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Evaluation of carbon stocks in above- and below-ground biomass in Central Africa: case study of Lesio-louna tropical rainforest of Congo

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Abstract

The study was aimed to estimate the carbon stocks of above- and below-ground biomass in Lesio-louna forest of Congo. The methodology of allometric equations was used to measure the carbon stocks of Lesio-louna natural forest. We are based precisely on the model II which is also called non-destructive method or indirect method of measuring carbon stocks. While there has been use of parameters such as the DBH and wood density. The research was done with 22 circular plots each 1256 m^2. In the 22 plots studied, 19 plots are in the gallery forest and three plots in the secondary forest. Also, 22 circular plots were distributed in 5 sites studies of Lesio-louna forest, including: Inkou forest island, Iboubikro, Ngoyili, Blue lake and Ngambali. So, there are two forest types (secondary forest and gallery forest) in this forest ecosystem. In the 5 sites studied, we made measurements on a total of 347 trees with 197 trees for the class of 10–30 cm diameter, 131 trees for the class of 30–60 cm diameter and 19 trees in the diameter class > 60 cm. The results show that in the whole forest, average carbon stock for the 22 plots of the study was 168.601 t C ha^{-1} for AGB, or 81 % and 39.551 t C ha^{-1} for BGB, or 19 %. The total carbon stocks in all the biomass was 3395.365 t C for AGB, which is 3.395365×10^{-6} Gt C and 909.689934 t C for BGB, which was $9.09689934 \times 10^{-7}$ Gt C. In this forest, the carbon stock was more important in AGB compared to BGB with respectively 3395.365 t C against 909.689934 t C. Plot10 (AGB = 363.899 t C ha^{-1} and BGB = 85.516 t C ha^{-1}) was the most dominant in terms of carbon quantification in Lesio-louna.

1 Introduction

In the context of climate change, special attention is given to carbon which is a major constituent of greenhouse gas emissions. The forest has a very important role in mitigating this phenomenon by photosynthesis (FAO, 2001). Globally, terrestrial ecosystems sequester annually 1.4 ± 0.7 Pg 1C yr^{-1}, or 22.2 % about the flux of fos-

sil fuels (IPCC, 2001). Forests account for 48 percent of the total storage capacity of carbon by worldwide terrestrial ecosystems (Watson et al., 2000; IPCC, 2001). Trees, the major components of forest, absorb large amounts of atmospheric carbon dioxide (CO_2) by photosynthesis, and forests return an almost equal amount to the atmosphere by auto- and heterotrophic respiration (Folega et al., 2010). One of the environmental issues of global concern today is the increase of carbon dioxide in the atmosphere and its potential effect on climate. However, a small fraction of carbon remaining in forests continuously accumulates in vegetation, detritus, and soil. Thus, undisturbed forest ecosystems are important global carbon sinks (Lorenz and Lal, 2009). Thus, in the forestry, there are seven carbon storages: the tree above the soil, vegetation above ground, underground roots, litters on the forest floor, dead wood, soils and wood products long lifetime (Pearson and Brown, 2005). However, the study does not have the same impact on all these seven reserves (IPCC, 2007). The choice of measuring reserves depends on several factors, including expected results in the rate of change, its magnitude and direction, the availability and accuracy of methods to quantify the change, and the cost measure. All reserves are expected to see a reduction in response to the human activities, thus, the need for these activities to be measured and monitored. The forest is a reservoir of carbon (FAO, 2008) because it has a good capacity to stock carbon from the atmosphere (Ullah and Amin, 2012). The decision to evaluate wood products depends on whether the trees will be harvested or not. Activities related to changes in forest management must analyze wood products (IPCC, 2001; Lorenz and Lal, 2009) because it often reduces the change in the active reserve of carbon; it is the same for an activity to keep the forest standing if the original activity was industrial forest production.

Forests act as carbon reservoirs by storing large amounts of carbon in trees, under story vegetation (FAO, 2003), in the forest floor and soil (Mokany et al., 2006; Nelson et al., 1999; Niklas, 1997). The idea of paying forest users in the developing world to deforest has given the world an acronym with universal appeal – REDD, or Reduced Emissions from Deforestation and Forest Degradation. Implicitly at least, REDD

(now REDD+ to include both avoided deforestation and enhancement of forest carbon stocks) promises a win-win solution for mitigating the effects of global warming (FAO, 2001). REDD+ promises to help maintain standing forests and sequester carbon from the atmosphere while providing cash incentives and other benefits to compensate forest users, build livelihoods and reward indigenous and community groups for their stewardship role. Although it builds quite strongly up on decades of experience with forest conservation and development, REDD+ also conjures up the image of a radical initiative that challenges predatory, business as usual practices (Hall, 2012). Ecology is the main response of tropical forest ecosystems to natural or anthropogenic environmental changes (Gorte, 2009; Lugo and Brown, 1986; Vicente et al., 2014). Long-term forest inventories are most useful in order to evaluate the magnitude of carbon fluxes between aboveground forest ecosystems and the atmosphere (Chave and Santamaría, 2006; Alvarez et al., 2012). Guidelines have been published for setting up permanent plots, censusing trees correctly (Brown et al., 2004; Chave et al., 2001), and for estimating aboveground biomass (AGB) stocks and changes from these datasets (Brown, 1997; Chave et al., 2006; Ekoungoulou et al., 2014b). However, one of the large sources of uncertainty in all estimates of carbon stocks in tropical forests is the lack of standard models for converting tree measurements to above-ground biomass estimates (FAO, 1997; Hall, 2012). Here, we directly appraise a critical step in the plot-based biomass estimation procedure, namely the conversion of plot census data into estimates of above-ground biomass (AGB). Most important, approaches under the Kyoto Protocol may increase CO_2 emissions from forestry by accelerating deforestation (Folega et al., 2010; IPCC, 2001). Yet, reduced emissions from deforestation and degradation (REDD) and compensated reduction in deforestation is improved mechanisms to include avoided tropical deforestation under the Kyoto Protocol or its successor. Also, the national inventory approach may be an attractive alternative to consider. Both established and future international agreements rely particularly on forest carbon accounting and monitoring systems (Lorenz and Lal, 2009).

