https://www.scirp.org/journal/ns Natural Science, 2026, Vol. 18, (No. 10), pp: 207-220

Assessing the Carbon Stock of Logs and Snags in a Congo Basin Forest Ecosystem

Romeo Ekoungoulou, Anderson Junior Mopiane Foundou, Felix Koubouana

Laboratory of Remote Sensing and Applied Tropical Ecology, National Higher School of Agronomy and Forestry, Marien Ngouabi University, Brazzaville, Republic of Congo

Correspondence to: Romeo Ekoungoulou, romeoekous@gmail.com

Keywords: Coarse Woody Debris, Decomposition, Diameter, Layer Deadwood, Standing Deadwood

Received: July 28, 2026 **Accepted:** October 27, 2026 **Published:** October 30, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution-NonCommercial International License (CC BY-NC 4.0).
http://creativecommons.org/licenses/by-nc/4.0/

Open Access

ABSTRACT

Forests act as carbon sinks because the trees that make them up absorb carbon dioxide. Forest carbon is stored in living and dead trees, litter and the soil. The study carried out in the Likouala Department, Dongou District, aims to improve understanding of how forest ecosystems function through coarse woody debris. The research was conducted in six rectangular plots, each measuring 5000 m² (200 m × 25 m), with a total of 312 large woody debris. All individuals with a DBH ≥ 10 cm were inventoried to estimate the carbon stock of coarse woody debris. The results of this study revealed that the average carbon stock of standing deadwood (snags) was 5.7 t·ha^{-1}, and the average carbon stock of logs was 36.95 t C ha^{-1} in the study area. It should be noted that classes with larger diameters store more carbon than those with smaller diameters. Regarding decomposition classes, it's the less advanced classes that store more carbon. Furthermore, this study has shown that windthrow plays a decisive role in the production of large woody debris.

1. INTRODUCTION

In the Republic of Congo, a country in the Congo Basin, forests cover 22.4 million hectares, divided into three main areas: the northern Congo massif, covering 17.4 million hectares, and the Mayombe and Chaillu massifs in southern Congo, covering approximately 4.7 million hectares [1]. The latter two were the first to be exploited since colonial times due to their proximity to the port of Pointe-Noire and the presence of the CFCO (Chemin de Fer Congo Océan) railway and the Compagnie minière de l'Ogooué, and when Limba and Okoumé became two species of great economic value [1]. This led foresters to raise questions very early on regarding the availability of biological diversity and the restoration of forest resources [2].

Consequently, the United Nations Framework Convention on Climate Change (UNFCCC) has explored the possibility of reducing these emissions through the international REDD+ (Reducing Emissions

from Deforestation and Forest Degradation) initiative. The REDD+ mechanism aims to encourage developing countries to preserve forest areas through financial compensation derived from carbon credits [3]. However, its implementation depends on a Measurement, Reporting and Verification (MRV) system for estimating the biomass and carbon stocks contained in forests [4-7].

To this end, coarse woody debris constitutes one of the components of forest ecosystems and plays a role in their structure and functioning [3]. It constitutes a significant carbon reservoir in forest ecosystems, acting as both a source and a sink of CO_2 for the atmosphere [4]. Studies of deadwood in North American temperate forests reveal that large woody debris accounts for nearly 12% of the total carbon mass in these forest ecosystems and that the quantity of woody debris varies considerably from one continent to another [4, 8]. Depending on the diameter of the woody debris, two categories are distinguished: large woody debris and small woody debris [8, 9]. Furthermore, scientists agree on the existence of three classes of large woody debris (LWD), which are: LWD lying on the ground (logs); Snags, which are standing woody debris with a height ≥ 1.5 m [9]; stumps, defined as standing dead wood with a height of ≤1.5 m. Our study focuses on large woody debris.

With regard to the definition of coarse woody debris, coarse woody debris refers to all lying plant debris, whether or not in direct contact with the ground, with a diameter of ≥10 cm. Thus, some authors define large woody debris as having a diameter > 8 - 10 cm [4], whilst others classify those with a diameter < 8 - 10 cm as small woody debris (SWD) [9]. Very few deadwood inventory studies have been carried out in the forests of the Congo in general [10]; among the existing studies, we can cite the work of [3] in two types of natural forest in the Teke Plateaus in the Republic of Congo and the work of [7] in the Likouala forests, as well as the work of [11] in the Likouala Department of the Republic of Congo.

However, whilst several studies have been conducted on various carbon pools, research into the deadwood compartment appears to have been neglected [3]. A few studies undertaken in Congolese forests on deadwood include: [3] in the Téké Plateaus; [7] in Likouala; [12] also in Likouala. Indeed, these studies didn't cover the entire Likouala Department, which has a significant forest area. A specific inventory of the deadwood compartment in the forests of Likouala in general, and those of the Ipendja UFA in particular, is therefore necessary to estimate the total carbon stock contained within this compartment.

It is also important to note that the deadwood pool serves as an indicator of the state of equilibrium within a forest ecosystem. In the current context, this should help to enhance our understanding of how forests in the Congo Basin function in general, and those in the Likouala region in particular; and to improve estimates of the percentage of CO_2 captured by these forests. Indeed, carbon inputs to the soil in ecosystems depend on standing biomass, tree residues of all forms, the lifespan of plant parts (turnover), the specific composition of the stand and its density, as well as the edaphic and climatic characteristics of the site [3]. Dead wood can have significant effects on flow structure, sediment transport, the organisation of river forms and river style [9]. It is against this backdrop that this study was conducted to understand the functioning of forest ecosystems in the Congo in general, and in the Likouala Department in particular, under the title Estimation of the carbon stock of large woody debris in the Ipendja Forest Management Unit (UFA), Likouala Department, with the aim of determining the carbon stock of large woody debris and ensuring the sustainable and rational management of forest ecosystems to combat climate change. This study aimed to: 1) Estimate the carbon stock by type of deadwood and by study plot; 2) Determine the carbon stock of large woody debris by diameter class; 3) Estimate the carbon stock of deadwood by decomposition class.

2. MATERIALS AND METHODS

2.1. Study Area

The study area is located in the northern part of the Republic of Congo, specifically within the Ipendja Forest Management Unit (UFA), which is situated in the Dongou district of the Likouala Department. The Ipendja UFA forms part of Zone I (Ibenga-Motaba) and covers an estimated area of 461.2 hectares [12, 13]. The department stretches 230 km from east to west and approximately 550 km from north to south. It is bordered: to the north by the Central African Republic, to the south by the Central Basin Department, to

the east by the Oubangui River, which separates it from the Democratic Republic of Congo, and to the west by the Sangha Department (Figure 1).

