Applied Ecology and Environmental Sciences, 2015, Vol. 3, No. 2, 51-59
Available online at http://pubs.sciepub.com/aees/3/2/4

DOI:10.12691/aees-3-2-4

Evaluating the Carbon Stock in Above-and Below-Ground Biomass in a Moist Central African Forest

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Received February 22, 2015; Revised April 08, 2015; Accepted April 22, 2015

Abstract The study aimed to estimate the carbon stocks of above-and below-ground biomass in Lesio-louna forest (Republic of Congo). The methodology of allometric equations was used to measure the carbon stocks of Lesio-louna moist forest. The research was done with 22 circular plots, each 1,256 m^2. 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. The results shows that in the whole forest, the average carbon stock across the 22 plots studied was 168.601 t C ha^{-1} for aboveground biomass (AGB), or 81% and 39.55t C ha^{-1} for belowground biomass (BGB), or 19%. The total carbon stocks in all the biomass was 3,395 t C for aboveground biomass (AGB) and 909.689 t C for belowground biomass (BGB).This study indicates that the forests in the studied sites are an important carbon sink, and they can also play a key role in global climate change mitigation. Lesio-louna tropical 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 (GHGs) offenders.

Keywords: *Carbon Stocks, Gallery Forest, Secondary Forest, Aboveground Biomass, Belowground Biomass, Lesio-louna forest*

Cite This Article: Romeo Ekoungoulou, Shukui Niu, Jean Joël Loumeto, Suspense Averti Ifo, Yannick Enock Bocko, Fleury Edgard Koula Mikieleko, Eusebe Devalon Mpane Guiekisse, Hamidou Senou, and Xiaodong Liu, "Evaluating the Carbon Stock in Above-and Below-Ground Biomass in a Moist Central African Forest." *Applied Ecology and Environmental Sciences*, vol. 3, no. 2 (2015): 51-59. doi: 10.12691/aees-3-2-4.

1. Introduction

In the context of climate change, special attention is given to carbon which is a major constituent of greenhouse gases (GHGs). Forests have a very important role for mitigating this phenomenon by photosynthesis [23,27]. Globally, terrestrial ecosystems sequester annually 1.4 ± 0.7 P. g1C.yr^{-1}, or 22.2% of the flux of fossil fuels [32]. Forests account for 48% of the total carbon storage capacity of worldwide terrestrial ecosystems [32,52]. Trees, the major components of forests, 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 [36]. 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. Moreover, undisturbed forest ecosystems are important global carbon sinks [36]. In forests, there are five storages of carbon: the above-and below-ground biomass of trees, litter on the forest floor, dead woods, soils and long-life wood products [47]. 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 measuring costs. All reserves are expected to see a reduction in response to the human activities, thus, there is a need for these activities to be measured and monitored. The forest is a reservoir of carbon [26] because it has a good capacity to stock carbon from the atmosphere [33,50]. The decision to evaluate wood products depends on whether the trees will be harvested or not. Activities related to forest management can be to analyze wood products [32,36] 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 [25], in the forest floor and soil [41,42,43]. The idea of paying forest users in the developing world to reforest 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 [27]. 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 [30].

Ecology is the main response of tropical forest ecosystems to natural or anthropogenic environmental changes [29,37,51]. Long-term forest inventories are most useful in order to evaluate the magnitude of carbon fluxes between aboveground forest ecosystems and the atmosphere [1,16]. Guidelines have been published for setting up permanent plots, censuring trees correctly [11,14], and for estimating aboveground biomass (AGB) stocks and changes from these datasets [7,16,28]. 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 aboveground biomass estimates [24,30]. Here, we directly appraise a critical step in the plot-based biomass estimation procedure, namely the conversion of plot census data into estimates of aboveground biomass (AGB). Most important, approaches under the Kyoto Protocol may increase CO_2 emissions from forestry by accelerating deforestation [28,34]. Yet, reduced emissions from deforestation and forest degradation (REDD), and compensated reduction in deforestation has 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 [36].

The use of allometric equations is a crucial step in estimating aboveground biomass (AGB), yet it is seldom directly tested [8,15,35]. Belowground biomass is estimated from aboveground biomass through allometric methods [41]. Because one hectare of tropical forest may shelter as many as 300 different tree species [44], one cannot use species-specific regression models, as in the temperate zone [9,43]. 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 [7,17,42]. 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 quality of the model [4]. Tropical forests hold large stores of carbon [23,31], yet uncertainty remains regarding their quantitative contribution to the global carbon cycle [6,22]. 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 [15]. The assessment of carbon stocks in this ecosystem is not yet satisfactorily known, but if it was, would enable countries with this heritage to access their carbon credit-another way to take advantage of the forest. Very little specific information is available in this field regarding the Republic of Congo.

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 [12]. Monitoring of logging activities therefore serves as an important function [13]. 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 Republic of Congo’s forest carbon quantification program. Within the carbon market, the result of this study on carbon stocks in Lesio-louna forest could allow the Republic of Congo to receive the carbon credit.

2. Materials and Methods

2.1. Study Area

The sites in which the experimental plots of this study were installed is located in the Lesio-louna protected area, found in the Teke-plateau (15°28′E, 03°16′S), around the Department of Pool in the Republic of Congo. Also, the Teke-plateau is a wide range of plateau starting from Republic of Gabon crossing Republic of Congo until Democratic Republic of Congo [20,23]. Lesio-louna is around 160 km in north part from Brazzaville [21]. It occupies the Centre of the Republic of Congo and covers about 12,000 km^2 [5]. The altitude varies between 600 and 800 m, and surrounded by a hilly area, occupies about 70,000 km^2 [5,22]. From a geographical point of view, in The Republic of Congo, Teke-plateau extend from the north of the city of Brazzaville and are limited to the east by the Congo River to the west by longitude 14°50'E, to the south by parallel 03°01'S latitude, the north by the parallel 03°17'S South latitude[5]. The annual precipitation is 1,500 to 2,000 mm [2-3].