The use of allometric regression models is a crucial step in estimating aboveground biomass (AGB), yet it is seldom directly tested (Brown et al., 2000; Chave et al., 2005; Killeen et al., 2002). Belowground biomass was estimated from aboveground biomass from allometry (Mokany et al., 2006). Because 1 ha of tropical forest may shelter as many as 300 different tree species (Ogawa et al., 1965), one cannot use species-specific regression models, as in the temperate zone (Brown, 2002; Niklas, 1997).

Instead, mixed species tree biomass regression models must be used. Moreover, published regression models are usually based on a small number of directly harvested trees and include very few large diameter trees, thus not well representing the forest at large. This explains why two models constructed for the same forest may yield different aboveground biomass (AGB) estimates, a difference exacerbated for large trees, which imposes a great uncertainty on stand level biomass estimates (Brown, 1997; Chave et al., 2008; Nelson et al., 1999). Direct tree harvest data are difficult to acquire in the field, and few published studies are available. Therefore, it is often impossible to independently assess the model's quality (Angelsen et al., 2009). Tropical forests hold large stores of carbon (Holmes et al., 1999), yet uncertainty remains regarding their quantitative contribution to the global carbon cycle. One approach to quantifying carbon biomass stores consists in inferring changes from long-term forest inventory plots. Regression models are used to convert inventory data into an estimate of aboveground biomass (Chave et al., 2005). However, the assessment of carbon stocks in this ecosystem is not yet satisfactorily known, to enable countries with this heritage to access the carbon credit which is another way to take advantage of the forest. Very little information is available in this field in Congo (FAO, 2001).

The harvesting of timber from forests is a central part of the economy of tropical nations as is exemplified by the case of the Republic of Congo (Brown et al., 2005a). Monitoring of logging activities therefore serves an important function (Brown et al., 2005b). The aims of this study are to estimate the carbon stocks of Lesio-louna tropical rainforest.

The results of this study will be useful to the national forest carbon quantification in Congo.

Within the carbon market, the result of this study about carbon stock in Lesio-louna Forest will allow Congo to benefit the carbon credit.

2 Materials and methods

2.1 Study area

The site in which the experimental devices of this study was installed is located in Lesio-louna (Fig. 1) located in the teke trays (14° E, 4° S), at the Department of Pool in the Republic of Congo. Lesio-louna is a protected air that is in the Teke Trays (Republic of Congo). Then, the Teke Trays are a wide range of trays starting from Republic of Gabon crossing Republic of Congo until Democratic Republic of Congo (Ekoungoulou et al., 2014a). Lesio-louna is about 160 km north of Brazzaville from the national road Number 2 (Fig. 1) (Ekoungoulou et al., 2014b). It occupies the center of Congo and covers about 12.000 km^2 (Anonymous, 2001). The altitudes vary between 600 and 800 m, and are surrounded by a hilly area that occupies about 70.000 km^2 (ANAC, 2013; Anonymous, 2001). From a geographical point of view, in Congo, Teke-Trays extend from north of the city of Brazzaville and are limited to the east by the Congo River to the west by longitude 14.5°, to the south by parallel 4° latitude, the north by the parallel 2° South latitude (ANAC, 2013). The annual precipitation is 2000 to 2087 mm (ANAC, 2010; Ekoungoulou et al., 2014a).

2.2 Trees species sampling

The field work was based on circular plots techniques (Brown et al., 2005b; Watson et al., 2000). The reason of choice of this type of plot is that circular plots are more appropriate because the real boundary around the plot does not need to be marked (Ekoungoulou et al., 2014a). We had used the study plots nested form (Fig. 2). Experience

has shown that the sample plots containing small sub-units of similar shape but of different sizes (nested plots) are advantageous economically and scientifically robust for most tree vegetation in Fig. 2. The study has retained 22 circular nested plots separated from each about 100 m.

The schematic diagram below represents a sample plot consisting of three concentric circles.

The methodology used was the non-destructive methodology (indirect methodology) and calculations was done by the allometric equation (model II) from Chave (2005) two-parameter field because there we did not use the clinometer (device used to measure the height of the tree by using the principles of trigonometry) and the DME haglöf (device for measuring the distance between the tree and the plot center). In this model, the power-law relationship is parameterized by $c = d = 0$.

2.3 Measuring trees and carbon stock determination

The tree measurements was conducted on plots with a slope $< 10^{\circ}$. Also, measurements were made solely on the trees DBH $\geq$ 10 cm and height 1.3 m (Folega et al., 2010), and only these were marked with a nail with plastic label (Table 1). We was used the DBH $\geq$ 10 because our forest is no quite young. So, the stems less than 10 cm would be measured in a forest quite young.