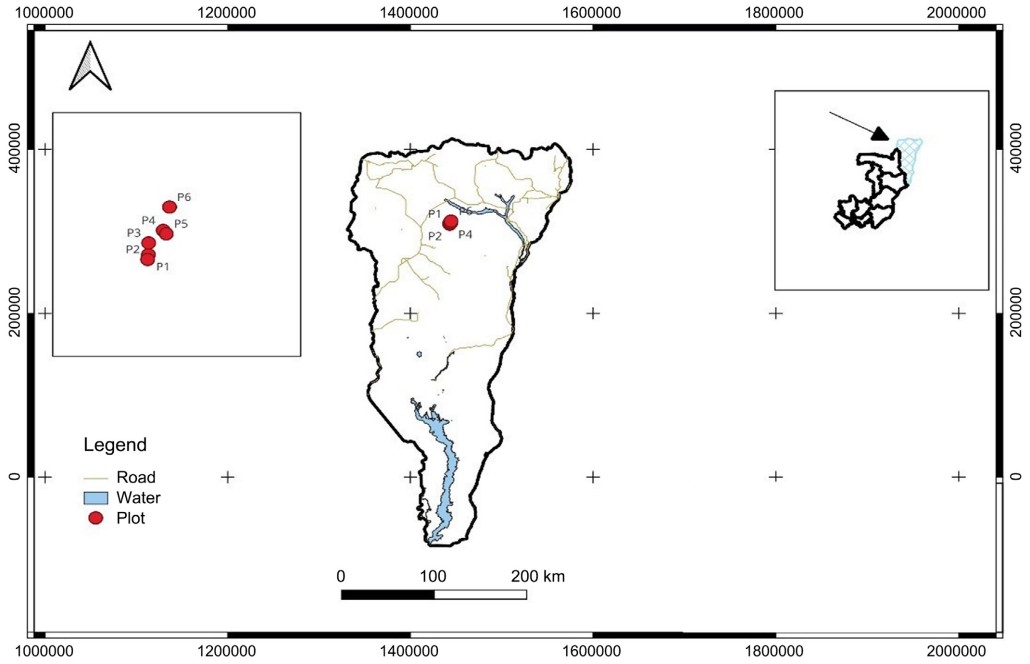


Figure 1. Overview of the study area.

2.2. Climate

The study area has an equatorial and humid tropical climate typical of the Guinean forest region. The average temperature in the Likouala department is 25˚C, whilst average rainfall is 1600 mm to 1800 mm with interannual variability of 10 to 15 per cent, and a dry season lasting 40 days from December to January; a drop in average annual temperature to 25˚C - 26˚C during the rainy season in July, with a range of 1˚C - 2˚C (Figure 2); relative humidity of 84% - 86% throughout the year [14].

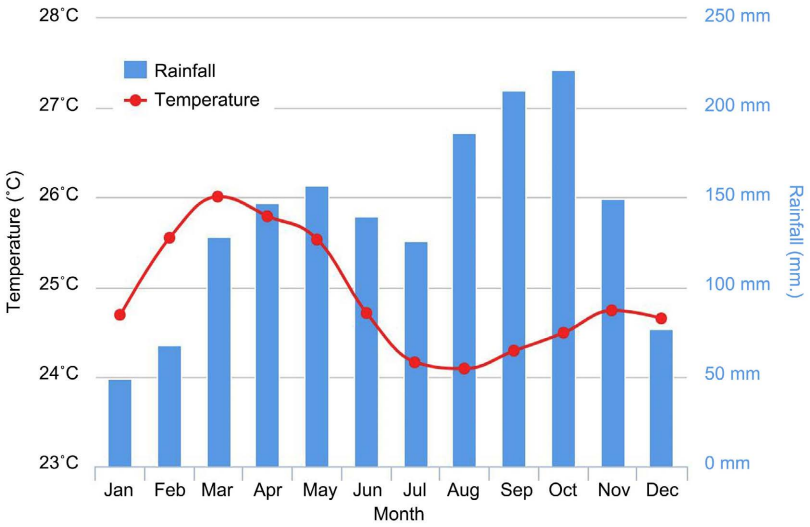


Figure 2. Climograph of the main meteorological station around the study area (average from 2014 to 2024).

2.3. Data Collection

Data collection involved an inventory of coarse woody debris samples within the study site. Plots were selected using a systematic inventory. The distance between plots was around 2000 m to ensure a certain degree of heterogeneity in the samples. Forest type of the study area is mixed terra firme lowland tropical forest. With an area of 461 thousand hectares, the Ipendja forest management unit (UFA) is in the shape of trapezoidal; it was named Ipendja because it is crossed by the Ipendja River. Each plot was subdivided into plots of four. In all, six plots were set up with a total area of 5000 m^2 in this zone. Within each plot, dead wood samples were collected, taking into account the two types of wood, namely: Large woody debris or dead wood lying on the ground or "Logs"; large woody debris is defined in this study as all woody debris lying, in direct contact or not with the ground and having a diameter ≥ 10 cm. "Snags" are standing woody debris with a diameter ≥ 10 cm.

The following operations were carried out to collect the data: surveying the study sites, establishing plot areas by clearing paths, recording geographical coordinates, counting trees and measuring trees. The plots were established according to the configuration of the area and compass directions (north-south and east-west) to create rectangular plots of 0.5 ha, *i.e.* 25 m × 200 m or 5000 m^2. In total, six plots were established, covering a total area of 30,000 m^2 in this area. However, there are several types of coarse woody debris; for this study, two types were used, namely standing deadwood (snags) and fallen deadwood (logs), in order to assess their carbon stocks and determine which of the two has the higher carbon stock.

The survey involved first measuring standing dead trees with a diameter ≥ 10 cm, where their diameters and condition were noted. The height was measured using a height gauge, and a number was assigned to each tree for identification purposes. Thus, the practical method for categorising the decomposition of dead trees still standing is as follows: Category 1: Tree with branches and twigs (small tree branches) resembling a living tree (except for the foliage); Category 2: Tree with no twigs but still with large and small branches; Category 3: Tree with large branches only; Category 4: Trunk only, without branches.

However, dead trees that had been felled or were lying on the ground were measured using the line-intersection sampling method [4, 8]. Only coarse deadwood (wood with a diameter greater than 10 cm) was measured using this method. Length measurements were taken using a 50-meter folding tape measure. Each piece of felled deadwood was assigned one of the following density categories: Solid or Sound (the machete bounces off the wood); Intermediate (the machete penetrates partially and there is some wood loss) and Rotten (greater loss and the wood is brittle).