2.2. Data Collection

The fieldwork was based on techniques using circular plots [13,47,52], each with a diameter of 40 m. The reason for choosing this more appropriate type of plot is that the real boundary of circular plots does not need to be marked [20,21,22]. We used a nested experimental design of study plots. Experience has shown that sample plots containing small sub-units of similar shape but of different sizes (i.e. nested plots) are advantageous economically and scientifically for most tree vegetation. The study retained 22 circular plots each separated by roughly 100 m. The study plots were permanent plots consisting of three concentric circles. The first circle is the smallest, with a radius of 6 m, to measure the trees with 10-30 cm diameter at breast height (DBH). The second is the intermediate circle, with a radius of 14 m, to measure the trees with 30-60 cm DBH. The third circle is the largest, with a radius of 20 m, to measure the trees >60 cm DBH.

Tree measurements were conducted on plots with a slope < 10°. Also, measurements were made solely on the trees DBH $\geq$ 10 cm and height 1.3 m [1,28], and only these were marked with a nail and plastic label. We used the criteria of DBH $\geq$ 10 because the stand age of the forest in the study area was not particularly young. Also, Lesio-louna forest is the tropical moist forest. The stems less than 10 cm would normally be measured in fairly young forest.

The measurements were performed by taking into account the tree locations. For trees with obstacles, we had to add 30 cm to 1.3 m to the normal size measurements.

The description of the approach used to measure trees of the study was incorporated into the data collection to allow measurements to be made with precision and accuracy. The steps followed were:

An enumerator responsible for recording data was focused exclusively on measuring and marking trees. Registration took place at the center of the plot being measured. The enumerator also monitored those measuring trees and ensured no trees were omitted;

To prevent double counting or omission of trees, the measurement started from north and the first tree was labeled [18,19,20,21]. Any measured tree would be immediately labeled with a permanent marker sign facing the center of the plot to allow the data enumerator to distinguish between measured and unmeasured trees;

Any tree of suitable size inside each nested plot had a numbered tag, preferably plastic, nailed to it.

2.3. Data Analysis

To estimate the carbon stock in Lesio-louna forest, we used the method from [15] by measurement of the biomass. The reason for choosing the allometry method is according to the recommendation of REDD+ process, also to contribute in the mitigation of global climate change. The methodology used was the non-destructive method and the calculations were done by the allometric equations from [15] to calculate the aboveground biomass (AGB). The model from [41] was used to calculate the belowground biomass (BGB). The main parameters for the calculation were diameter at breast height (DBH) and wood density. In this model, the power-law relationship is parameterized by c=d=0. To estimate carbon, the biomass was divided by two to obtain the carbon for each plot [6,14,47]. Moreover, a carbon stock is typically derived from aboveground biomass by assuming that 50% of the biomass is made up carbon as asserted by [6]. The most accurate method for the estimation of biomass is through cutting of trees and weighing of their parts. This destructive method is often used to validate others, less invasive and costly methods, such as the estimation of carbon stock using non-destructive in-situ measurements. Total aboveground biomass of each tree in the plots was estimated using the following allometric equation:

$$AGB = \rho \times \exp o \begin{pmatrix} -1.499 + 2.148 \ln(DBH) \\ +0.207(\ln(DBH))^2 \\ -0.0281(\ln(DBH))^3 \end{pmatrix} \quad (1)$$

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 [15,18]. A concave shaped relationship is observed when the logarithm of height, *ln(H)*, is plotted against the logarithm of diameter, *ln*(DBH) [19]. 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 [19,43]. Assuming such a polynomial relationship between *ln*(H) and *ln*(DBH) [48], it is straightforward to deduce the following mathematical equation:

$$ln(AGB) = a + b ln(DBH) + c(ln(DBH))^2 + d(ln(DBH))^3 + ln(\rho) \quad (2)$$

For unidentified species, we applied the mean wood density for each plot, weighted by the number of trees from each species [39].

The general model for moist forest was chosen [15]:

$$AGB_{est} = \rho \times exp \begin{pmatrix} -1.499 + 2.148 ln(D) \\ +0.207(ln(D))^2 \\ -0.0281(ln(D))^3 \end{pmatrix} \quad (3)$$

The reason for choosing the model from [15] (Eq.3) is because it is developed for tropical moist forests and Lesio-louna area is a tropical moist forest. This pan-tropic model for tropical forests based on diameter at breast height (DBH) measurements and wood density was applied to our current data.

Wood density for each tree was provided by Global Wood Density Database from DRYAD (accessed on 28 December 2014 from http://datadryad.org/handle/10255/dryad.235). For example, one of the studied trees (*Millettia laurentii* De wild.) from plot1 in Lesio-louna's Inkou forest island(secondary forest) has a DBH of 40 cm. Then, 40 cm is well within the maximum DBH for this equation, which is reliable up to 148 cm [7].

$$AGB(kg) = \rho \times exp \begin{pmatrix} -1.499 + 2.148 ln(D) \\ +0.207(ln(D))^2 \\ -0.0281(ln(D))^3 \end{pmatrix} \quad (4)$$

$$\rho = wood\ density = 0.761 g\ cm^{-3}$$

$$D = DBH = 40 cm$$

$$AGB\ (kg) = \rho \times \exp \begin{pmatrix} -1.499 + 2.148 \ln(DBH) \\ + 0.207(\ln(DBH))^2 \\ -0.0281(\ln(DBH))^3 \end{pmatrix}$$

$$AGB = 302.766\ kg$$

Aboveground biomass (AGB) of this *Millettia laurentii* (Fabaceae) was 302.766 kg, or 0.302t. From [47], the follow equation is used to determine the estimation of carbon stock of the tree:

$$C(t) = \frac{AGB}{2} \quad (5)$$

$$C = 0.151\,t$$

So, the carbon stock estimation of this tree was 0.151 t.

