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ANTHROPOGENIC IMPACT ON STRUCTURAL VARIABILITY AND CARBON STOCK IN MAMBASA FORESTS IN ITURI, DR CONGO.

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ABSTRACT

The present study carried out in the different forest types of Mambasa, anthropogenic or not, aimed to highlight the impact of anthropogenic actions on the structural variability and carbon stock of its different forest successions (fallow, secondary forest and primary forest).

Data collection covered 24 plots of 0.25 ha (50 m × 50 m) planted due to 8 plots in the primary forest and 16 plots in vegetation degraded by human activities but under different phases of their reconstitution, i.e. 8 fallow plots and 8 other plots in the secondary forest. In each plot, a full inventory with botanical identification at the specific scale, measurement of diameter and total height of all trees at dbh ≥ 10 cm. The results obtained show that in terms of density, basal area and carbon stock contained in above-ground biomass, secondary forest records the highest averages, while only the fallow averages are statistically different from other forest types. The calculated relative error highlights the gain and loss of density, basal area and carbon stock values for secondary forest and fallow respectively compared to primary forest. As for the diametric structure, the distribution of numbers by diameter classes does not differ between the forest types studied.

KEYWORDS: Anthropization, structural variability, carbon stock, Mambasa forests, Ituri.

INTRODUCTION

Since the advent of climate change and its inclusion in political agendas and the scientific community, the ecological and environmental importance of tropical forests has raised the issue of their sustainable management. And yet, the population growth observed in the tropical environment and the unemployment rate associated with it are increasing the pressure on these forest ecosystems. The ensuing transformations affect the structure of the landscapes, leading to numerous ecological consequences (Burrel & Brandy, 1999).

This study is part of the sustainable management of tropical forests. In Africa, these ecosystems represent an exceptional mass for huge populations whose survival is directly linked to the natural resources they offer, which contribute to the satisfaction of the food and/or nutritional, economic and medicinal needs of more than 30 million people. They also play a major role in the balance of the climate on a global scale (Levêque, 1994; Loore, 2007; Menga, 2011; De Wasseige et al., 2012).

However, the rate of exploitation that these forests are currently undergoing is jeopardizing their future, especially with regard to the carbon sink and biodiversity conservation function that they are called upon to play. These forests, which represent an important compartment of the above-ground carbon stock reservoir, are undergoing transformations through logging and the conversion of forests into agricultural areas. An inventory of the consequences of these transformations on the structure and carbon stock of these stands is necessary in the implementation of sustainable management strategies.

1. PROBLEM

Tropical forest ecosystems are subject to deforestation, despite their great complexity, their remarkable diversity and the significant richness of biological form they shelter. In recent decades, several hundred million hectares of natural forests in this region have disappeared or degraded by various factors, the main ones being regional climate change (Vauder, Welf et al., 2008) and the types of anthropogenic activities practiced there, including slash-and-burn agriculture (Mate, 2001).

These forests appear today to be complex, even contradictory ecosystems insofar as their high biodiversity, their extreme exuberance and their heterogeneity seem to contradict the fact that they are very fragile environments subject to strong constraints (Piug, 2001). And yet, they are of increasing interest because of their economic function in the countries that possess them and even more so for ecological reasons in global climate change and the conservation of biodiversity and genetic resources (Graubünden, 1991, Geist & Lambin, 2001).

In tropical Africa, the forests of the Congo Basin, the second largest continuous forest area in this region, are home to some 30 million people and provide the livelihoods of more than 75 million people who use its natural resources to meet their food, medicine, energy needs, etc. Non-timber forest products taken from these forests account for a significant share of local people's incomes (Megevand, 2013).

However, the management of these forests is carried out in a context of extreme poverty. Population growth in this region and the dependence on forests for their survival are increasing the pace of transformation of their natural landscape. Withregard to the socio-economic and environmental functions they perform (BTC, 2007; Greco, 1979; FAO, 2012 and Proisy, 1999); their contribution to livelihoods and their importance at the local level far exceed what can be inferred from official statistics (Shackleton et al., 2007).

Nevertheless, the rapid change in land use observed in tropical countries (Veldkamp and Lambin, 2001 and Hansen et al., 2008) and the fragmentation of natural habitats due to increasing anthropogenic pressures are leading to dysfunctions of terrestrial ecosystems and loss of biodiversity (Roche, 1998). Further amplified by inappropriate modes and systems of exploitation of available resources, these changes have direct repercussions on the configuration of the landscape, cause significant variations in the structure and floristic composition of these forests and weaken their productive potential for wood as well as their ability to mitigate the effects of climate change.

The Mambasa region is located on the border of the tropical rainforest zone with the mountainous regions of the east. In recent decades, this region has experienced a significant displacement of the population from the east of the country in search of arable land. The population growth brought about by these displacements of the population, which is mainly farmers, subjects the forest areas of this region to significant anthropogenic pressures through the commercial exploitation of timber with the eastern border countries and wood energy for domestic use, mining and shifting cultivation practices with slash-and-burn harvesting. These practices disrupt the natural dynamics of these ecosystems and the post-anthropogenic vegetation succession results in incessant variations in the structure and floristic composition of the forest types characterizing each phase of this process.

Contributing to the improvement of knowledge of the dynamics of tropical forest stands is an important tool for the sustainable management of these ecosystems. Given the importance of the role to be played by these forests in the major environmental balances and therefore their contribution to the socio-economic life of the mass of the people dependent on them for their survival, a quantification of the effects of human activities on the variability of structural parameters within different ecological successionsThe implementation of the forests (fallow, secondary and primary forest) of Mambasa is important for the implementation of policies for the rational use of the land resource and sustainable forest management.