Identification of Decomposition Classes

The decomposition classes of woody plant debris were studied during the survey of logs and snags. The physical condition of the woody debris is assessed based on the wood's resistance to penetration by a metal object (in our study, a machete) into the body of the woody plant debris [8]. For this study, we defined four decomposition classes, namely: Class I: More than 75% of the wood is still intact, and a large part of the bark is still intact; the metal does not penetrate; Class II: 25% - 50% of the wood is beginning to soften and the bark only partially covers the dead wood; Class III: 75% of the tree trunk is decomposed, the bark is completely degraded; Class IV: more than 75% of the wood is decomposed and the metal penetrates very easily.

2.4. Data Analysis

2.4.1. Calculation of Logs Volume

To calculate the volume of logs or fallen deadwood, Equation (1) proposed by [15] has been used:

$$V = \frac{\pi 2\left(\sum di2\right)}{8L} \quad (1)$$

V = volume of large woody debris ($m^3 \cdot ha^{-1}$); di is the diameter of each piece of woody debris sampled

(m); L = 100. The results are converted from volume to mass by setting the density of wood to 0.5 kg/m^{-3}.

2.4.2. Calculation of Snags Volume

Along the entire line, the diameter of every piece of deadwood encountered with a diameter greater than 10 cm was measured. A dendrometric tape was used to measure the diameter. A piece of deadwood should only be measured if: 1) more than 50% of the piece is above ground, and 2) the sampling line crosses at least 50% of the piece's diameter [16]. To calculate the volume of felled dead trees, the equation (2) proposed by [16] was used:

$$V_{(m^3)} = \pi \times h \times f \times \left(\frac{D}{2}\right)^2 \quad (2)$$

where V is the volume of dead trees felled per unit area (m^3), di is the diameter (cm), π is 3.14 and L (m) is the length of the transect line [16]. The results obtained for mass volume were converted by setting the wood density for each sample to 0.5 [17]. To estimate carbon stocks, the mass of woody debris was multiplied by the wood density to obtain the carbon content for each plot [17, 18].

2.4.3. Estimation of Coarse Woody Debris Carbon Stock

The conversion of biomass to carbon was carried out by multiplying the dry biomass by 0.50, which is a default value for tropical woods proposed by [18] and [19] on a per-hectare basis using Equation (3).

$$\text{FE} = \frac{10000\text{m}^2}{\text{Plot inventoried area}} \quad (3)$$

where FE = expansion factor and the surveyed area, which is 200 m^2. Standing deadwood is also known as snags, whilst felled or fallen deadwood is known as logs.

2.4.4. Statistical Analysis

For data processing, the tables and graphs were created using Microsoft Excel 2019, in which all the information collected in the field was recorded. Statistical analysis was carried out using R software (version 4.3.1). Normality was checked, leading to the application of the Wilcoxon t-test to compare two groups at a 5% significance level. QGIS software version 3.8.1 was used to produce the map of the study area (**Figure 1**).

3. RESULTS

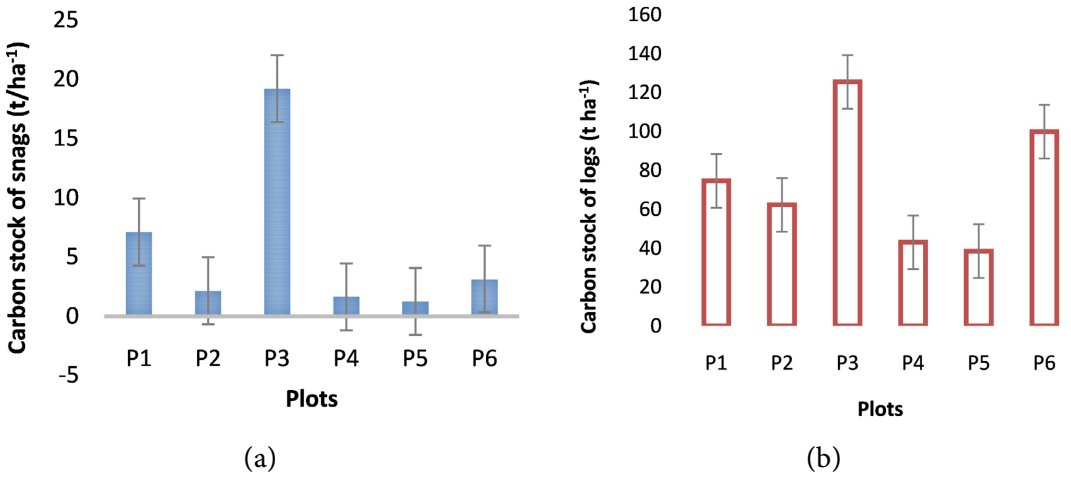
3.1. Composition of Coarse Woody Debris

This study involved the collection of 312 samples of dead wood with a diameter ≥ 10 cm from six permanent rectangular plots measuring 200 m × 25 m, covering a total area of 5000 m^2 or 0.5 ha. These are distributed as follows: 79 standing dead trees in four different categories and 233 felled dead trees in three different classes. These results highlight a marked predominance of felled dead trees (233 individuals divided into 3 classes) compared to standing dead trees (79 individuals divided into 4 categories).

This structural characterization reflects the dynamics of degradation and renewal of woody biomass within this ecosystem. The diversity of the classes and categories observed is a key indicator of habitat complexity, which is essential for maintaining saproxylic biodiversity and the carbon cycle.

3.2. Standing Deadwood (Snags)

Figure 3(a) shows the carbon stock in standing deadwood (snags) by plot. **Figure 3(a)** shows that the average carbon stock in standing deadwood is highest in plots 3, 1 and 6, with values of 19.19 t C ha^{-1}, 7.10 t C ha^{-1} and 3.12 t C ha^{-1}, respectively. The other plots are under-represented (2.13 t C ha^{-1}, 1.63 t C ha^{-1}, 1.23 t C ha^{-1}).



(a) (b)

Figure 3. Variability in the carbon stock of large woody debris within the study area. (a) Distribution of carbon stock in snags by study plot. (b) Distribution of carbon stock in felled deadwood (logs) by study plot.

3.3. Deadwood Lying on the Ground or Felled

Figure 3(b) shows the carbon stock of felled deadwood by plot within the study area. Figure 3(b) shows that the average carbon stock of felled deadwood is highest in plots 3, 6, 1 and 2, with values of 125.39 t C ha^{-1}, 99.83 t C ha^{-1}, 74.57 t C ha^{-1} and 62.22 t C ha^{-1}, respectively. The other plots are under-represented, with values ranging from 42.96 t C ha^{-1} (Plot 4) to 38.44 t C ha^{-1} (Plot 5).

