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Aboveground Biomass in Humid Tropical Wetland Forests of the Republic of Congo, Congo Basin

Ifo Suspense Averti1[*1], Koubouana Felix[2], Bocko Yannick[2]
[*1] Département des Sciences Naturelles, Ecole Normale Supérieure, Université Marien Ngouabi, BP 237 Brazzaville, Republic of Congo
[2] Ecole Nationale Supérieure d'Agronomie et de Foresterie, B.P. 69 Université Marien Ngouabi.
[3]Laboratoire d'Ecologie Végétale. Faculté des Sciences et Techniques, Université Marien, Ngouabi, BP69 Brazzaville, Republic of Congo

Abstracts

Tree aboveground biomass (AGB) distribution and carbon storage in different DBH (diameter at breast height) classes were calculated and compared between three different humid forest of the north of Congo (peat land's forest, seasonally flooded forest, and terra ferma forest) mainly in the forest of Likouala. AGB carbon stock varies in this study from 82 MgC.ha $^{-1}$ to 404 MgC.ha $^{-1}$ across the five sites where data were recorded (68 plots) with an average AGB of 223 MgC.ha $^{-1}$. The AGB in the peat land forest was slightly low compared to the other two forest types. Trees ≥ 60 cm in diameter coupled with over high wood density of 0.70 g.m-^{3} explained 91% of the variability among plots in aboveground biomass obtained in this study. These trees represent less than 20% of the total trees sampled. This study revealed a complex relationship between biodiversity of forest trees in this area and aboveground biomass.

Keywords: aboveground biomass, humid tropical forest, REED+, Congo RC, Carbon.

Introduction

Estimates of carbon stocks in tropical ecosystems are of high relevance for understanding the global carbon cycle, the formulation and evaluation of global initiatives to reduce global warming (Sierra *et al*. 2007). The interest to preserve these forests has increased in recent years within the framework of climate change and could play a crucial role in the mitigation of their effects, through carbon sequestration, and also by the reduction of CO_2 emissions due to deforestation and forest degradation (Malhi & Grace 2000, Gibbs et al. 2007). Recording data on the stock of carbon and understanding of the factors explains his variability are very important because of the link with the emissions from deforestation and degradation (Houghton, 2005). In addition, considering the global climate changes, efforts are being invested to reduce global greenhouse gas emissions. One example of such a climate change mitigation mechanism is REDD+ which aims at reducing emissions from deforestation, forest degradation and making an accent on the role of conservation, sustainable management of forests and enhancement of forest carbon stocks (Campbell & Copenhagen 2009).

Many studies have been carried out in different rainforests of the world to estimate the carbon stock in their different pools. Two basic approaches exist to quantify carbon stocks, namely direct method (sampling or destructive method) and indirect methods (non destructive methods). Because the direct sampling is laborious and time consuming and also because it destructive, several studies used indirect methods for carbon quantification. Allometric equations constitute now days the most common method to estimate the aboveground biomass methods (Chave *et al*. 2005; Henri *et al*. 2010; Vieilledent *et al.* 2012; Fayolle *et al.* 2013) as an indirect approach to estimate carbon stocks.

Some studies (Baccini *et al*. 2008; Saatchi *et al*. 2011) have used remote sensing to estimate the stock of carbon on the ground. Others have attempted a combination of field measurements, remotely sensed data, and physiological models to produce world map of Net Primary Productivity (NPP); however, these estimates are with considerable amount of uncertainties in the tropics (Field *et al*. 1998, Turner *et al* 2005).

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Carbon amount in tropical forest varies widely among studies, and this variation contributes immensely to the uncertainty in estimations of carbon fluxes (Chave *et al*. 2008). Even though a number of forest inventories have been carried out in tropical forests, there remain large areas where such inventories are out of date, incomplete, or entirely lacking (Houghton 2005). Many individual plots have been sampled and analyzed; however, extrapolating the results to an entire region is problematic. Pending the validation of a method that would allow quantification of carbon with excellent accuracy, sampling of carbon by forest inventory will remain the only way to allow the countries engaged in REDD+ to calculate the baseline forest carbon.

Very few studies reported the data of the aboveground biomass of humid tropical forest of the north of Congo RC (Simon *et al*. 2013).

A number of abiotic and biotic factors: wood density, bioclimatic parameters, endemism, tree diameter, soil fertilities, effects of soil and topography, tree height are among the factors that explains the spatial variability of the above- and belowground biomass of trees in tropical forests (Chave *et al.* 2005; Chave *et al.* 2006; Djomo *et al.* 2010; Fayolle *et al.* 2013; Baker *et al*. 2004; Ter Steege et al. 2006).

In the Republic of Congo, the forest cover approximately 2/3 of the total land with a low rate of deforestation 0.07% gross deforestation and an annual rate of only 0.02% net deforestation (Duveiller *et al*. 2008). Likouala's department is covered by 95% by the tropical evergreen rainforest. The forest cover net changes for the periods 1990-2000 and 2000-2010 was of 0.30% and 0.10% respectively. These forest areas are in the focus of REDD+ projects, which require an accurate monitoring of their carbon stocks or aboveground biomass (AGB).