2. ASSUMPTIONS

The Mambasa region is located almost at the edge of the lowland rainforest zone. With these large expanses of forest and the influx of migrants from the eastern mountainous region in search of agricultural land, these forests are subject to significant anthropogenic pressures, the different stages of post-crop plant succession induce variations in the structure and stock of carbon contained in the above-ground biomass. To verify this statement, we make the following assumptions:

(1) In the Mambasa region, there is a variability in density, basal area, diametric structure and carbon stock between the different forest formations of a post-crop vegetation succession;
(2) The relative error obtained by post-crop plant formations is so large that the disturbance is recent.

3. OBJECTIVES

The general objective assigned to this work is to evaluate the impact of anthropization of the Mambasa forests on the variability of their structure. The specific objectives to be achieved by this work relate to: (1) highlight the structural variability (density, basal area, diametric structure and carbon stock) between the different forest formations of the post-crop plant succession; (2) with reference to primary forest, quantify the relative error created by plant formations resulting from anthropogenic disturbances.

I. METHODOLOGICAL APPROACH

1.1 Study environment

The present study was carried out in the Mambasa Territory, Ituri Province in the Democratic Republic of Congo (Figure 1).

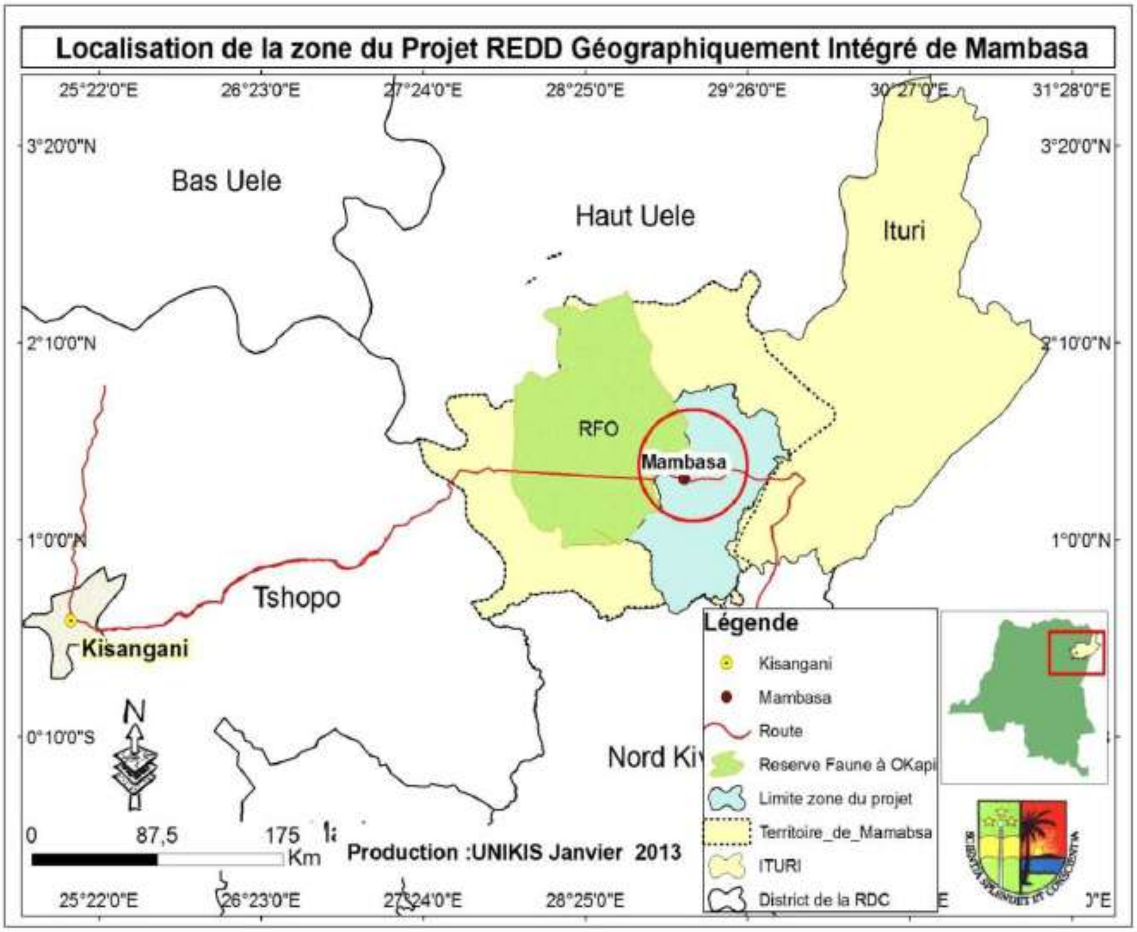
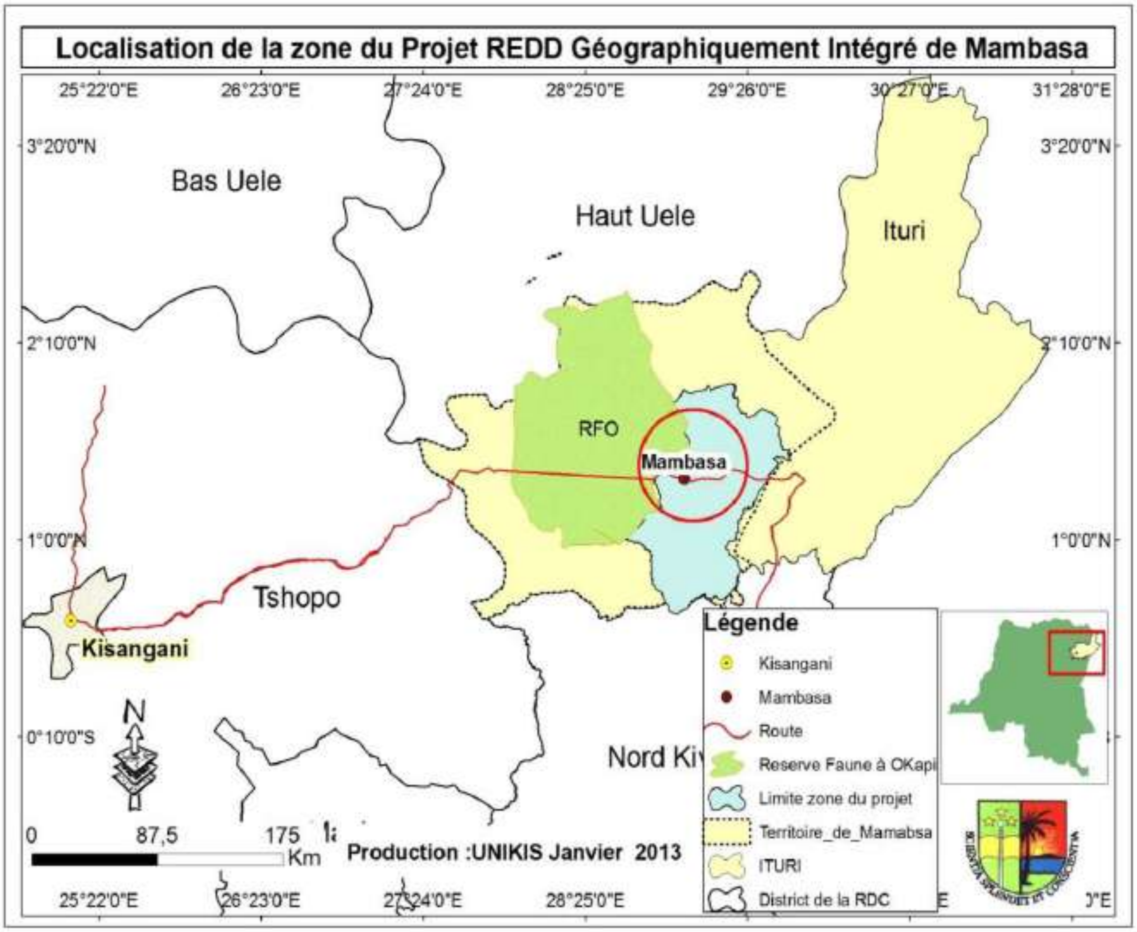