3.4. Stock by Deadwood Decomposition Class

This study reveals a high proportion of wood in an advanced stage of decomposition in certain plots, which may indicate an accumulation of older deadwood or a low rate of natural ecosystem degradation. The predominance of decomposition classes 2 and 3 in certain plots may reflect more recent felling or more active forest regeneration. This analysis can help to understand forest dynamics, particularly in terms of deadwood management and its impact on the ecosystem.

The Wilcoxon test was used to compare carbon stocks in two types of dead wood: Ab (presumably felled trees or a certain type of dead wood) and Sp (presumably another type of dead wood). The Wilcoxon test is used when the data do not follow a normal distribution. In this case, it is possible that the carbon stocks of the different types of dead wood do not follow a normal distribution, which precludes the use of the standard Student's t-test (which requires the data to be normally distributed). The Wilcoxon test allows the medians of the two groups to be compared without making strict assumptions about the distribution of the data. Indeed, Figure 4 shows a box plot comparing the carbon stock (in t C ha^{-1}) between two types of dead wood, identified as "ab" and "sp". The y-axis represents the carbon stock in tons per hectare (t/ha). A Wilcoxon test was carried out, and the *p*-value is very low (<2.2e−16), indicating a statistically significant difference between the two groups (Figure 4).

The carbon stock is significantly higher in the "ab" type of deadwood compared with "ab" (Figure 4). The large interquartile range in "ab" indicates high variability in the value, whilst "sp" has a more homogeneous distribution but with lower values. Furthermore, the very low p-value (<2.2e−16) indicates that there is a highly significant difference between the two groups, ruling out the hypothesis of mere random variation. Finally, this analysis suggests that the type of dead wood strongly influences carbon storage. "ab" is associated with higher carbon storage, which could be due to differences in density, decomposition, or tree species. Further investigation (e.g., environmental factors, ecosystem type) could explain this observed difference.

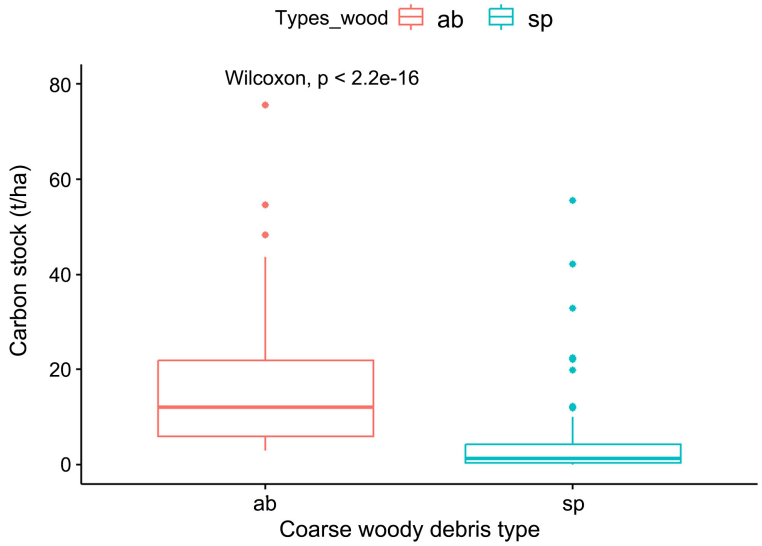


Figure 4. Comparison of two types of deadwood in the study site. Ab: likely felled timber or a certain type of deadwood; Sp: likely another type of deadwood.

3.5. Carbon Stock by Decomposition Class of Standing Deadwood or Snags

Figure 5(a) shows the distribution of carbon stock by decomposition class for standing timber. Here is a detailed analysis of this graph and an interpretation of its results: Vertical axis (Y): This represents the carbon stock (in terms of quantity or units, in $t \cdot ha^{-1}$). Horizontal axis (X): This indicates the different classes of wood decomposition. The classes appear to be labelled C, CI, CII, CIII and CIV, which may indicate different stages of wood decomposition (for example, from freshly dead wood to highly decomposed wood). Class CI: Fresh wood or wood in the early stages of decomposition. Classes CII to CIII: Wood undergoing progressive decomposition, with an increasingly high degree of degradation. Class CIV: A specific category of wood or highly decomposed wood. Class C (fresh wood): The highest bar is observed in class CII, suggesting that fresh or slightly decomposed wood contains more carbon than the other classes.

This can be explained by the fact that recently dead wood (which has not yet decomposed) still contains a large amount of carbon, before it is released as carbon dioxide during decomposition. Classes CI, CIII and CIV (gradual decomposition): The bars decrease gradually in these classes. This may indicate that, as the wood decomposes, some of the carbon is released into the atmosphere (as CO_2) through biological processes such as decomposition by fungi and micro-organisms (Figure 5(a)). These classes show a gradual reduction in carbon stock, which is consistent with the biological degradation of the wood.

3.6. Ecological and Environmental Implications

Figure 5 shows that carbon storage is highest in fresh wood (class CII) and decreases as the wood decomposes. This is important for understanding the role of woody debris in the forest carbon cycle. Dead wood stores a significant amount of carbon, but as it decomposes, this carbon is released into the atmosphere. Role of decomposition: Wood decomposition is a key stage in the carbon cycle of forest ecosystems. If the rate of wood decomposition increases (for example, due to climate change or an increase in forest fires), more carbon will be released into the atmosphere, thereby potentially contributing to greenhouse gas emissions.

3.7. Carbon Stock by Decomposition Class of Felled Deadwood or Logs

Figure 5(b) shows a graph illustrating the average carbon stock by decomposition class for felled wood. The decomposition classes (CI to CIV) are defined as follows: CI is the first decomposition class (slightly

decomposed wood); CII: second decomposition class; CIII: third decomposition class; CIV: fourth decomposition class (highly decomposed wood). Figure 5(b) shows that the CI class has the highest carbon stock, far exceeding that of the other classes. From CII onwards, the carbon stock decreases drastically and remains relatively low in classes CIII and CIV. The relationship between decomposition and carbon stock shows that the more decomposed the wood is, the lower its carbon stock becomes (Figure 5(b)). This is due to the gradual breakdown of organic matter, which releases carbon in the form of CO_2 into the atmosphere. Wood in the early stages of decomposition (CI) still stores a large amount of carbon, which means that forest management can influence the carbon cycle by delaying decomposition or promoting the storage of deadwood. However, from an ecological impact perspective, the significant loss of carbon between CI and CII indicates that wood decomposition is a rapid process that influences the carbon balance of forest ecosystems.