The measurement is performed by taking into account the location of trees. For trees with obstacles, we must add 30 cm to 1.3 m to the normal size measurements. The description of the approach used to measure trees of the study will be incorporated into the data collection to allow measurements to be made with precision and efficiency. The steps to follow are:

- A person responsible for recording data and others was focus exclusively on measuring and marking trees. Registration was take place at the center of the plot which is been measured.

He was monitor those load measuring trees and was seek to ensure that no tree is omitted;

- To prevent double counting or omission of trees, the measurement should start in from north and the first tree should be labeled (Chave et al., 2009; Djomo et al., 2010; Alvarez et al., 2012). Any measured tree should be immediately labeled with a permanent marker sign facing the center of the plot to allow the data recorder person to distinguish between measured and unmeasured trees;

- Any tree of suitable size inside each nested plot has a numbered tag, preferably plastics, nailed on it.

Total tree height is not always available in field inventories, and it may sometimes be better not to include it in procedures of biomass estimation (Chave et al., 2005, 2009). A concave shaped relationship is observed when the logarithm of height, ln(H), is plotted against the logarithm of diameter, ln(DBH) (Djomo et al., 2010). This indicates a progressive departure from the ideal allometry during the trees ontogeny. A polynomial model relating ln(H) and ln(DBH) provides a reasonable generalization of the power-law model (Djomo et al., 2010; Niklas, 1997). Assuming such a polynomial relationship between ln(H) and ln(DBH) (Richard and Dean, 2007). It's easy to deduce the following mathematic equation:

$$\ln(\mathrm{AGB}) = a + b\ln(\mathrm{DBH}) + c(\ln(\mathrm{DBH}))^2 + d(\ln(\mathrm{DBH}))^3 + \beta\ln(\rho) \quad (1)$$

3 Data processing and results

To measure the quantification of carbon stock in Lesio-louna forest, we had used the model II of non-destructive method of Chave (2005) to estimate the biomass of the forest ecosystem study. Then, we had used allometric equations Mathematics having two parameters (density and diameter). Total above- and below-ground biomass of

each tree in the plot was estimated using the allometric equation:

$$AGB = \rho \cdot \text{expo}(-1.239 + 1.980\ln(\text{DBH}) + 0.207(\ln(\text{DBH}))^2 - 0.0281(\ln(\text{DBH}))^3) \quad (2)$$

For unidentified species, we applied the mean wood density for each plot weighted, by the number of trees from each species (Malhi et al., 2004).

The general equation for the rainforests was chosen (Chave et al., 2005):

$$\text{AGB(kg)} = \rho \cdot \exp(-1.239 + 1.980\ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3) \quad (3)$$

However, all plots were circular and each plot had a diameter of 40 m.

3.1 Calculating of circle area

$$\text{Circle area} = r^2 \times \pi \quad (4)$$
$$= \pi \times r^2$$
$$\text{Or, } r = \frac{d}{2} = \frac{40\,\text{m}}{2} = 20\,\text{m}$$

$r = 20$ m
d = diameter
r = radius
$\pi = 3.14$
Circle area = $(20\,\text{m})^2 \times 3.14 = 1256\,\text{m}^2$
Circle area = 1256 m^2

For example, one of study's trees from the plot1 in Lesio-louna gallery forest which has a DBH of 80 cm. Then, 80 cm is well within the maximum DBH (diameter at breast height) for this equation, which is reliable up to 148 cm as mentioned by Chave (2005);

and Pearson and Brown (2005).

$$\text{AGB (kg)} = \rho \cdot \exp(-1.239 + 1.980\ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3) \quad (5)$$

$\rho = 0.05\,\text{g cm}^{-3}$
D = DBH = 80 cm

$$\text{AGB (kg)} = \rho\exp(-1.239 + 1.9802\ln(\text{DBH}) + 0.207(\ln(\text{DBH}))^2 - -0.0281(\ln(\text{DBH}))^3)$$

The aboveground biomass (AGB) of this tree (Eq. 5) was 423 kg, or 0.423 t. From Pearson and Brown (2005), the follow equation is to determine the estimation of carbon stock of tree:

$$\text{C(t)} = \frac{\text{AGB}}{2} \quad (6)$$

So, the carbon stock estimation of this tree (Eq. 6) was 0.2115 t C.
t = ton
C = Carbon
AGB = Above-ground biomass

Thus, to estimate the carbon stock of the below-ground biomass (BGBC), we was used the equation from Mokany (2006). The equation from Mokany (2006) is as follows:

$$Y = 0.235 \cdot \text{AGB if AGBC} > 62.5\,\text{t C ha}^{-1} \quad (7)$$
$$Y = 0.205 \cdot \text{AGB if AGBC} \leq 62.5\,\text{t C ha}^{-1} \quad (8)$$

So, Y = BGBC = Below-ground biomass carbon (t C ha^{-1})
BGBC = 0.235 · AGB if AGBC > 62.5 t C ha^{-1}
BGBC = 0.205 · AGB if AGBC ≤ 62.5 t C ha^{-1}

The study was done with 22 circular plots each 1256 m^2 with 20 m radius/plot (Fig. 3). In the 22 plots studied, 19 plots are in the gallery forest and three plots in the secondary forest.

However, in the 22 plots, we made measurements on a total of 347 trees with 197 trees for the class of 10–30 cm diameter, 131 trees for the class of 30–60 cm diameter and 19 trees in the diameter class > 60 cm (Fig. 4).