Figure 1 – Location of the Mambasa Territory (source: LECAFOR 2014)

This Territory, covering 36,785 km², occupies more than 55% of the area of Ituri Province, which covers an area of 65,658 km² (Nkoy, 2007). It is bordered to the east by the Territories of Djugu and Irumu, to the west by the Territories of Bafwasende and Wamba, to the north by the Territory of Watsa and to the south by the Territories of Beni and Lubero (Malankanga, 2015); it extends between 1°00' and 1°30' north latitude and 29°00' and 29°30' east longitude. This administrative entity has seven communities: Babila Babombi, Babila Bakwanza, Bandaka, Bambo, Mambasa, Walese Dese and Walese Karo and 27 groupings (Figure 2).



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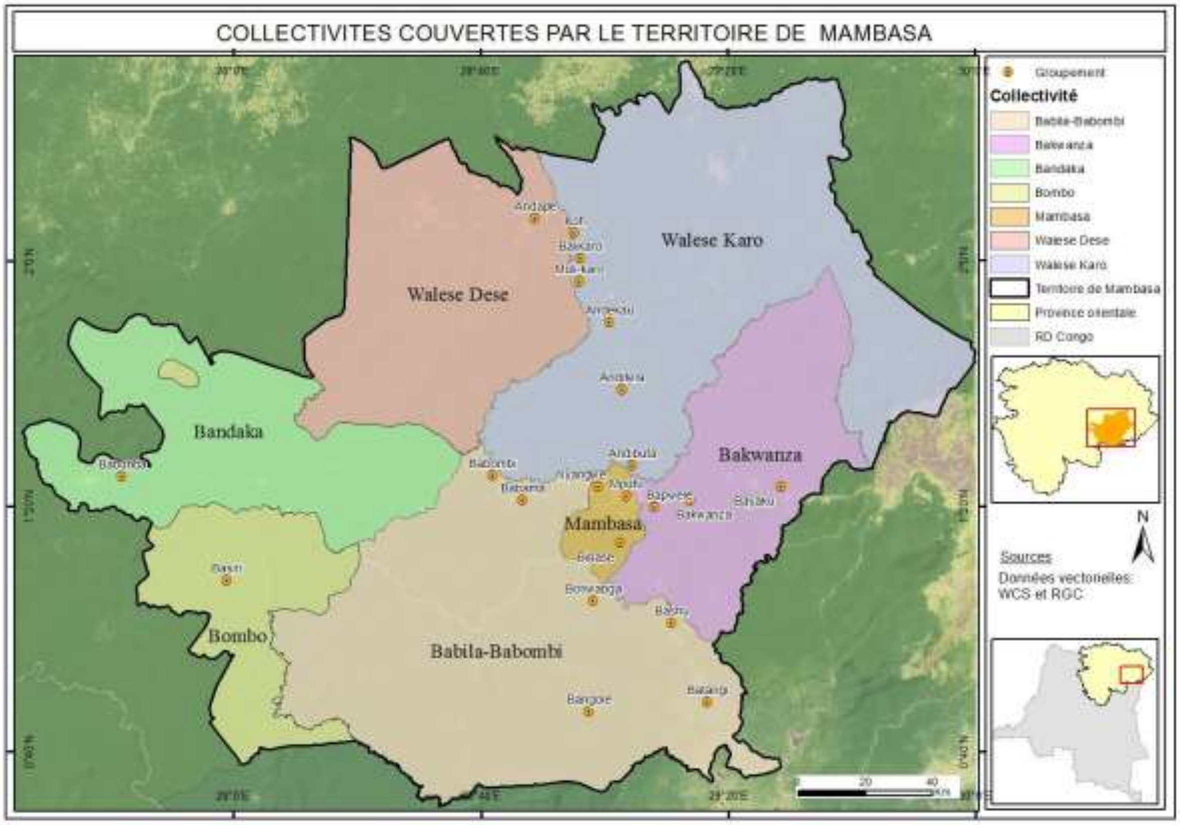