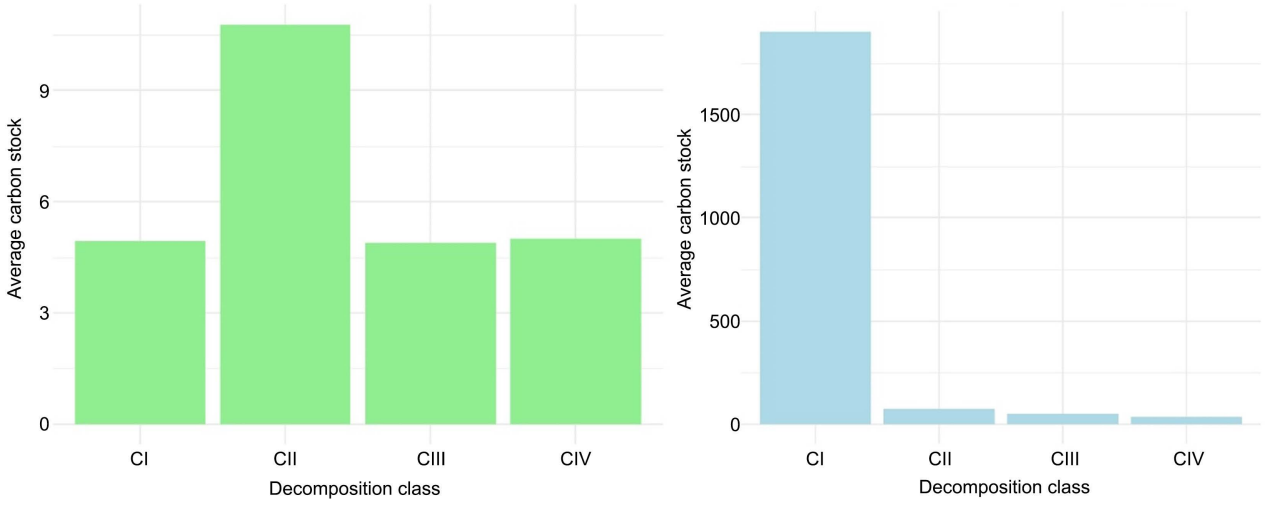


Figure 5. Variability in carbon stock by decomposition class within the study area. (a) Distribution of carbon stock in snags by decomposition class (t/ha^{-1}). (b) Distribution of carbon stock in logs by decomposition class (t/ha^{-1}).

3.8. Carbon stock by Diameter Class

Figure 6 illustrates the distribution of carbon stock by diameter class, comparing two types of dead wood: standing dead wood and felled dead wood. This graph is a box plot, which effectively visualizes the distribution of the data and allows for a comparison of the differences between these two types of dead wood for each diameter class (Figure 6). The vertical axis (Y) represents carbon stock (in logarithmic units, likely in metric tons of carbon or kilograms of carbon per hectare). The scale is logarithmic, meaning it covers a wide range of values. In contrast, the horizontal axis (X) shows the different tree diameter classes, likely categorized by diameter intervals (for example, Class I for smaller diameters and Class V for larger ones). Logs (BA) are a type of harvested wood represented by red bars, and snags (BSP) are another type of standing wood represented by blue bars. In the "Box Plots" section, each bar represents a box plot, which shows the distribution of carbon stocks within each diameter class for each wood type. The box represents the 25th percentile (Q1), the median (the line inside the box), and the 75th percentile (Q3). The whiskers indicate the range of the data, excluding outliers (points located outside the whiskers). The black dots are outliers, which are extreme values that differ significantly from the other observations.

3.9. Comparison of the Two Types of Dead Wood by Diameter Class

About logs (red bars), it has been observed that in the smaller diameter classes (Classes I and II), the

carbon stock is relatively low, but it increases as tree diameter increases (Classes III, IV, and V), as shown in Figure 6. Larger BA or log trees (classes III through V) appear to have a larger and more variable carbon stock, with outliers in certain classes, suggesting the presence of a few trees with exceptionally high carbon stocks (Figure 6). For BSP or snags (blue bars), the carbon stock for snags appears less variable, with a more stable trend across the different diameter classes. The blue bars show reduced variability in the large-diameter classes (Classes IV, V), which could indicate that this type of wood has a more uniform carbon stock across different tree sizes (Figure 6).

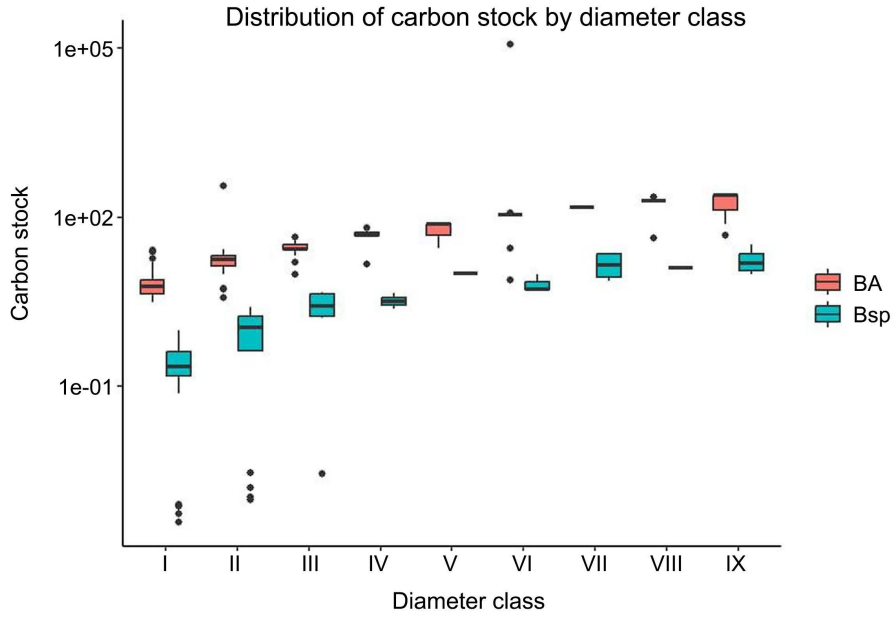


Figure 6. Distribution of carbon stock by diameter class in study area (t C ha^{-1}).

Diameter classes I and II, which consist of small-diameter BA or logs, have lower carbon stocks compared to BSP (snags), with greater variability. This study shows that log samples do not store as much carbon as the BSP (snags) type. Classes III through V show that as tree diameter increases, the carbon stock for both types of dead wood also increases significantly. However, logs tend to accumulate more carbon than snags in the larger diameter classes. This could be explained by the fact that as logs grow larger, they become more efficient at storing carbon.