Most of calculations determine the values for biomass reserve data, except for the soil, for which usually measures the carbon directly as mentioned by Chave (2005).

Values to extrapolate up to the values of the plots per hectare requires expansion factor.

These expansion factors indicate which surface is represented by each plot or sample as reported by Ekoungoulou (2014a). This standardization is needed to easily interpret the results and also make comparisons with other studies.

This study shows that the species density is more than higher in the gallery forest compared to the secondary forest. Table 2 shows that all 22 plots are the same size (1256 m^2) and the radius of each plot is also the same size in all plots. But, plot10 is the most dominant in terms of number of trees, as it contains 30 trees, and plot16 is that contains very few species (9 trees). However, in this forest ecosystem, plot10 which has a higher carbon stock of above-ground biomass (AGB) that was 363.899 t C ha^{-1} tracking Plot11 has a carbon stock of above-ground biomass (AGB) with the quantity 293.642 t C ha^{-1} (Table 2).

The lower ground carbon stock of AGB was in the plot16 which was 51.012 t C ha^{-1}. Also, in this forest ecosystem, the average of aboveground biomass carbon stock was 168.601 t C ha^{-1}, or 81 % (Fig. 5). For cons, the average of belowground biomass carbon stock was 39.551 t C ha^{-1}, or 19 %. We find that the carbon stock of AGB was high in relation to carbon stock quantity of belowground biomass (BGB).

Figure 5 shows that in this study, the carbon stock estimation of AGB (168.601 t C ha^{-1}) was height more than the carbon stock estimation of BGB (39.551 t C ha^{-1}).

We tried to make the comparison between the carbon stock of secondary forest and the gallery forest in Fig. 6. In the gallery forest, we used random plots P14, P15 and P16

(Fig. 7). About AGB, the average of carbon stock of secondary forest (135.976 t C ha^{-1}) was higher more than the average carbon stock of the gallery forest (74.965 t C ha^{-1}).

About BGB, the average of carbon stock of secondary forest (31.946 t C ha^{-1}) is higher more 20 than the average carbon stock of the gallery forest, its 17.1 t C ha^{-1} (Fig. 6).

Also, the three selected plots of the gallery forest are in the site of Blue Lake, and three plots of secondary forest are in the site of Inkou Forest Island. At the three plots of the gallery forest (P14, P15 and P16), there are no trees within a radius of 20 m (tree > 60 cm DBH).

By cons, in the secondary forest (P1, P2 and P21), There are 4 trees presented in the 20 m radius (trees > 60 cm 15DBH). In the radius of 6 m (trees 10–30 cm DBH) and the radius of 14 m (trees 30–60 cm DBH) there are the trees presented in both types of forest.

4 Discussion

This research was aimed to estimate the carbon stocks of above- and below-ground biomass in Lesio-louna forest of Congo. Results obtained in this study and elsewhere (Brown et al., 2000, 2003; Brown, 2002) show the necessity of developing specific biomass models for each plot and forest type in Lesio-louna tropical rainforest. The general models of total above-ground biomass should be carefully used in specific areas or carbon projects (Ekoungoulou et al., 2014b; FAO, 2008; Pearson et al., 2005b). In this study, the carbon stock estimation can be directed to researchers and administrators to analyses (Ullah and Amin, 2012) for global carbon credit, which can be helpful to improve the forest resources and environmental sectors like Congo, others Congo basin countries and tropical countries with similar conditions.

The results of this study indicate that, the carbon stock in Lesio-louna forest varies from one site to another and from one plot to another. The carbon stock of above-ground biomass (Midgley et al., 2003) was higher than below-ground biomass in all

study plots. In this study, we found that the carbon stock is not based on the number of trees, but rather in relation to DBH and wood density. In this study area, the plot10 was the higher about carbon stock (AGB was 363.899 t C ha^{-1}). Plot10 (Fig. 7) was in the gallery forest of the site Ngoyili, 30 trees were measured, AGB was 363.899 t C ha^{-1}, BGB was 85.5161768 t C ha^{-1} and average DBH was 29.89 cm. In Lesio-louna tropical rainforest, the carbon stock is higher amount in the above-ground biomass compared to belowground biomass (Fig. 8).

Plot10 was in a submerged area (swamp) and in this area, there's less of Chablis, Ngoyili River is just close to this plot, the undergrowth of the forest is somewhat sparse and trees of this area are a considerable height (Fig. 8). Also, high carbon stock of this forest (IPCC, 2001; McMahon et al., 1976; Pearson et al., 2005a) due to it is natural reserve of flora and fauna, and less disturbed forest ecosystem.

The study from Brown (2002) about measuring carbon in forests: current status and future challenges, determined that, to accurately and precisely measure the carbon in forests is gaining global attention as countries seek to comply with agreements under the United Nations Framework Convention on Climate Change. Methods for measuring coarse AGB have been tested in many forest types, but the methods could be improved if a non-destructive tool for measuring the density of dead wood was developed. Future measurements of carbon storage in forests may rely more on remote sensing data, and new remote data collection technologies are in development. The study about tree allometry and improved estimation of carbon stocks and balance in tropical forests from Chave (2005) determined that total above-ground stand biomass differed by over 20 % from the measured value in several sites, and most of these sites had less than 30 trees, and in such small samples, only a few trees may bias the overall prediction. In Lesio-louna tropical rainforest ecosystem, logging and poaching are strictly prohibited because it's a reserve of flora and fauna (Anonymous, 2001). In a general view, the carbon stock of Lesio-louna was higher compared to the results of Madgwick and Satoo (1975). In the forest of Lesio-louna, there is a good functioning of ecosystems and the ecological balance is respected. Then, the relationship between