Figure 2 - **Map of the territory of Mambasa and its communities (source: Malanganka 2015)**

The Mambasa Territory generally benefits from the equatorial climate with two seasons: dry and rainy. Average temperatures vary between 23.7°C and 25.6°C for the cooler months and between 28.0°C and 33.7°C for the warmest months. Annual precipitation amounts range from 1600 to 2000 mm.

The landscape of Mambasa is largely covered by the forest of the northeastern part of the Congo Basin forming the eastern limit of the vast Guinea-Congo rainforest belt that extends to West Africa. Four main forest types are observed: (1) mixed forest classified according to White (1983) as mixed semi-evergreen rainforests. It is diversified in tree species, the most abundant of which in the canopy are *Cynometra alexandri*, *Julbernardia seretii*, *Brachistegia laurentii*, *Uapaca guinensis*, etc.); (2) the monodominant forest with *Gilbertiodendron dewevrei* classified according to White in the category of evergreen and semi-evergreen rainforests with the only dominant species: *G. dewevrei*; (3) swamp forest along stream edges and flooded areas, and (4) secondary forest, which represents post-disturbance vegetation located primarily near high-density roads.

1.2 Data Collection Methods

1.2.1 Forest stratification and installation of inventory plots

The choice of the installation of the inventory plots was guided by the analysis of the texture of the SPOT images to distinguish two forest strata: primary forest and degraded forest (grouping secondary forest and shrub fallow). The surveys carried out in the field made it possible to record the geographical coordinates by the GPS, whose superposition on the SPOT image led to a definitive stratification of these strata. Once the geographical coordinates of the plot had been determined on the basis of the texture of the SPOT images, the fieldwork consisted of assessing the vegetation of the place where the point fell for the delimitation of the plot by 0.25 ha (50 m × 50 m) for its maintenance or shifting. Following this protocol, 24 plots were set up, 8 plots in primary forest, 8 plots in secondary forest and 8 plots fallow.

1.2.2 Botanical identification and measurement of trees

The tree inventory focused mainly on individuals with a diameter at breast height greater than or equal to 10 cm. Each individual encountered was identified on the basis of certain characteristics such as the edge of the bark (colour, smell), external characteristics of the bark, leaves and possibly flowers and fruits; labeled, its measured diameter and the paint line marked at the measurement height. The herbariums of individuals not actually identified in the field were assembled and then brought back to the herbarium for identification. Two measurements were made on each tree: the diameter made using the circumferential tape and the total height measured using the Vertex IV, which is a new generation dendrometer using ultrasonic technology (Rondeux and Pauwels, 1998).

<u>Photo 1</u> – Bark notch, dhp measurement and tree numbering and paint line (from left to right)

1.2.3 Supplementary data to the tree inventory

The densities of the woods used for the calculation of above-ground biomass were taken from the international database (DRYAD). This provides values according to geographical areas (Chave et al. 2009; Zanne et al. 2009). Thus, for species with no wood density values, the genus-wide wood density, derived from the average of the wood density of the species of which it is composed, was used (Slik, 2006). And for the genera with no densities in the database, the average value of all genera for the site was assigned.

1.3 Data Analytics

1.3.1 Density and basal area of trees

Tree density represents the total number of individuals (at dhp≥10 cm) recorded on a given area. Considering trees as cylindrical, the basal area refers to the area occupied by the trunk, measured at 1.30 m above the ground. The numbers of trees from the inventory and their diameter were used to calculate these parameters. The expression of the density result is the number of individuals per hectare while that of the basal area, obtained by the formula below, is the square metre per hectare ($m^2.^{ha-1}$).

$$G = \sum_{a=1}^{n} \frac{\pi D^2 a}{4}$$

G = basal area; Da = diameter at 1.3 m from the soil of tree a; n = total number of trees of the species.

1.3.2 Diameter structure

The diameter structure or size distribution indicates the number of stems inventoried by diameter classes. It was established by taking into account the diameters of all the individuals inventoried (Rollet, 1974).