$$t = ton$$
$$C = Carbon$$
$$AGB = Aboveground\ biomass$$

Next, to estimate the belowground biomass (BGB), the equation from [41] was used. The carbon stock of belowground biomass has been estimate from the belowground biomass as a carbon stock for belowground biomass is typically derived from belowground biomass by assuming that 50% of the belowground biomass is made up carbon. The equation developed by [41] for the moist forest is as follows:

$$BGB_{est} = 0.205 \times AGB\ if\ AGB \leq 125\text{Mgha}^{-1} \quad (6)$$

$$BGB_{est} = 0.235 \times AGB\ if\ AGB > 125\text{Mg ha}^{-1} \quad (7)$$

So, *BGBC*= Belowground biomass carbon (t C ha^{-1})
(6)

$$BGBC = 0.205 \times AGBC\ if\ AGBC \leq 62.5tC\ ha^{-1}$$

(7)

$$BGBC = 0.235 \times AGBC\ if\ AGBC > 62.5\ tCha^{-1}$$

$$1Mg = 1000kg = 1\ ton$$

The statistical analyses were performed using the statistical software *SPSS version 18.0* and the statistical software *Sigma Plot version 12.0*.

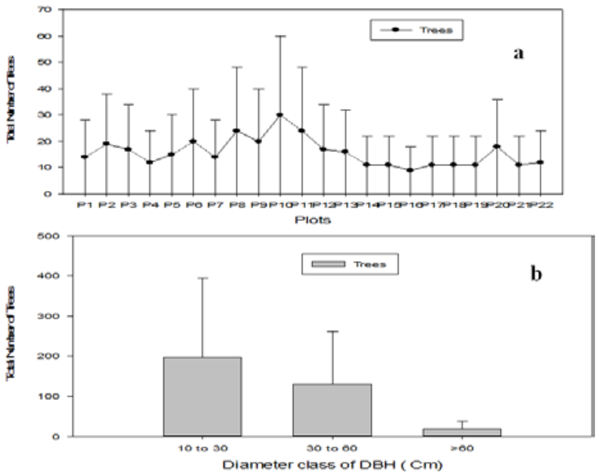

Figure 1. Distribution of trees in the study area. Total number of trees in 22 plots of study sites (a) and total number of trees by diameter class of DBH (b)

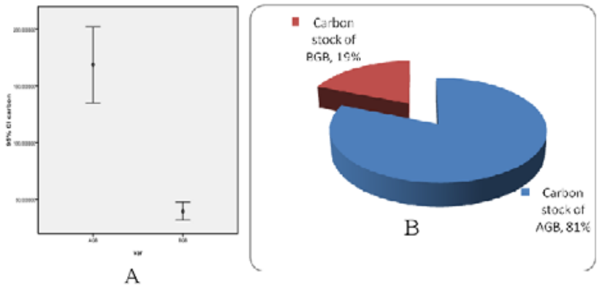

Figure 2. Carbon stock of aboveground-and below-ground biomass (A) in the study sites (t C ha^{-1}), and the frequency of carbon stock in aboveground biomass (AGB) and belowground biomass (BGB) for different studied plots (B)

3. Results

Table 1. Structuring the study sites and distribution of the carbon stock in Lesio-louna forest

Plot	Forest Type	n	AGB[b]	BGB[c]	Nest Area[d]	Site	Average DBH[a]	Area State
P1	SF	14	137.914	32.40	1,256	IFI	30.75	AUE
P2	SF	19	147.404	34.63	1,256	IFI	30.98	AUE
P3	GF	17	197.147	46.32	1,256	IBK	28.82	AUE
P4	GF	12	123.034	28.91	1,256	IBK	23.86	AUE
P5	GF	15	193.740	45.52	1,256	IBK	30.84	AUE
P6	GF	20	223.192	52.45	1,256	IBK	24.56	AUE
P7	GF	14	108.336	25.45	1,256	IBK	24.08	AUE
P8	GF	24	273.940	64.37	1,256	Ngo	31.79	Swamp
P9	GF	20	236.628	55.60	1,256	Ngo	25.98	Swamp
P10	GF	30	363.899	85.51	1,256	Ngo	29.89	Swamp
P11	GF	22	293.642	69	1,256	Ngo	26.98	Swamp
P12	GF	17	197.597	46.43	1,256	Ngo	28.23	AUE
P13	GF	16	173.999	40.88	1,256	Ngo	26.98	AUE
P14	GF	11	96.72	22.72	1,256	BLF	24.49	AUE
P15	GF	11	77.16	18.13	1,256	BLF	28.09	AUE
P16	GF	9	51.01	10.45	1,256	BLF	27.75	AUE
P17	GF	11	153.274	36.01	1,256	BLF	40.38	AUE
P18	GF	11	128.020	30.08	1,256	BLF	41.91	Swamp
P19	GF	11	99.57	23.39	1,256	Nga	31.86	AUE
P20	GF	18	185.078	43.49	1,256	Nga	40.17	Swamp
P21	SF	11	122.611	28.81	1,256	IFI	42.01	EDF
P22	GF	12	125.305	29.44	1,256	Nga	34.44	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]: Plot size (m^2), n: Number of trees recorded, IFI: Inkou forest island, IBK: Iboubikro, BLF: Blue lake forest, Ngo: Ngoyili, Nga: Ngambali, SF: Secondary forest, GF: Gallery forest, P: Plot, AUE: An Undisturbed Ecosystem, EDF: Ecosystem disturbance by fire.

This study was conducted using 22 circular plots each 1,256 m^2 with 20 m radius / plot. All 22 plots studied were divided between 5 sites, including: Iboubikro, Ngoyili, Blue Lake Forest, Inkou Forest Island and Ngoyili (Table 1). In the 22 plots studied, 19 plots are in gallery forest and three plots in 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 (Figure 1). Most calculations determine the values for biomass reserve data, except for soil, which usually measures the carbon directly [15].

Values to extrapolate up to the values of the plots per hectare required an expansion factor. These expansion factors indicate which surface is represented by each plot or sample as observed by [20]. This standardization is needed to easily interpret the results and also make comparisons with other studies.