In Figure 6, the black dots in the large-diameter classes (especially for logs wood types) indicate that there are very large trees or trees with exceptionally high carbon content in these classes. These values could represent old trees or exceptionally healthy trees. The logs appear to exhibit greater variability in carbon stocks across all diameter classes, suggesting that this type of deadwood can accumulate carbon in a more variable manner depending on environmental conditions or individual tree characteristics. The snags appear to be more homogeneous, with a more even distribution of carbon stock. This may mean that deadwood of this type is less likely to exhibit significant fluctuations in carbon storage based on its size.

3.10. Ecological and Environmental Implications

With regard to carbon storage in forests, Figure 6 can be helpful in understanding the role of different types of wood in carbon storage based on tree size. Large trees, particularly those classified as logs, appear to be significant carbon reservoirs. In the context of forestry, these findings are essential for better understanding forest management and carbon sequestration strategies. It is important to recognize that large-diameter trees (specifically logs) play a crucial role in carbon accumulation. Smaller trees may be less significant in terms of carbon storage, but their management could be essential in the long term.

4. DISCUSSION

The study to estimate the carbon stock of coarse woody debris in the Ipendja Forest Management Unit (UFA), Likouala Department, yielded three hundred and twelve samples of coarse woody debris with a DBH ≥ 10 cm, comprising 233 logs and 79 snags, with a distribution that varied across the plots. This diversity of woody debris is confirmed by several previous studies, notably [4] and [8], which show that the distribution of deadwood in a forest ecosystem is influenced by natural disturbances (windthrow, wind, disease) and anthropogenic disturbances (logging, deforestation). The proportion of coarse woody debris varies between plots, with the highest values observed in plots 2 and 3.

[11] also highlighted spatial heterogeneity in the distribution of deadwood in Central Africa, emphasising the impact of local soil conditions, slope and canopy openness. The results indicate that deadwood in the Ipendja forest has a significant carbon stock capacity. These results are higher than those reported by [10] on the carbon stock of coarse woody debris in Central Africa, who recorded 135 individuals with a DBH ≥ 10 cm at two sites: Mokelimwaekili (site 1, n = 57) and Sombo (site 2, n = 78). The high number of specimens in our findings can be attributed to several factors, including strong winds, windthrow, the decomposition of dead wood, the felling of one tree causing others to fall, and bark beetles. In the area, small variations in tree spacing, temperature, etc. Furthermore, it is important to note that we used a 200 meter transect line per study plot in the Ipendja Forest in Likouala, unlike the interested work from [10] in the tropical forest; however, this was not the case in other studies in Central Africa [4, 7, 20, 21], which used transect lines of 400 m, 100 m, 100 m and 800 m per study plot, respectively, in southern Peru, Republic of Congo, Democratic Republic of Congo and Gabon. Their results showed that stocks of coarse woody debris also increase with the length of the transect line studied [10]. However, [22] examined coarse woody debris (CWD) in tropical forests as a major carbon pool, establishing standardized protocols for measuring necromass, decay rates, and wood density loss. Their research classifies deadwood ≥ 10 cm in diameter to accurately estimate carbon flux and long-term carbon storage.

4.1. Types of Coarse Woody Debris

The study distinguishes between standing deadwood (snags) and felled deadwood (logs). Standing deadwood (snags): The carbon stock is higher in certain plots (P3, P1, P6), which could be linked to specific mortality factors (windthrow, diseases). [20, 23] show that snags decompose more slowly due to their upright position, which allows them to retain carbon for longer before falling to the ground. Felled deadwood (logs): the values are significantly higher than those for snags, with an average carbon stock reaching 125.39 t C ha^{-1} in some plots. This finding is consistent with the work of [22, 24], which indicates that logs play a major role in carbon storage, but that they decompose more rapidly due to direct contact with the ground and moisture. The woody debris stocks obtained in our study show considerable spatial variability between the different types of coarse woody debris.

The results obtained indicate that logs store more carbon than snags. This difference is undoubtedly due to the lack of light reaching the ground, leading to the death of certain sun-loving species. Indeed, we observed that the canopy was closed. With regard to deadwood lying on the ground, we observed higher carbon stocks compared with standing deadwood. This difference is due to the fact that we observed several dead trees lying on the ground, caused by natural factors such as recurrent windthrow and the ageing of the trees. Numerically, there is a difference, but statistically there are significant differences (P-value of 2.2e−16) between the carbon stored in dead wood lying on the ground and that stored in standing dead wood. The Wilcoxon test was used here because it is well suited to situations where the data do not follow a normal distribution, which is frequently the case with ecological data such as the carbon stock of deadwood. The test allows the medians of the two independent groups (ab and sp) to be compared and provides an indication of the statistical significance of the difference between these groups. The very low p-value (close to zero) shows that there is a statistically significant difference between the two types of coarse woody debris in terms of carbon storage.

4.2. Decomposition Class of Coarse Woody Debris

The distribution of decomposition classes for snags and logs shows considerable variability. Standing deadwood (snags): The majority fall into category C4 (heavily decomposed), which may be linked to natural ageing processes also observed by [8]. Felled dead wood (logs): The categories are more diverse, with a significant number of intermediate (I) and decayed (P) logs, which is consistent with the findings of [21], who observed that logs decompose more heterogeneously depending on their position and exposure to the elements. The Wilcoxon test indicates a highly significant difference between snags and logs, with felled wood storing more carbon. These results are consistent with those from [7], who show that the biomass of felled wood is greater and that its decomposition generates different carbon dynamics. In the Mipoutou area, we observed an abundance of standing deadwood belonging to Class II, which is probably due to climatic disturbances. We also observed an abundance of dead wood lying on the ground belonging to Class I, which is probably due to local factors such as windthrow – trees that fall as a result of natural death – or the action of strong winds preceding heavy rainfall; the present work is consistent with that from [21].

Logs during the initial stage of decomposition still store a large amount of carbon; the more the wood decomposes, the more the carbon stock decreases, which makes sense as decomposition gradually releases carbon into the environment. This highlights the importance of conserving wood at the start of decomposition for forest carbon storage. It is also necessary to preserve standing dead trees in forest ecosystems to promote more sustainable carbon storage. For snags, class CII has the highest carbon storage, followed by classes CIV and I, with the lowest found in class CIII. With regard to logs, the highest carbon stock values were found in class CI, followed by class CII and CIII, with the lowest in class CIV. This is consistent with the observations of [23], who emphasise that snags in an early stage of decomposition retain a structure that allows for prolonged carbon storage. Some types of dead wood store more carbon than others. This could be due to the properties of the wood or the tree species. Furthermore, targeted forest management could prioritise certain species to maximise carbon storage. Finally, the biological differences between logs and snags could explain these findings. Carbon stocks are significantly higher in logs than in snags, with a statistically highly significant difference, and these findings may be useful in forest ecology and carbon management to guide strategies for conservation and CO_2 sequestration.