1.3.3 Estimation of above-ground biomass and tree carbon stock

Above-ground biomass corresponds to the mass of dry woody plant matter per unit area. Estimating this biomass is an essential aspect for the study of the structural variability of forest stands. In the absence of region-specific models, this biomass was determined using two allometric equations, each with two predictors and an equation with three predictors: the international standard model proposed by Chave et al. (2005) applicable to tropical rainforests of the most forest type, and the model by Fayolle et al. (2013) used to assess the validity of thepantropical allometric equations developed by Chave et al. (2005) and the model of Djomo et al. (2010) integrating three predictors. The diameter values used are those measured on the trees of the study plots and the densities of the wood of each species come from the international database (DRYAD). The results of these three equations were used to average above-ground biomass per plot for its rough estimate. The conversion of above-ground biomass into carbon stock was obtained by multiplying it by a factor of 0.47 (0.44; 0.49), the fraction of carbon that the IPCC attributes to tropical and subtropical forests (IPCCv4, 2006).

(1) $(AGB)_{is} = \varphi \times \exp(-1.499+2.148\times\ln(D)+0.207\times(\ln(D))^2-0.0281\times(\ln(D))^3)$ (Chave et al., 2005)

(2) $(AGB)_{est} = \varphi \times \exp(-1.183+1.940\times\ln(D)+0.239\times(\ln(D))^2-0.0285\times(\ln(D))^3)$ (Fayolle et al., 2013)

(3) $(AGB)_{est} = \exp(-2.4360+0.1399\times(\ln D)^2+0.7373\times\ln(D2H)+0.2790\times\ln(\varphi))$ (Djomo et al., 2010)

$(AGB)_{is}$ = above-ground biomass per tree (kg); exp = exponential; φ = dry wood density ($g/^{cm3}$); ln = natural logarithm; D = diameter at 1.30 cm (cm); H = total height (m).

1.3.4 Calculation of the relative error

In order to highlight the effects of anthropogenic forest disturbances on density, basal area and carbon stock, we calculated the relative error made by each of the two forest types of degraded forest compared to primary forest. The relative error was considered to be the ratio of the difference between the forest type parameter i of the degraded forest ($PiTFx_{FD}$) and the primary forest parameter i (PiFP) to the primary forest parameter i (PiFP).

$$\mathrm{er}\ (\%) = \frac{\mathrm{PiTFxFD} - \mathrm{PiFP}}{\mathrm{PiFP}} \times 100$$

1.4 Data processing

Comparison of means of density, basal area and carbon stock by one-way analysis of variance (one-factor ANOVA) was performed using R 3.1.3 software. In case of a significant difference, the post-hoc multiple comparison test of Tukey was used to compare these means two to two. The comparison of the relative error means of each parameter between the two strata of the degraded forest was carried out by the student test. The comparison of the diametric structures was carried out by the Chi-square test.

II. RESULTS

2.1 Variability in density and basal area between the forest groups studied

A total of 2159 trees (for all species in all plots) were inventoried, including 418 individuals in fallow, 911 individuals in secondary forest and 830 individuals in primary forest. They represent the average densities of 209±56 respectively; 456±47 and 415±41 individuals per hectare. The corresponding average basal areas are: 15.0±5.1; 32.9±4.4 and 28.7±4.4 $m^2.^{ha-1}$. For both density and basal area, the highest averages are observed in secondary forest and the lowest averages in fallow. Statistical analyses highlight statistical differences between these three forest stands (*p-value* = 0.0265 < 0.05 for density and *p-value* = 0.0137 < 0.05 for basal area). The multiple comparison of the means (Tukey HSD test, *Honest Significant Differences*) highlights only significant differences between primary forest and fallow on the one hand (t = 8.38; df = 12.83; *p-value* = 1.462e-06 for density and t = 5.74; df = 13.76; *p-value* = 5.517e-05 for basal area) and between secondary forest and fallow land on the other hand (t = 9.548; df = 13.563; *p-value* = 2.155e-07 for density and t = 7.485; df = 13.725; *p-value* = 3.317e-06 for basal area). The dispersals of density and basal area values observed by forest type in Mambasa are shown in Figure 3.