natural resources and the environment is favorable. However, this forest is preserved and sustainably managed by the Lesio-louna Project from The Aspinall Foundation of UK and Ministry of Forest Economy of Congo. The average carbon stock for 22 plots of this study is 168.601 t C ha^{-1} for above-ground biomass, or 81 % and 39.551 t C ha^{-1} for below-ground biomass, or 19 % (Fig. 5). The total carbon stock in 22 plots for AGB is 3395.365 t C, which was 3.395365×10^{-6} Gt C, and for BGB its 909.689934 t C, which was $9.09689934 \times 10^{-7}$ Gt C. The results reveal that in this forest, the carbon stock is important in AGB compared to BGB with respectively 3395.365 t Carbon against 909.689934 t Carbon.

The comparison test of average between plots revealed that the significant difference was 129.05 t C ha^{-1}.

In addition, we compared the carbon stock of the carbon stock of secondary forest with the carbon stock of gallery forest. We made the choice of P1, P2 and P21 for the secondary forest and the P14, P15 and P16 for the gallery forest (Fig. 6). The results indicate that the carbon stock: (i) for AGB is important in secondary forest more than the gallery forest, with average respectively 135.976 t C ha^{-1} against 74.965 t C ha^{-1}, and (ii) for BGB is important in secondary forest more than the gallery forest, with averages respectively 31.946 t C ha^{-1} against 17.1 t C ha^{-1}. Comparison test of means between the two forest types (gallery forest and secondary forest) revealed a significant difference that was 61.011 t C for aboveground biomass (AGB) and 14.846 t C for belowground biomass (BGB). Figure 9 shows that plot10 is the most dominant plot in the 5study site about the carbon quantity or carbon stock (for above-ground biomass we have 363.899 t C ha^{-1}, and 85.516 t C ha^{-1} for below-ground biomass).

Saatchi (2011) about Benchmark map of forest carbon stocks in tropical regions across three continents, the estimation of the total forest biomass carbon stocks at 10 % tree cover as 247 Gt C, with 193 Gt C in above-ground biomass (AGB) and 54 Gt C in below-ground biomass (BGB). Forests in Latin America are the most extensive and contain ~ 49 % of the total biomass carbon, followed by 26 % in Asia and 25 % in Africa. Applying a higher tree cover threshold (30 %) eliminates large areas of savanna wood-

lands in Africa from the forest domain and reduces the total carbon stock to 208 Gt C (16 % reduction with 163 Gt C for AGB and 45 Gt C for BGB).

5 Conclusions

This study allowed us to estimate the carbon stock of aboveground biomass (AGB) and belowground biomass (BGB) in Lesio-louna forest of Congo. To estimate the carbon stocks of above-ground biomass (AGB), we used the model II of the allometric equations methodology from Chave (2005) with two main parameters, including wood density and DBH. Then, to estimate the carbon stocks of the below-ground biomass (BGB), we used the equation from Mokany (2006). This study was done with 22 circular plots each 1256 m^2 (20 m radius / plot). In the 22 plots studied, 19 plots are in the gallery forest and three plots in the secondary forest. However, with the 22 plots, we made measurements on a total of 347 trees with 197 trees for the class of 10–30 cm diameter, 131 trees for the class of 30–60 cm diameter and 19 trees in the diameter class > 60 cm. The results of this study indicate that throughout this forest, the carbon stock for aboveground biomass (AGB) was 81 % and the carbon stock for belowground biomass (BGB) was 19 %. The Plot10 was the most dominant in terms of carbon stocks in study area (Figs. 8 and 10). Thus, the carbon stock of the plot16 was low more than others plots in the study area. However, the test comparison of means between plots revealed that a significant difference was 129.05 t C ha^{-1}. The results of this study indicate that, the forests in the study area are an important reservoir of carbon, and they can also play a key role in mitigating climate change. However, Lesio-louna forest has the capacity to trap vast amounts of carbon which would otherwise escape into the atmosphere as CO_2, one of the worst greenhouse gases offenders. The potential of carbon stocks capacity in different forest types of Lesio-louna may help the developing African nations to earn carbon credits, reduce deforestation, eliminate poverty and in long run to ensure the sustainable forest management. Given the significant differences in carbon stock, Lesio louna forest could play an important role in carbon sequestration

and thus could provide a carbon sink in all Teke trays, and also in the whole basin forest of Central Africa (Congo Basin). Thus, knowing the carbon stocks of Lesio-louna forest was important to contribute to the sustainable management of this forest ecosystem to support the REDD + process. Also, the growth of the forest to savanna is remarkable in Lesio-louna, because several species of bushland are found in the forest edge and even in the plain forest.

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Table 1. Size of circular plots.

Diameter trees	Radius of circular plots
10–30 cm DBH	6 m
30–60 cm DBH	14 m
> 60 cm DBH	20 m

Table 2. Structuring of study area and distribution of the carbon stocks in Lesio-louna natural forest.