This study shows that the species density is higher in the gallery forest compared to the secondary forest. Table 1 shows that all 22 plots are the same size (1,256 m^2) and the radius of each plot is also the same size in all plots. However, plot10 is the most dominant in terms of number of trees, as it contains 30 trees, and plot16 contains only a few species (9 trees). The total carbon stock in all the biomass was 3,395 t C for aboveground biomass (AGB) and 909.689 t C for belowground biomass (BGB). Moreover, in this forest, the carbon stock was more substantial in aboveground biomass compared to belowground biomass (3,395t C and 909.689t C respectively). In this forest ecosystem, plot10 had a higher carbon stock of aboveground biomass (363.899t C ha^{-1}), closely followed by plot11, with a carbon stock of aboveground biomass (AGB) measuring 293.642t Cha^{-1}, as shown in Table 1. The lower carbon stock of aboveground biomass (AGB) is in plot16 which was measured at 51.01t Cha^{-1}. Also, in this forest ecosystem, the average aboveground biomass carbon stock was 168.601t C ha^{-1}, or 81% (Figure 2). In contrast, the average of belowground biomass carbon stock was 39.55t C ha^{-1}, or 19%. The frequency distribution of aboveground biomass was higher compared to belowground biomass in the study area (Figure 6). We found that the carbon stock of aboveground biomass (AGB) is high in relation to carbon stock of belowground biomass (BGB). Figure 2 shows that in this study, the carbon stock estimation of AGB (168.601 t Cha^{-1}) is higher than the carbon stock estimation of BGB (39.55 t C ha^{-1}).

We have presented the comparison between the carbon stock of secondary forest and the gallery forest in Figure 3. In the gallery forest, we used random plots P14, P15 and P16 (Table 1). The scientific reason to choice P14, P15, and P16 as representative of the gallery forest is because these three plots have an area state similar with most of plots from the secondary forest. Area state of P14, P14, and P16 is an undisturbed ecosystem. Thus, with regards to AGB, the average of carbon stock of secondary forest (135.976tC ha^{-1}) is higher than the average carbon stock of the gallery forest (74.96tC ha^{-1}). Regarding belowground biomass (BGB), the average carbon stock of secondary forest (31.94tC ha^{-1}) is higher than the average carbon stock of the gallery forest (17.1 tC ha^{-1}) (Figure 3). Also, the three selected plots of the gallery forest are in the site of Blue Lake Forest, 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). In contrast, in the secondary forest (P1, P2 and P21), there are 4 trees presented in the 20 m radius (trees>60 cm DBH). In the radius of 6 m (trees 10-30 cm DBH) and the radius of 14 m (trees 30-60 cm DBH) there are trees presented in both types of forest.

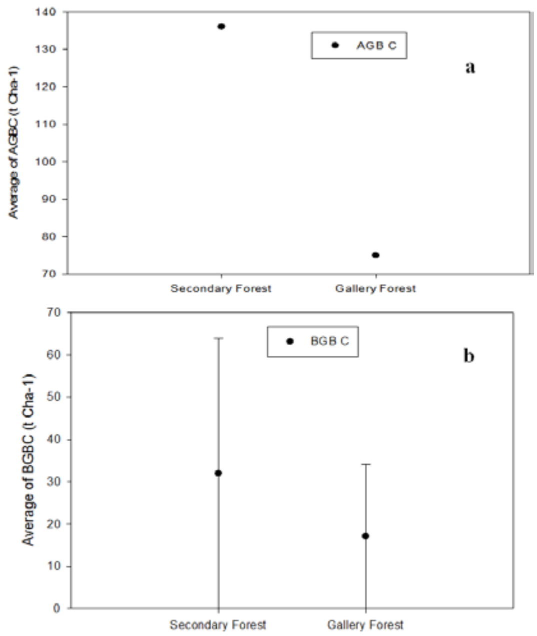

Figure 3. Comparison of the distribution of aboveground biomass (AGB) carbon stock (a), and distribution of belowground biomass (BGB) carbon stock (b) in secondary and gallery forests

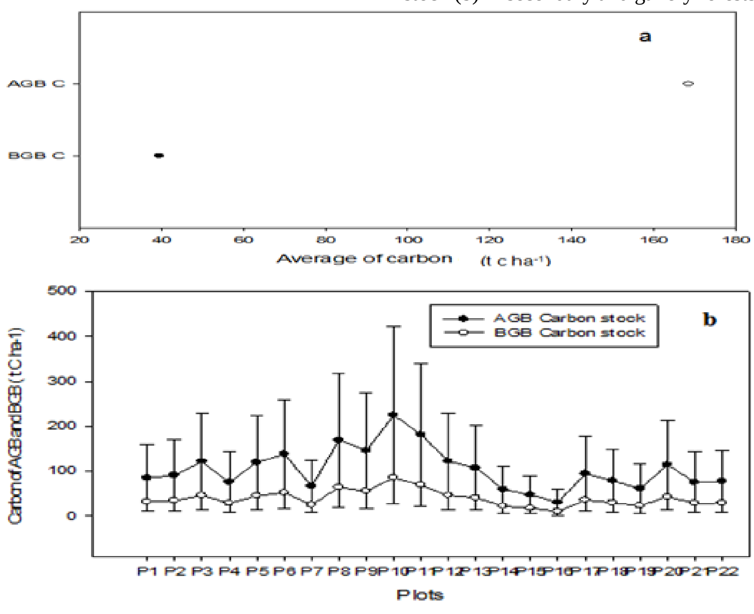

Figure 4. Average of aboveground biomass (AGB) carbon and below ground biomass (BGB) carbon in Lesio-louna forest in t C ha^{-1} (a). Total carbon stocks of above-and below-ground biomass by plot in Lesio-louna tropical rainforest (b) by t C ha^{-1}.This figure shows that the carbon stock reaches a higher amount in the aboveground biomass compared to belowground biomass in the study area