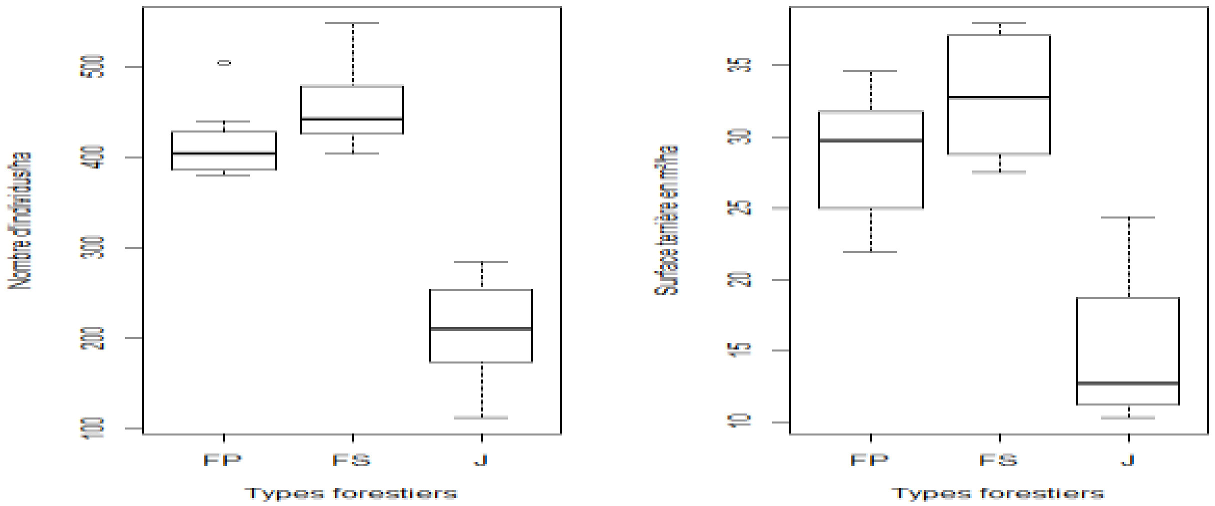


Figure 3 - Dispersion of density (left) and basal area (right) values by forest type in Mambasa. Meaning of the letters: FP = primary forest, FS = secondary forest and J = fallow.

2.2 Diameter structure

The distribution of stem abundance by diameter classes as shown in Figure 4 shows a fairly steady decrease in numbers as the diameter increases. The trend pattern shows an inverted "J" structure for all forest types considered: primary forest, secondary forest and fallow. The statistical comparison of the diametric classes of these plots taking into account their size by the chi-square significance test highlights significant differences between the three forest types considered ($\chi^2 = 15.55$; *p-value* = 0.98).

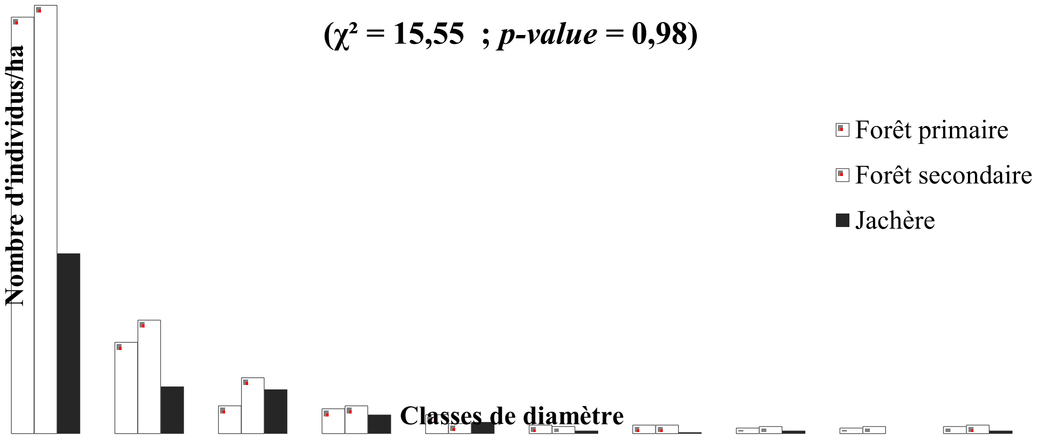


Figure 4 - **Diametric distribution of inventoried individuals by forest type. Meaning of diameter classes: 1 = 10-20 cm dbh, 2 = 20-30 cm dbh; ..., 10 = ≥ 100 cm of dbh.**

2.3 Variability of forest carbon stocks between the forest groups studied

The amount of carbon stored per hectare varies between 31-125T, 167-273T and 150-318T respectively in fallow, secondary and primary forest. The average stocks are: 67±30.9 T/ha in fallow; 224±39.3 T/ha in secondary forest and 226±60.5 T/ha in primary forest. The pattern of distribution of this stock changes in line with the dynamics of a forest ecosystem after disturbance: primary forest has the highest average and fallow has the lowest average. Figure 5 illustrates the dispersion of these values between plots of the same forest type.

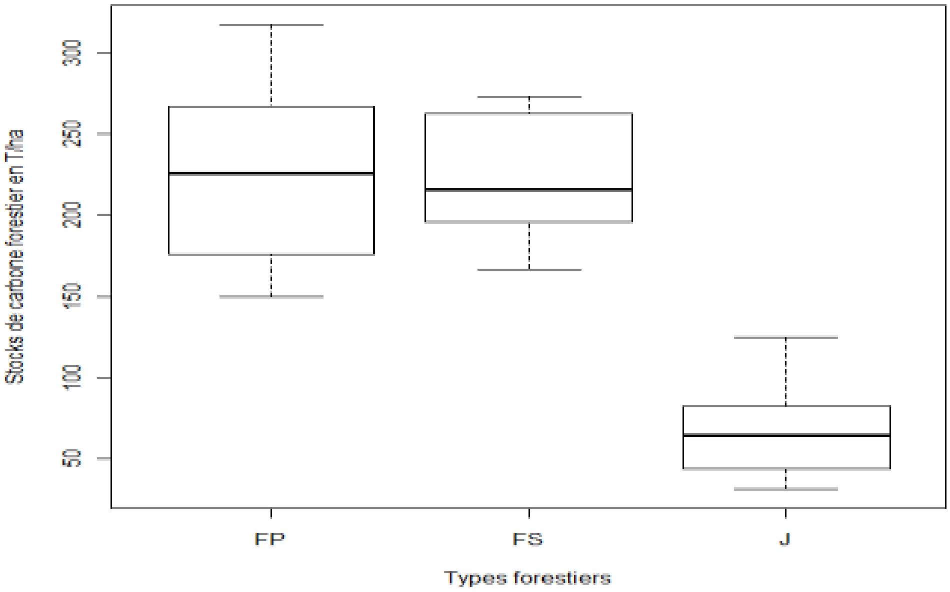


Figure 5 - Dispersion of carbon stock values in different forest types.