Plot	Forest Type	Nb. Trees	AGB[b]	BGB[c]	Nest Area[d]	Site	Average DBH[a]	Area State
Plot1	Secondary forest	14	137.914	32.4098172	1256.63706	Inkou forest island	30.75	Normal
Plot2	Secondary forest	19	147.404	34.639853	1256.63706	Inkou forest island	30.9894737	Normal
Plot3	Gallery forest	17	197.147	46.3294508	1256.63706	Iboubikro	28.8294118	Normal
Plot4	Gallery forest	12	123.034	28.9128916	1256.63706	Iboubikro	23.8666667	Normal
Plot5	Gallery forest	15	193.740	45.5287948	1256.63706	Iboubikro	30.84	Normal
Plot6	Gallery forest	20	223.192	52.4501047	1256.63706	Iboubikro	24.56	Normal
Plot7	Gallery forest	14	108.336	25.4589241	1256.63706	Iboubikro	24.0857143	Normal
Plot8	Gallery forest	24	273.940	64.3759274	1256.63706	Ngoyili	31.7947368	Swamp
Plot9	Gallery forest	20	236.628	55.6075953	1256.63706	Ngoyili	25.98	Swamp
Plot10	Gallery forest	30	363.899	85.5161768	1256.63706	Ngoyili	29.89	Swamp
Plot11	Gallery forest	22	293.642	69.0058923	1256.63706	Ngoyili	26.9833333	Swamp
Plot12	Gallery forest	17	197.597	46.4353762	1256.63706	Ngoyili	28.2352941	Normal
Plot13	Gallery forest	16	173.999	40.8896497	1256.63706	Ngoyili	26.98125	Normal
Plot14	Gallery forest	11	96.722	22.7297033	1256.63706	Blue lake	24.4909091	Normal
Plot15	Gallery forest	11	77.162	18.1330827	1256.63706	Blue lake	28.0909091	Normal
Plot16	Gallery forest	9	51.012	10.4573734	1256.63706	Blue lake	27.7555556	Normal
Plot17	Gallery forest	11	153.274	36.0192979	1256.63706	Blue lake	40.3818182	Normal
Plot18	Gallery forest	11	128.020	30.0847666	1256.63706	Blue lake	41.9181818	Swamp
Plot19	Gallery forest	11	99.574	23.3998108	1256.63706	Ngambali	31.8636364	Normal
Plot20	Gallery forest	18	185.078	43.4934251	1256.63706	Ngambali	40.1722222	Swamp
Plot21	Secondary forest	11	122.611	28.8135527	1256.63706	Inkou forest island	42.0181818	ecosystem disturbance by fire
Plot22	Gallery forest	12	125.305	29.4467317	1256.63706	Ngambali	34.4416667	Swamp

[a] diameter at breast height of tree (cm),
[b] carbon stock of aboveground biomass (t C ha^{-1}),
[c] carbon stock of belowground biomass (t C ha^{-1}),
[d] Nest area (m^2).

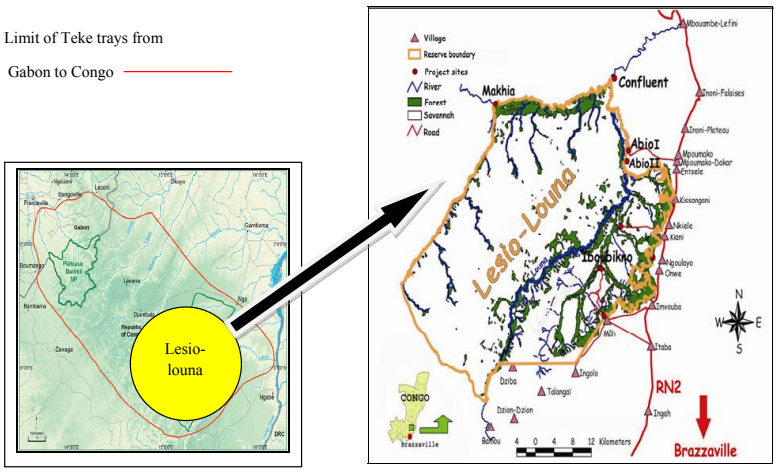

Figure 1. Location of study area in Teke trays (Congo).

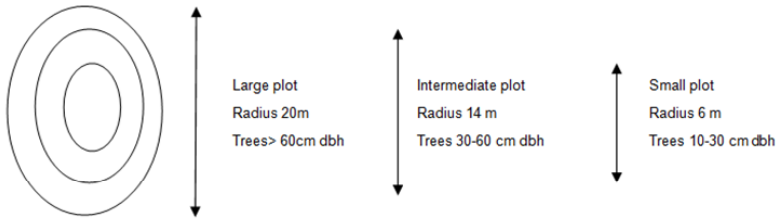

Figure 2. Circular plot to measure the carbon stock of biomass (Source: Ekoungoulou et al., 2014a).

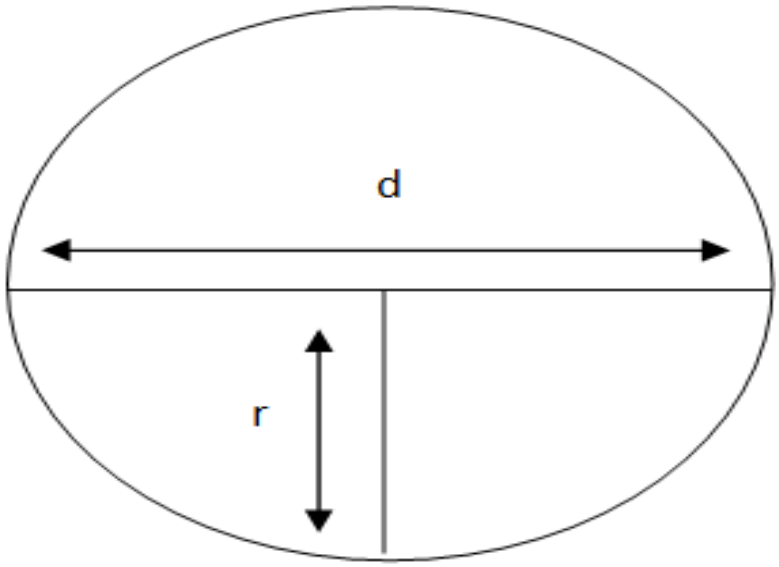

Figure 3. The view of the circle area.

