for Congress, 7-5700 www.crs.gov RL31432, 2009.

[20] FAO, State of the World's Forests, Food and Agriculture Organization of United Nations (UNFAO), pp.60, Italy-Rome, 2008.

[21] FAO, State of the World's Forests (Situation des forets du monde), Organisation des Nations Unies pour l'Alimentation et l'Agriculture, Rome, Pp. 177, 2011.

[22] F. Folega et al., Ecological and numerical analysis of plant communities of the most conserved protected area in North-Togo, *International Journal of Biodiversity and Conservation*, 2(10): 359-369, 2010.

[23] F. Folega, Wooded vegetation of protected areas in Northern Togo, Case of Barkoissi, Galangashi and Oti-Keran: Ecological and Structure Analysis of Plant Communities, Forestry Studies in China .2011, 13(1):23-35, 2011.

[24] IPCC, Third Assessment Report of IPCC, Climate Change: The Scientific Basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change(IPCC), Cambridge, United Kingdom and New York, USA, Cambridge University Press, pp.881, 2001.

[25] IPCC, Renewable energy sources and climate change mitigation. Special report of the Intergovernmental Panel on Climate Change (IPCC). Summary for policymakers and technical summary. WMO. UNEP, Pp. 246, 2011.

[26] A. Hall, Forests and climate change. The Social dimensions of REDD (Reducing Emissions from Deforestation and Forest Degradation) in Latin America, pp.213, 2012.

[27] J. R.Holdaway et al., Propagating Uncertainty in Plot-based Estimates of Forest Carbon Stock and Carbon Stock Change, Uncertainty in Forest Carbon Estimates, Ecosystems. Pp. 14, 2014.

[28] K. Lorenz, and R. Lal, ''Carbon sequestration in forest ecosystems'', Springer, pp. 241-260, USA, 2009.

[29] K. Mokany, R.J. Raison, and A.S. Prokushkin, Critical analysis of root: shoot ratios in terrestrial biomes. Global Change Biology 12: 84-96, 2006

[30] L. Moundzeo et al., Carbon sequestration in sugarcane plantation in Niari valley in Congo. Journal of Environmental Science and Technology 4 (4): 411-418, 2011.

[31] J. Nguema and Pavageau, Adaptation et Atténuation en Guinée Equatoriale. Acteurs et processus politiques, Document de Travail 98, Center for International Forestry Research (CIFOR), pp. 62, Bogor, Indonesia ,2012.

[32] H. Ogawa et al., Comparative ecological studies on three main types of forest vegetation in Thailand II Plant biomass, Nat Life Southeast Asia 4:49–80, 1965.

[33] T.S. Pearson et al., Application of Multispectral 3-Dimensional Aerial Digital Imagery for Estimating Carbon Stocks in a Bottomland Hardwood Forest, Winrock International, 2-17, 2005.

[34] T.S. Pearson et al., Use of aerial digital imagery to measure the impact of selective logging on carbon stocks of tropical forests in the Republic of Congo. Delivelable 9 to USAID, Cooperative Agreement No. EEM- A- 00-03-00006-00, pp 5-21, 2005.

[35] T.S. Pearson and S.Brown, Guide for measuring and monitoring carbon in forests and grasslands (Guide de mesure et de suivi du carbone dans les forêts et prairies herbeuses), Winrock International, pp.35, 2005.

[36] A. J. Richard and W.W. Dean Applied Multivariate Statistical Analysis, Sixth Edition, Pearson Education Beijing Office, Tsinghua university press, pp. 3-755, China, 2007.