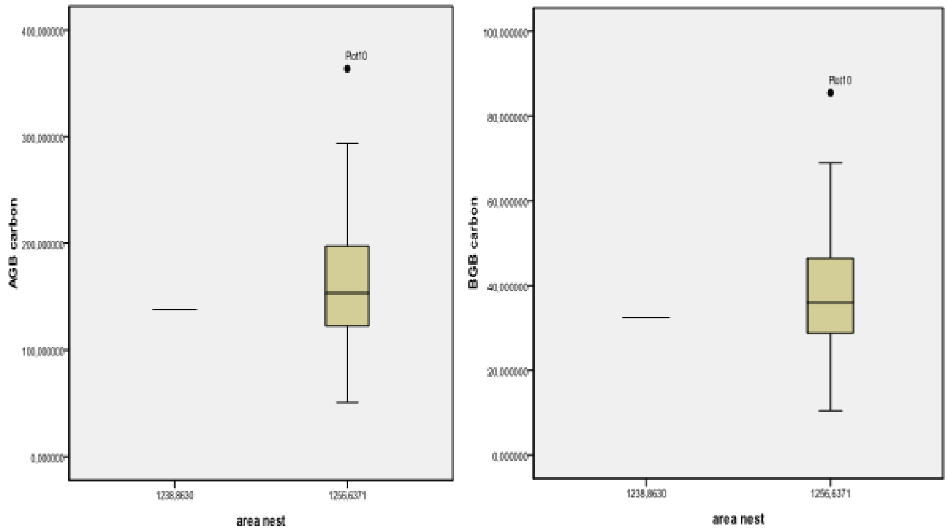

Figure 5. Carbon stock of the most dominant plot in the study area. Plot10 is the most dominant plot in the study site with regards to carbon quantity (for above-ground biomass is 363.899t C ha^{-1}, and for below-ground biomass is 85.51t C ha^{-1})

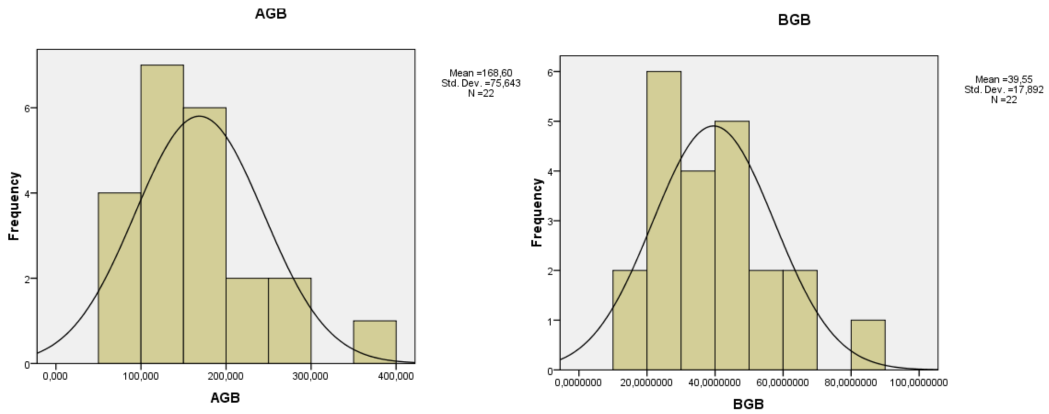

Figure 6. Frequency distribution of above-and below-ground biomass in Lesio-louna forest

4. Discussion

This research aimed to estimate the carbon stocks of above-and below-ground biomass in Lesio-louna forest (Republic of Congo). The methodology of allometric equations from [15] and [41] was used to measure the biomass of the Lesio-louna natural forest [15,41-46]. Results obtained in this study and elsewhere [8,9,10] show the necessity of developing specific biomass models for each plot and forest type in Lesio-louna moist forest. The general models of total aboveground biomass should be carefully used in specific areas or carbon projects [21,26,46]. In this study, the carbon stock estimation can be directed to researchers and administrators for analyses [50] used to calculate global carbon credits. These can be helpful in improving the forest resources and environmental sectors like those within the Republic of Congo, other Congo basin countries and tropical countries with similar conditions.

This study shows that the carbon stocks in Lesio-louna forest varies from one site to another and from one plot to another (Figure 4). The carbon stock of aboveground biomass [40] is higher compared to belowground biomass (BGB) in all studied plots. The average frequency of aboveground biomass (AGB) was more important compared to belowground biomass (BGB) in studied sites (Figure 6). In this study, we found that the carbon stock is not based on the number of trees, but rather is related to DBH and wood density. In this study area, plot10 is the higher about carbon stock (AGB was 363.899t C ha^{-1}). Plot10 (Figure 5) was in the gallery forest of the Ngoyili site, 30 trees were measured, AGB was 363.899 t C ha^{-1}, BGB was 85.51 t C ha^{-1} and average DBH was 29.89 cm (Table 1). In Lesio-louna tropical moist forest, the carbon stock was higher within in the aboveground biomass(AGB) compared to belowground biomass as shown in Figure 4. Plot10 is in a submerged area (swamp) and in this area, there's less of Chablis.

The carbon stock in plot 10 is the highest, while the average of tree diameter (DBH) was lower compared to plot 5, because in plot 10 we recorded an important number of trees from Fabaceae and Mimosaceae. Plot 10 is dominated by the *Millettia laurentii* De Wild., and *Piptadeniastrum africanum* (Hook.f.) Brenan. So, *Millettia laurentii* (Fabaceae) and *Piptadeniastrum africanum* (Mimosaceae) are from the Leguminosae and can play a key role in the functioning of ecosystems. The Leguminosae capture atmospheric nitrogen and enrich the soil with nitrogen. Also, nitrogen is essential for plant growth. Generally, the trees from Leguminosae have the highest quantity of biomass [26].

The number of trees, trees DBH, trees biomass and carbon stock are influenced by the state of area in this forest. Ngoyili River is very close to this plot and the undergrowth of the forest is somewhat sparse and trees of this area generally are considerable in height (Figure 4). Also, high carbon stock of this forest [34,36] is potentially due to its natural reserve of flora and fauna, and by being a less disturbed forest ecosystem.