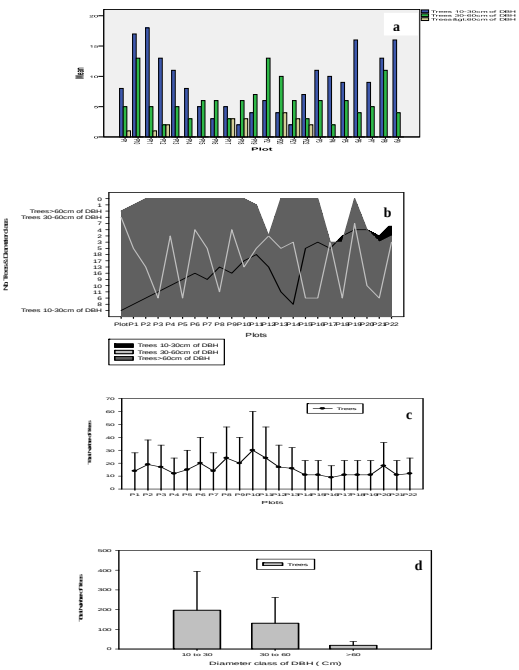

Figure 4. Distribution of trees in the study area (grouped). **(a)** Mean (trees 10–30 cm of DBH) mean (trees 30–60cmof DBH) mean (trees > 60 cm of DBH) by plot; **(b)** number of trees and diameter class by plot, P = plot; **(d)** total number of trees by diameter class of DBH (cm) and **(c)** total number of trees in 22 plots of study sites.

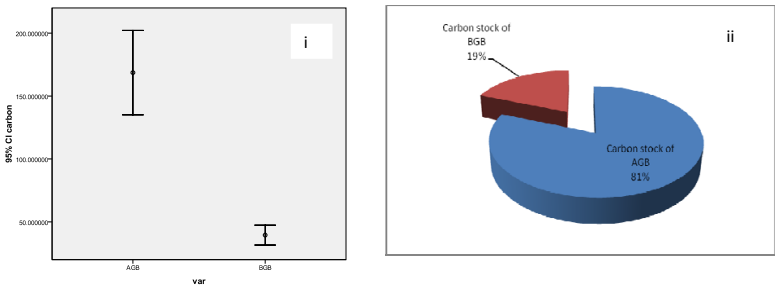

Figure 5. Carbon stock of above- and below-ground biomass **(i)**, and carbon stock of AGB and BGB in percentage of different plot **(ii)**.

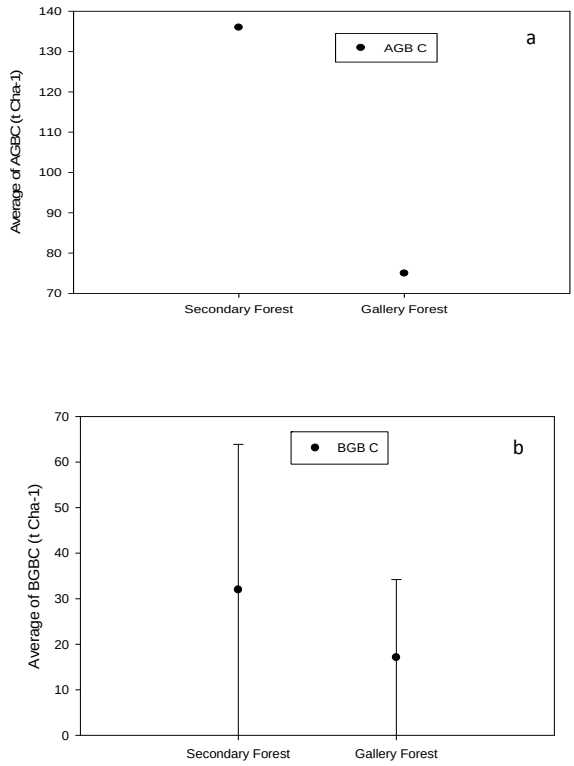

Figure 6. Comparison about the distribution of AGB carbon stock **(a)**, and distribution of BGB carbon stock **(b)** in secondary and gallery forests.