The results of the one-factor ANOVA applied to the carbon stock values between the three forest types indicate significant differences. The comparison of the means two by two highlights these differences between primary forest and fallow (*p-value* = 4.849e-05 < 0.05) and between secondary forest and fallow (*p-value* = 6.066e-07 < 0.05).

2.4 Relative error in density, basal area and carbon stocks

To test the impact of human activities on certain structural parameters and carbon stocks on forests, we calculated the relative error made by each of the two anthropogenic forest types compared to the primary forest. Generally speaking, the impact of anthropogenic forests varies according to the stage reached by this ecosystem after disturbance. The analysis of the results obtained shows that this action has an average impact of 11±14%; 17±21% and 5±32% respectively for density, basal area and carbon stocks in secondary forests, while in fallow, it is -49±15% (density); -48±14% (basal area) and -68±17% (carbon stocks). From the above, it emerges that considering the post-disturbance dynamics of the forest after human actions, the variability of structural parameters and carbon stocks is very significant in the early phases of spatial colonization and gradually cancels out with the evolution of the silvigenetic cycle. Figures 6, 7 and 8 show the dispersions of the relative error values of density, basal area and carbon stocks.

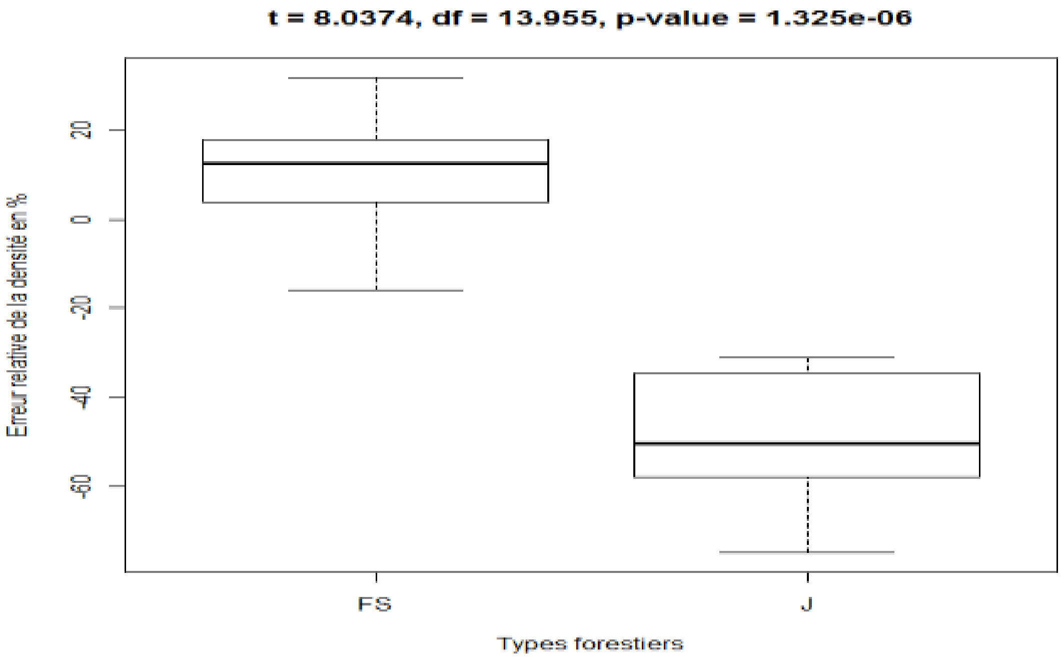
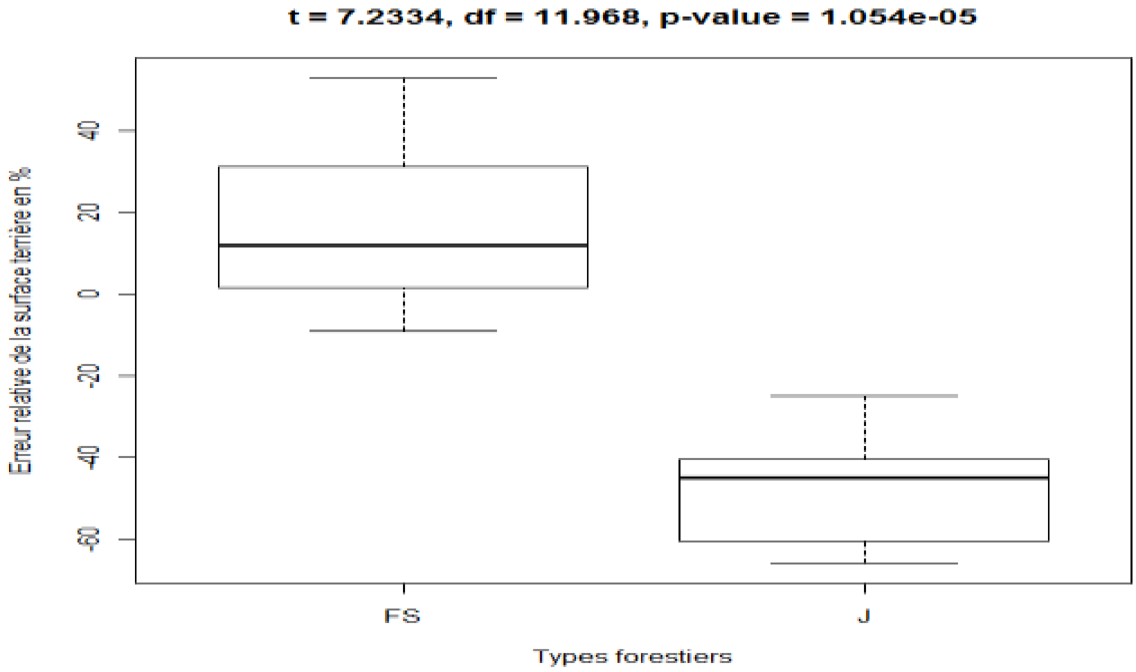