With regard to the current status and future challenges in measuring carbon in forest, [9] asserted that, to accurately and precisely measure the carbon in forests would allow global attention as to be sought by countries, comply with agreements under the United Nations Framework Convention on Climate Change (UNFCCC). 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 concerning tree allometry and improved estimation of carbon stocks and balance in tropical forests from [15] determined that total aboveground stand biomass differed by over 20% from the measured value in several sites, and most of these sites had less than 30 trees, and such small samples may bias the overall predictions. In Lesio-louna tropical forest ecosystem, logging and poaching are strictly prohibited because it is a protected reserve for flora and fauna [5]. In general, the carbon stock of Lesio-louna is higher compared to the study from [38]. In the forest of Lesio-louna, there is a good functioning of ecosystems and the ecological balance is respected. Therefore, 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 from UK and The Republic of Congo's Ministry of Forest Economy and Sustainable Development. The average carbon stock for 22 plots of this study was 168.601 t C ha^{-1} for aboveground biomass, or 81% and 39.55 t C ha^{-1} for belowground biomass, or 19% (Figure 2). The total carbon stock in 22 plots for AGB was 3,395.36 t C, and for BGB its 909.689 t C. The results reveal that in this forest, the carbon stock is important in aboveground biomass (AGB) compared to belowground biomass (BGB) with measurements of 3,395.36 t C and 909.689 t Carbon respectively. The comparison test of average between plots revealed that the significant difference is 129.05t Cha^{-1}. In addition, we compared 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 (Figure 3). The results of this work indicate that the carbon stocks for AGB is more important in secondary forest compared to the gallery forest, with averages of 135.976 t C ha^{-1} against 74.96 t C ha^{-1} respectively (Figure 3a), and for BGB is also more important in secondary forest compared to the gallery forest, with averages of 31.94 t C ha^{-1} against 17.1 t C ha^{-1} respectively (Figure 3b). Comparison test of means between the two forest types (gallery and secondary forests) revealed a significant difference which is 61.01 t C for Aboveground biomass (AGB) and 14.84 t C for Belowground biomass (BGB). Figure 5 shows that plot10 is the most dominant plot in the study site with regards to carbon quantity or carbon stock (for aboveground biomass we have 363.899 t C ha^{-1} and 85.51 t C ha^{-1} for belowground biomass).

Regarding a benchmark map of forest carbon stocks in tropical regions across three continents, [49] asserted thatestimation of the total forest biomass carbon stocks at 10% tree cover is 247 Gt C, with 193 Gt C in AGB and 54 Gt C in BGB. Forests in Latin America are the most extensive and contain around 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 woodlands 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).

In Lesio-louna forest, the carbon stock was higher in the aboveground biomass (AGB) compared to belowground biomass (BGB). The study shows that Plot10 in Ngoyili forest recorded an important number of trees (30 trees) compared to other studied plots. However, the average DBH in Plot10 (Ngoyili site) wasless (29.89 cm) compared to other plots in the study sites. Also, we recorded an important carbon stock in secondary forest compared to the gallery forest, that stock is built up for aboveground biomass (AGB) as well as for belowground biomass (BGB).Moreover, Inkou Forest Island site (secondary forest) is located on the hill and the growth of trees in this forest ecosystem is natural because the sun light penetrates normally. We observed that, in this area, the growth of the forest to savanna is remarkable, because several species of bush land are found in the forest edge and even in the plain forest.

This has an important secondary forest because it is a carbon stock forest of Fabaceae. Fabaceae has species which have the ability to capture atmospheric nitrogen by the presence of nodules in their roots. In this forest ecosystem, we found species such as *Millettia laurentii* De Wild**.**, *Musanga cecropioides* R.Br. ex Tedlie, and *Piptadeniastrum africanum* (Hook.f.) Brenan, that promotes the mitigation of global climate change by the photosynthesis phenomenon.

5. Conclusion

This study allowed us to estimate the carbon stock of aboveground biomass (AGB) and belowground biomass (BGB) in Lesio-louna moist forest of The Republic of Congo. This study indicates that throughout this forest, the carbon stock for aboveground biomass (AGB) was 81% and the carbon stock for belowground biomass (BGB) was 19%. Plot 10 was the most dominant in terms of carbon stocks in the study area. Thus, the carbon stock of plot16 was less than other plots in the study area. The comparison test of means between plots revealed that a significant difference was 129.05t C ha^{-1}. By this study we found that, the forests in the study area are an important reservoir of carbon, and they can also play a key role for mitigating the global 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 main greenhouse gases. 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 the 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-plateau, 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.

Conflict of Interests

The authors declare that there is no conflict of interests regarding this paper.

Acknowledgements

The authors grateful acknowledge China Scholarship Council (CSC), Beijing Forestry University, Republic of Congo's Ministry of Forest Economy and Sustainable Development, Lesio-louna Project from *The Aspinall Foundation*, The National Science and Technology Support Project (Project No: 2011BAD32B05) from China, and Université Marien Ngouabi for supporting this work. It is a pleasure to acknowledge Thechel Ekoungoulou from Food and Agriculture Organization of the United Nations (FAO),and Charlotte Witham from Beijing Forestry University's School of Nature Conservation for their contribution regarding this study. We also thank an anonymous referee for insightful comments on a previous version of the manuscript.

References

[1] Alvarez, E., Duque, A., Saldarriaga, J., Cabrera, K., De-Las-Salas, G., Del-Valle, I., Lema, A., Moreno, F., Orrego, S. and Rodríguez, L, "Tree above-ground biomass allometries for carbon stocks estimation in the natural forests of Colombia", *Forest Ecology and Management,* 267: 297-308, 2012.

[2] ANAC,*Situation Météorologique Nationale*, Rapport annuel de l'agence nationale de l'aviation civile (ANAC), Ministère de transport et de l'aviation civile, Brazzaville, Congo, 2010.

[3] ANAC,*Situation Météorologique Nationale*, Rapport annuel de l'agence nationale de l'aviation civile (ANAC), Ministère de transport et de l'aviation civile de la République du Congo, Brazzaville, Congo,2013.