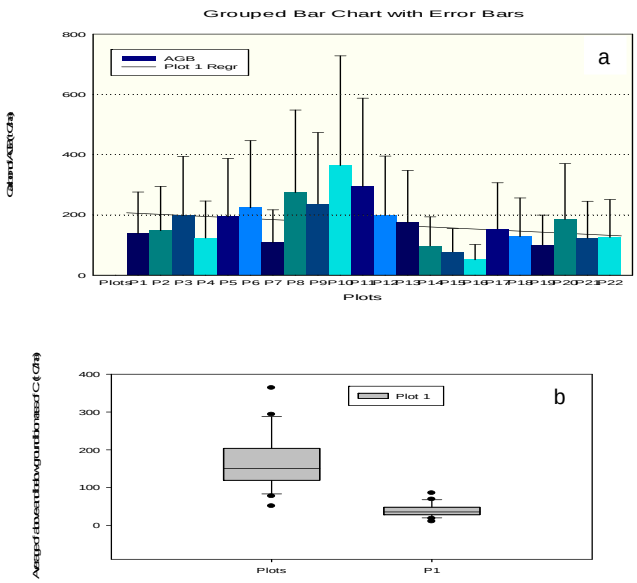

Figure 7. Comparison of the average of above- and below-ground biomass of 21plots and the plot1 of study site **(d)**. Carbon of aboveground biomass (t C ha^{-1}) in Lesio-louna forest by grouped bar chart with error bars **(c)**. In this figure **(c)** there is the regression in plot1. Distribution of Carbon stocks of above ground biomass by plot in the study area **(a)**. Carbon stocks of belowground biomass by plot in the study area **(b)**. This figure (**a** and **b**) indicated that the carbon stock is higher in the plot10 that is 363.899 t C ha^{-1} about AGB and 85.516 t C ha^{-1} about BGB. In this study, the plot16 with AGB = 51.012 t C ha^{-1} and BGB = 10.457 t C ha^{-1} is lower compared to others study plots of study area **(a–c)**.

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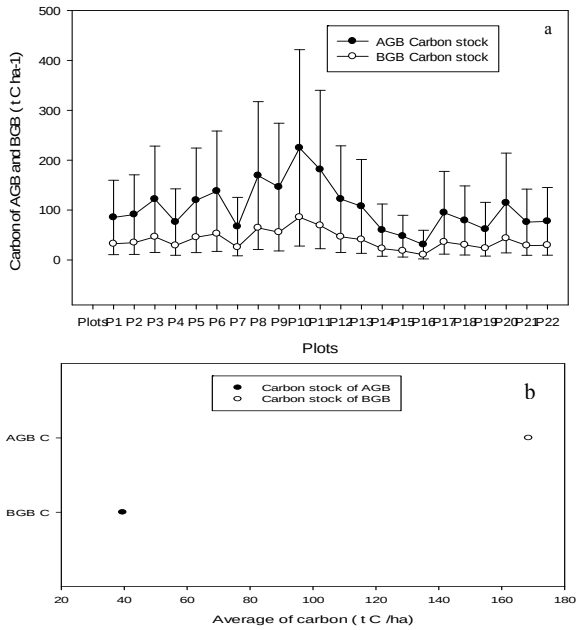

Figure 8. Total carbon stock of aboveground biomass and belowground biomass by plot in Lesio-louna tropical rainforest **(a)**. Average of AGB carbon and BGB carbon in the study site **(b)**. This figure **(b)** shows that the carbon stock is higher amount in the AGB compared to BGB biomass.

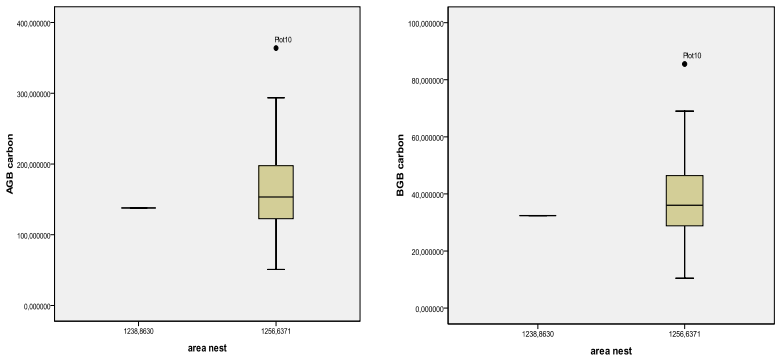

Figure 9. Carbon stock of the most dominant plot in study area. The plot10 is the most dominant plot in the study site about the carbon quantity (for above-ground biomass = 363.899 t C ha^{-1}, and for below-ground biomass = 85.516 t C ha^{-1}).

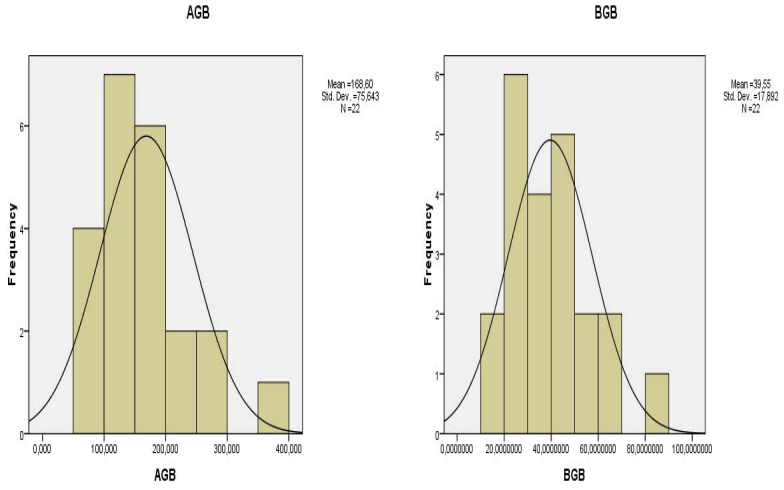

Figure 10. Frequency distribution of aboveground biomass and belowground biomass in Lesiolouna forest (study site).