4.3. Carbon Stock by Diameter Class

The Wilcoxon test appears to be the most likely test used in this case, as it is suitable for situations where the data are non-parametric and potentially asymmetric. However, if the data were parametric, an ANOVA or Student's t-test might also have been used. To validate this hypothesis, it would be useful to know the exact distribution of the data and to check the preliminary statistical tests carried out on the data. The increase in carbon stock with diameter is confirmed by several authors, notably [10, 22]. Larger-diameter trees store more carbon, which is logical given that density and total biomass are proportional to tree diameter. However, the trend is less pronounced in classes IV and V, which may be explained by differences in species composition or decomposition dynamics.

[2, 24] also observed that certain species decompose more rapidly than others, influencing the distribution of carbon stock over time. Trees with larger diameters play a crucial role in carbon stock. It may be worthwhile to prioritise the conservation of large-diameter trees in order to maximise carbon stock. Indeed, tree species or log types appear to be more effective at storing carbon than snags. The variability in deadwood carbon stock depends mainly on diameter classes. It is evident that, across all the deadwood studied, the highest carbon quantities are found in the large-diameter sample classes. Our results clearly show that the diameter classes containing a large number of samples are those that store the most carbon. For standing deadwood, the lowest stock is found in classes V and VIII, at 10.03 t C ha^{-1}. In contrast, the highest stock is found in class IX, at 32.92 t C ha^{-1}.

For logs, class XX has the highest number of samples, at 117.9 t C ha^{-1}. In contrast, Class I has the lowest number of samples, at 3.01 t C ha^{-1}. These results do not correspond to those of [24], who found the highest carbon stock in forests with fewer samples than in those with a very large number of samples. In the

mature floodplain forest of *Lophira alata* (Banks.), the lowest stock was recorded in Class I at 14.41 t C ha^{-1}, comprising 303 samples. In contrast, the highest stock was recorded in Class VII (50.82 t C ha^{-1}, comprising 13 samples). In the mature forest (Engl.), Class I has the highest number of trees (17.43 tC/ha, comprising 353 samples), whereas Class VII has 10 samples with a significant stock (43.93 t C ha^{-1}). Mature forest in Class I had 13.5 t C ha^{-1} from 251 samples of large woody debris, with the highest carbon stock found in Class VI (82 t C ha^{-1} from 28 trees). In the secondary forest, Class I has the highest number of samples, namely 425, with a low carbon stock (8.05 t C ha^{-1}).

However, Class VII, with 5 samples, stored more carbon (13.92 t C ha^{-1}). Class II, the secondary forest, has a high carbon stock (31.13 t C ha^{-1} and 310 samples). This study shows that carbon stock does not depend on the number of trees but on tree diameter and specific density [4]. Large-diameter trees [22, 23, 25] constitute significant carbon stocks (trunk, branches, large roots). [8] emphasise that trees with a DBH ≥ 79 cm contribute to a carbon stock that is approximately 30% higher. Finally, these results show that carbon stock increases with tree diameter and that logs store more carbon than snags. These findings are useful for forest management and the fight against climate change. These highly significant findings will enable the Government of the Republic of Congo, through the National REDD+ Coordination Unit (CN-REDD+) led by the Ministry of Forest Economy, to occupy a prominent position in the carbon market through the sale of carbon credits.

5. CONCLUSION

Ultimately, the study on estimating the carbon stock of coarse woody debris in the Ipendja Forest Management Unit (UFA), in the northern Republic of Congo, has provided an update on our understanding of the coarse woody debris compartment, specifically regarding the type of deadwood, its decomposition class, its diameter class, and the role this compartment plays in the functioning of forest ecosystems in terms of carbon quantification. This study shows that deadwood lying on the forest floor has a higher carbon stock than that recorded in standing deadwood. Furthermore, this study demonstrates that the deadwood compartment must be taken into account when quantifying carbon stocks in forest ecosystems. It should be noted that very little information is available on the carbon stocks of large woody debris in the Republic of Congo in general, and the Likouala Department in particular. This study has demonstrated the vital, yet often underestimated, role of the deadwood compartment in the functional balance and carbon sequestration capacity of the forests of Likouala and the Congo Basin. It provides concrete quantitative data that is essential for the implementation of the international REDD+ mechanism in the Republic of Congo.

ACKNOWLEDGEMENTS

The authors would like to thank STC (Société Thanry Congo) for supporting this work. We greatly thank LGETA (Laboratoire de géomatique et d'écologie tropicale appliquée) for its valuable contribution regarding this work. National Higher School of Agronomy and Forestry from Marien Ngouabi University also supported this study. Different anonymous referees have provided substantial contributions, and the authors address them with their heartfelt thanks.

AUTHOR CONTRIBUTIONS

Conceptualization: **Romeo Ekoungoulou** and **Anderson Junior Mopiane Foundou**; methodology: **Romeo Ekoungoulou**; software: **Romeo Ekoungoulou** and **Anderson Junior Mopiane Foundou**; validation: **Romeo Ekoungoulou**, **Anderson Junior Mopiane Foundou**, and **Felix Koubouana**; formal analysis: **Anderson Junior Mopiane Foundou**; investigation: **Romeo Ekoungoulou**; resources: **Romeo Ekoungoulou** and **Felix Koubouana**; data curation: **Romeo Ekoungoulou** and **Anderson Junior Mopiane Foundou**; writing original draft preparation: **Romeo Ekoungoulou**; writing review and editing: **Romeo Ekoungoulou**; visualization: **Anderson Junior Mopiane Foundou**; supervision: **Felix Koubouana**; project administration: **Romeo Ekoungoulou**; funding acquisition: **Romeo Ekoungoulou**. All authors have read and agreed to the

published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest regarding the publication of this paper.