[4] Angelsen, A., Brockhaus, M., Kanninen, M., Sills, E., Sunderlin, W.D. and Kanounnikoff, W.S, *Realising REDD+: National strategy and policy*, Center for International Forestry Research (CIFOR), Bogor, Indonesia, 2009.

[5] Anon,*Rapport annuel du projet Lesio-louna*, Ministère de l'Economie Forestière et du Développement Durable, The AspinallFoundation, Brazzaville, Congo, 2010.

[6] Basuki, T.M., Van-Laake, P.E., Skidmore, A.K. and Hussin, Y.A, "Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests", *Forest Ecology and Management*, 257 (8): 1684-1694, 2009.

[7] Brown, S, *Estimating biomass and biomass change of tropical forests: a primer UN FAO Forestry Paper 134*, Food and Agriculture Organization of United Nations (FAO), Rome, Italy, 1997.

[8] Brown, S., Burnham. M., Delaney, M., Vaca, R., Powell, M. and Moreno, A, "Issues and challenges for forest-based carbon-offset projects: a case study of the Noel Kempff Climate Action Project in Bolivia", *Mitigation and Adaptation Strategies for Climate Change,* 5 (1): 99-121, 2000.

[9] Brown, S, "Measuring carbon in forests: current status and future challenges", *Environmental pollution,* 116 (3): 363-372, 2002.

[10] Brown, S., Pearson, T., Delaney, M., Shoch, D., Vaca, R. and Quispe, J, *The 2003 carbon offsets analysis and status report for the Noel Kempff Climate Action Project*, Report to the Nature Conservancy, 2003.

[11] Brown, S., Pearson, T., Slaymaker, D., Ambagis, S., Moore, N., Novelo, D. and Sabido, W, *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, 2004.

[12] Brown, S., Pearson, T., Moore, N., Parveen, A., Ambagis, S. and Shoch, D, *Impact of selective logging on the carbon stocks of tropical forests: Republic of Congo as a case study*, Deliverable 6 to USAID, Cooperative Agreement No. EEM-A-00-03-00006-00, Winrock international, Arlington, VA, USA, 2005a.

[13] Brown, S., Pearson, T., Slaymaker, D., Ambagis, S., Moore, N., Novelo, D. and Sabido W, "Creating a virtual tropical forest from three-dimensional aerial imagery to estimate carbon stocks", *Ecological Applications,* 15: 1083-1095, 2005b.

[14] Chave, J., Rie´ra, B. and Dubois, M.A, "Estimation of biomass in a neotropical forest of French Guiana: spatial and temporal variability", *Journal of Tropical Ecology,* 17: 79-96, 2001.

[15] Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Rie´ra, B. and Yamakura, T, "Tree allometry and improved estimation of carbon stocks and balance in tropical forests", *Oecologia*, 145: 87-99, 2005.

[16] Chave, J, Muller-Landau, H.C, Baker, T.R., Easdale, T.A., Ter-Steege, H. and Webb, C.O, "Regional and phylogenetic variation of wood density across 2,456 neotropical tree species", *Ecological Applications,* 16: 2356-2367, 2006.

[17] Chave, J., Condit, R., Muller-Landau, H., Thomas, S., Ashton, P., Bunyavejchewin, S., Co, L., Dattaraja, H., Davies, S., Esufali, S., Ewango, C., Feeley, K., Foster, R., Gunatilleke, N., Gunatilleke, S., Hall, P., Hart, T., Hernández, C., Hubbell, S., Itoh, A., Iratiprayoon, S., Lafrankie, J., Loo-De-Lao, S., Makana, J., Moore, N., Kassim, A., Samper, C., Sukumar, R., Suresh, H., Tan, S., Thompson, J., Tongco, M., Valencia, R., Vallejo, M., Villa, G., Yamakura, T., Zimmerman, J. and Losos, E, "Assessing evidence for a pervasive alteration in tropical tree communities", *Plos Biology,* 6 (3): e45, 2008.

[18] Chave, J., Coomes, D., Jansen, S., Lewis, S.L., Swenson, N.G. and Zanne, A.E, "Towards a worldwide wood economics spectrum", *Ecology Letters,* 12:351-366, 2009.

[19] Djomo, A.N., Ibrahima, A., Saborowski, J. and Gravenhorst, G, "Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa", *Forest Ecology and Management,* 260 (10): 1873-1885, 2010.

[20] Ekoungoulou, R., Liu, X., Ifo, S.A., Loumeto, J.J. and Folega, F, "Carbon stock estimation in secondary forest and gallery forest of Congo using allometric equations", *International Journal of Scientific and Technology Research,* 3 (3): 465-474, 2014a.

[21] Ekoungoulou, R., Liu, X., Loumeto, J.J. and Ifo, S.A, "Tree Above-And Below-Ground Biomass Allometries for Carbon Stocks Estimation in Secondary Forest of Congo", *Journal of Environmental Science, Toxicology and Food Technology,* 8 (4): 09-20, 2014b.

[22] Ekoungoulou, R., Liu, X., Loumeto, J.J., Ifo, S.., Bocko, Y.E., Koula, F.E. andNiu, S, "Tree Allometry in Tropical Forest of Congo for Carbon Stocks Estimation in Above-Ground Biomass", *Open Journal of Forestry,* 4 (5): 481-491, 2014c.

[23] Ekoungoulou, R, *Carbon Stocks Evaluation in Tropical Forest, Congo*, Carbon Stocks in Forest Ecosystems, Lambert Academic Publishing, Edited by Megan Moore, Saarbrucken, Germany, 2014.

[24] FAO, *Forest harvesting in natural forests of the Republic of Congo*, Forest Harvesting Case Studies-07, Food and Agriculture Organization of United Nations (FAO), Rome, Italy, 1997.

[25] FAO, *State of the World's Forests*, Food and Agriculture Organization of United Nations (FAO), Rome, Italy, 2003.