Figure 6 - Dispersion of relative error values of density between the plots of anthropogenic forest stands.



<u>Figure 7</u> - Dispersion of relative error values of basal area between the plots of anthropogenic forest stands.

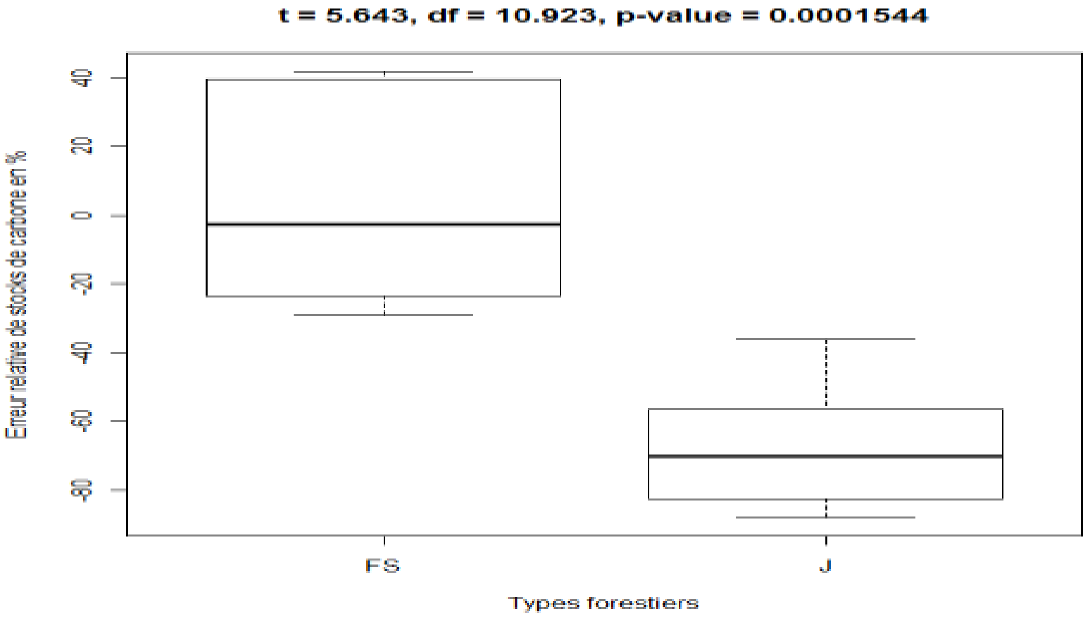


Figure 8 – Dispersion of relative error values of carbon stocks between plots of anthropogenic forest stands.

A brief overview of these figures shows that all values of the relative error of the plots and for all fallow parameters are within the negative range of the figure and vary from -31 to -58 for density, -25 to -66 for basal area, and -36 to -88 for carbon stocks in contrast to secondary forest where the majority of these values are within the range positive of the figure. Converted into a percentage, fallow land loses 31 to 58% of tree size, 25 to 66% of basal area and 36 to 88% of carbon stock, while in secondary forest, it gains on average 11% of its population, 17% of its basal area and 5% of its carbon stock.

CONCLUSION

The question of climate change currently puts tropical forests at the heart of international negotiations, whose sustainable management is more than ever on both national and international political agendas. Recognized for their complexity, the implementation of a rational management plan for these ecosystems requires an understanding of the factors at the root of the transformations of their landscape. The anthropogenic pressures they are subjected to through agriculture and the different uses to which they are subject and the ensuing post-anthropization forest dynamics result in a structural variability of these ecosystems. The objective of this study in the different forest types of Mambasa, whether or not they have been anthropogenic, was to highlight the impact of anthropogenic actions on the structural variability and carbon stock of different forest successions in Mambasa.

To achieve this, the data from 24 plots of 0.25 ha were sorted from all the plots installed as part of the Isangi Geographically Integrated REDD Pilot Project (PPRGIM) by the UNIKIS component (University of Kisangani) for the implementation of an MRV (Monitoring, Reporting and Verification) system for forest carbon stocks due to 8 plots in each of the three forest types considered: primary forest, secondary forest and fallow. In each plot, a full inventory with botanical identification at the specific scale, measurement of dhp and total height of the trees was carried out on all individuals with a diameter at breast height greater than or equal to 10 cm.

The results obtained show that in terms of density, basal area and carbon stock contained in above-ground biomass, secondary forest records the highest averages, while only the fallow averages are statistically different from other forest types. The calculated relative error highlights the gain and loss of density, basal area and carbon stock values for secondary forest and fallow respectively compared to primary forest. As for the diametric structure, the distribution of numbers by diameter classes does not differ between the forest types studied.

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