REFERENCES

1. De Wasseige, C., Flynn, J., Louppe, D., Hiol Hiol, F. and Mayaux, P. (2014) The Forests of the Congo Basin: State of the Forests 2013. Publications Office of the European Union, Food and Agriculture Organisation of the United Nations (FAO).
2. Tritsch, I., Le Velly, G., Mertens, B., Meyfroidt, P., Sannier, C., Makak, J., *et al.* (2020) Do Forest-Management Plans and FSC Certification Help Avoid Deforestation in the Congo Basin? *Ecological Economics*, **175**, Article ID: 106660. https://doi.org/10.1016/j.ecolecon.2020.106660
3. Ifo, A.S., Koubouana, F., Jourdain, C. and Nganga, D. (2015) Stock and Flow of Carbon in Plant Woody Debris in Two Different Types of Natural Forests in Bateke Plateau, Central Africa. *Open Journal of Forestry*, **5**, 38-47. https://doi.org/10.4236/ojf.2015.51005
4. Baker, T.R., Honorio Coronado, E.N., Phillips, O.L., Martin, J., van der Heijden, G.M.F., Garcia, M., *et al.* (2007) Low Stocks of Coarse Woody Debris in a Southwest Amazonian Forest. *Oecologia*, **152**, 495-504. https://doi.org/10.1007/s00442-007-0667-5
5. Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T.A., Salas, W., *et al.* (2011) Benchmark Map of Forest Carbon Stocks in Tropical Regions across Three Continents. *Proceedings of the National Academy of Sciences*, **108**, 9899-9904. https://doi.org/10.1073/pnas.1019576108
6. Baccini, A., Goetz, S.J., Walker, W.S., Laporte, N.T., Sun, M., Sulla-Menashe, D., *et al.* (2012) Estimated Carbon Dioxide Emissions from Tropical Deforestation Improved by Carbon-Density Maps. *Nature Climate Change*, **2**, 182-185. https://doi.org/10.1038/nclimate1354
7. Bocko, Y.E., Ifo, S.A. and Loumeto, J.J. (2017) Quantification Des Stocks De Carbone De Trois Pools Clés De Carbone En Afrique Centrale: Cas De La Forêt Marécageuse De La Likouala (Nord Congo). *European Scientific Journal, ESJ*, **13**, Article No. 438. https://doi.org/10.19044/esj.2017.v13n5p438
8. Clark, D.B., Clark, D.A., Brown, S., Oberbauer, S.F. and Veldkamp, E. (2002) Stocks and Flows of Coarse Woody Debris across a Tropical Rain Forest Nutrient and Topography Gradient. *Forest Ecology and Management*, **164**, 237-248. https://doi.org/10.1016/s0378-1127(01)00597-7
9. Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., *et al.* (2011) A Large and Persistent Carbon Sink in the World's Forests. *Science*, **333**, 988-993. https://doi.org/10.1126/science.1201609
10. Ekoungoulou, R., Bamissamou, B.J., Ndzai, S.F., Folega, F., Mbouilou, C.B.M., Bikouta, J.L. and Koubouana, F. (2025) Carbon Stock Estimation for Coarse Woody Debris in a Northern Republic of Congo's Forest. *Ukrainian Journal of Ecology*, **15**, 1-11.
11. Ekoungoulou, R., Niu, S., Folega, F., Nzala, D. and Liu, X. (2018) Carbon Stocks of Coarse Woody Debris in Central African Tropical Forests. *Sustainability in Environment*, **3**, 142-160. https://doi.org/10.22158/se.v3n2p142
12. Ekoungoulou, R., Nzala, D., Liu, X. and Niu, S. (2018) Tree Biomass Estimation in Central African Forests Using Allometric Models. *Open Journal of Ecology*, **8**, 209-237. https://doi.org/10.4236/oje.2018.83014
13. STC (2025) Annual Report of the Company Thanry Congo (STC). Vicwood Group. Ipendja.
14. ANAC (2025) Average Temperature and Precipitation of Congo for the Period from 2014 to 2024. Annual Report from National Civil Aviation Agency (ANAC).

15. Warren, W.G. and Olsen, P.F. (1964) A Line Intersect Technique for Assessing Logging Waste. *Forest Science*, **10**, 267-276. https://doi.org/10.1093/forestscience/10.3.267

16. Mund, M. (2004) Carbon Pools of European Beech Forests (*Fagus sylvatica*) under Different Silvicultural Management Forest. Doctoral Dissertation, Forschungszentrum Waldökosysteme.

17. Pearson, T. and Brown, S. (2005) A Guide to Measuring and Monitoring Carbon in Forests and Grasslands. Winrock International.

18. Basuki, T.M., van Laake, P.E., Skidmore, A.K. and Hussin, Y.A. (2009) Allometric Equations for Estimating the Above-Ground Biomass in Tropical Lowland Dipterocarp Forests. *Forest Ecology and Management*, **257**, 1684-1694. https://doi.org/10.1016/j.foreco.2009.01.027

19. Chave, J., Réjou-Méchain, M., Búrquez, A., Chidumayo, E., Colgan, M.S., Delitti, W.B.C., *et al.* (2014) Improved Allometric Models to Estimate the Aboveground Biomass of Tropical Trees. *Global Change Biology*, **20**, 3177-3190. https://doi.org/10.1111/gcb.12629

20. Carlson, B. (2013) Gabon's Overlooked Carbon. A Tropical Forest of Coarse Woody Debris. Master Thesis, Environmental Management Degree, Duke University.

21. Ifo, S.A., Mbemba, M., Koubouana, F. and Binsangou, S. (2017) Stock de carbone dans les gros débris ligneux végétaux: Cas des forêts tropicales pluvieuses de la Likouala, République du Congo. *European Scientific Journal, ESJ*, **13**, 384-399. https://doi.org/10.19044/esj.2017.v13n12p384

22. Sullivan, M.J.P., Talbot, J., Lewis, S.L., Phillips, O.L., Qie, L., Begne, S.K., *et al.* (2017) Diversity and Carbon Storage across the Tropical Forest Biome. *Scientific Reports*, **7**, Article No. 39102. https://doi.org/10.1038/srep39102

23. Fayolle, A., Loubota Panzou, G.J., Drouet, T., Swaine, M.D., Bauwens, S., Vleminckx, J., *et al.* (2016) Taller Trees, Denser Stands and Greater Biomass in Semi-Deciduous than in Evergreen Lowland Central African Forests. *Forest Ecology and Management*, **374**, 42-50. https://doi.org/10.1016/j.foreco.2016.04.033

24. Ndzai, S.F. (2022) Characterization and Estimation of Carbon Stocks in Adult and Secondary Tropical Forests in the Impfondo-Dongou Zone, Likouala Department. Doctoral Thesis, Forest Botany, ENSAF, Marien NGOUABI University.

25. Walker, S., Pearson, T., Harris, N., Sean, G., Silvia, P., Felipe, C. and Brown, S. (2011) Standard Operating Procedures for Terrestrial Carbon Measurement. Winrock International—Procédures Opérationnelles Standards pour la Mesure du Carbone Terrestre. Winrock International.