[26] FAO,*Les forêts du Bassin du Congo*, Etat des Forets. Organisation des Nations Unies pour l'Alimentation et l'Agriculture (FAO), Rome, Italy, 2008.

[27] FAO, *State of the World's Forests*, Food and Agriculture Organization of United Nations (FAO), Rome, Italy, 2011.

[28] Folega, F., Zhao, H., Zhang, Y., Wala, K. and Akpagana, K, "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.

[29] Gorte, W.R, *Carbon Sequestration in Forests*, Congressional Research Service, Natural Resources Policy, CRS Report for Congress, 2009.

[30] Hall, A, *Forests and climate change*, The Social dimensions of REDD in Latin America, 2012.

[31] Holmes, T.P., Blake, G.M., Zweede, J.C., Pereira, R., Barreto, P., Boltz, F. and Bauch, R, *Financial costs and benefits of reduced-impact logging relative to conventional logging in the eastern Amazon*, Tropical Forest Foundation, Arlington, VA, USA, 1999.

[32] IPCC, *Third Assessment Report of IPCC*, Climate Change 2001: The Scientific Basis, Contribution of Working Group1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK, 2001.

[33] IPCC, *Special report*, Intergovernmental Panel on Climate Change (IPCC), UNEP, New-York, USA, 2007.

[34] 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, New-York, USA, 2011.

[35] Killeen, T.J., Siles, T.M., Grimwood, T., Tieszen, L.L., Steininger, M.K., Tucker, C.J. and Panfil, S, *Habitat herterogeneity on a forest-savanna ecotone in Noel Kempff Mercado National Park (Santa Cruz, Bolivia): implications for the long-term conservation of biodiversity in a changing climate*, In How Landscapes Change: human disturbance and ecosystem fragmentation in the Americas, Edited by Bradshaw, G.A. and Marquet, P.A, Springer-Verlag, Heidelberg, Germany, 2002.

[36] Lorenz, K. and Lal, R, *Carbon sequestration in forest ecosystems*, Springer, California, USA, 2009.

[37] Lugo, A.E. and Brown, S, "Steady state ecosystems and the global carbon cycle", *Vegetatio,* 68:83-90, 1986.

[38] Madgwick, H. and Satoo, T, "On estimating the above ground weights of tree stands", *Ecology,* 56: 1446-1450, 1975.

[39] Malhi, Y., Baker, T.R., Phillips, O.L., Almeida, S., Alvarez, E., Arroyo, L., Chave, J., Czimczik, C.I. Di-Fiore, A., Higuchi, N., Killeen, T.J., Laurance, S.G., Laurance, W.F., Lewis, S.L., Montoya, L.M.M., Monteagudo, A., Neill, D.A., Nunez-Vargas, P., Patino, S., Pitman, N.C.A., Quesada, C.A., Silva, J.N.M., Lezama, A.T., Vasques-Martinez, R., Terborgh, J., Vinceti, B. and Lloyd, J, "The above-ground coarse wood productivity of 104 Neotropical forest plots", *Global Change Biology,* 10 (5): 563-591, 2004.

[40] Midgley, J.J, "Is bigger better in plants? The hydraulic costs of increasing size in trees", *Trends in Ecology & Evolution,* 18: 5-6, 2003.

[41] Mokany, K., Raison, R.J. and Prokushkin, A.S, "Critical analysis of root: shoot ratios in terrestrial biomes", *Global Change Biology,* 12 (1): 84-96, 2006.

[42] Nelson, B.W., Mesquita, R., Pereira, J.L.G., De-Souza, S.G.A., Batista, G.T. and Couto, L.B, "Allometric regressions for improved estimate of secondary forest biomass in the central Amazon", *Forest Ecology and Management,* 117: 149-167, 1999.

[43] Niklas, K.J, "Mechanical properties of black locust (*Robiniapseudoacacia* L.) Wood", Size- and age-dependent variations in sap- and heartwood, *Annals of Botany*, 79: 265-272, 1997.

[44] Ogawa, H., Yoda, K., Ogino, K. and Kira, T, "Comparative ecological studies on three main types of forest vegetation in Thailand II Plant biomass", *Nature and Life in Southeast Asia,* 4: 49-80, 1965.

[45] Pearson, T., Ambagis, S., Brown, S., Slaymaker, D., Moore, N, *Application of Multispectral 3-Dimensional Aerial Digital Imagery for Estimating Carbon Stocks in a Bottomland Hardwood Forest*, Winrock International, Arlington, VA, USA, 2005a.

[46] Pearson, T., Brown, S., Parveen, A. and Moore, N, *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, Winrock international, Arlington, VA, USA, 2005b.

[47] Pearson, T. and Brown, S,*Guide de mesure et de suivi du carbone dans les forêts et prairies herbeuses*,Winrock international, Arlington, VA, USA, 2005.

[48] Richard, A.J. and Dean, W.W, *Applied Multivariate Statistical Analysis*, Sixth Edition, Pearson Education Beijing Office, Tsinghua University Press, Beijing, China, 2007.

[49] Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T.A., Salas, W., Zutta, B.R., Buermann, W., Lewis, S.L., Hagen, S., Petrova, S., White, L., Silman, M. and Morel, A, "Benchmark map of forest carbon stock in tropical regions across three continents", *Proceeding of the National Academy of Sciences of the United States of America*, 108 (24): 9899-9904, 2011.

[50] Ullah, M.R. and Amin, M, "Above- and below-ground carbon stock estimation in a natural forest of Bangladesh", *Journal of forest science,* 58 (8): 372-379, 2012.

[51] Vicente, F.B., Carbajal, N. and Pineda-Martínez, L.F.P, "Estimation of Total Yearly CO_2 Emissions by Wildfires in Mexico during the Period 1999-2010", *Advances in Meteorology,* 1-8, 2014.

[52] Watson, R.T., Noble, I.R, Bolin, B., Ravindranath, N.H., Verardo, D.J. and Donken, D.J, *L and Use, Land-Use Change and Forestry*, Special Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK, 2000.