Congo's tropical forests are characterized by a very high biological diversity per hectare (Moutsabote 2011, Kimpouni *et al*. 2013), and play many environmental ecosystem services.

Our study takes place in a dense humid tropical forest of Likouala. The area is characterized by the fact that a part of the forest is growing in a swamp area (area flooded a part of the year), a transition zone between Earth farm and area seasonally flooded.

It should be noted that in Congo Brazzaville, flooded forests occupy approximately 38% of Congolese forests. In this study, we want to test the following hypothesis: (i) - Do means of carbon stock varies in the three zones where plots were installed? (ii) How vary plant biodiversity as well as distribution of trees density per hectare in these typical rain forests

Our objectives were to: (i) estimate the aboveground biomass in the tropical rain forest of the North of Congo using Pantropical allometric equation published by Chave *et al*. (2005); (ii) show the variability of aboveground biomass along different transect; (iii) study the influence of trees diversity on the carbon stock.

Materials and methods

Study site

Our study was carried out in the forest of Likouala (North of the Republic of Congo). In this forest, five transects were established in the localities of Bondoki, Bondzale, Ekolongo, Itanga, Mabla (Figure 1). Experimental plots were established outside the logging concession. This area has one of the very low density of human population (0.93 km^{-2}) of the Republic of Congo. The forest of Likouala contains a high diversity of trees and plants (Moutsambote 2011). Rainfall is 1760 mm y^{-1}, with a dry season from December to January, and a long wet season from March to November. Tree canopy closure of the forest varies from 93% to 100% while the tree height from 30 to above 45 meter (own data).

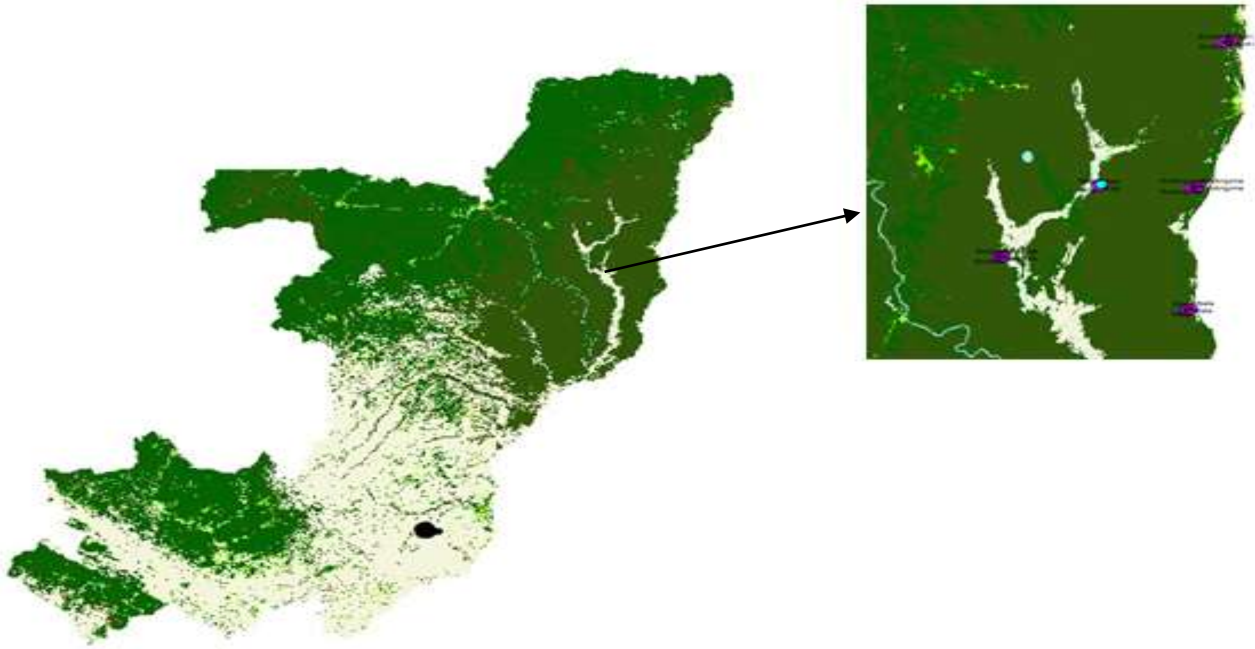

Figure 1: Locations of the fives transects

Plot establishment

To conduct inventories of total aboveground biomass, we sampled 88 plots distributed into five transects **(Table 1)** as presented in study site section. The transects were randomly place in different sites in the western direction – and inside them, all 300 meters a plot has been installed following the protocol developed below.

In each transect, plots were installed in three areas or zone along the transect: forest in seasonally flooded areas (FSF), forest in terra ferma land area (FTF), which is not flooded throughout the year forests flooded throughout the year (FF), in areas of peat lands. It is important to note that these tree type of forests do not refer to a typical existing forest.

Trees ≥ 10 cm dbh (diameter at 130 cm above ground) were recorded. All plots were tagged using GPS points. Nested circular plots (**Figure 2**) were installed to collect the data. Nested circular plots consists of several concentric circles, the smaller circles for smaller trees (radius= 6 m), medium circles (radius= 14 m) and the larger circles for larger trees (Pearson et al. 2007).

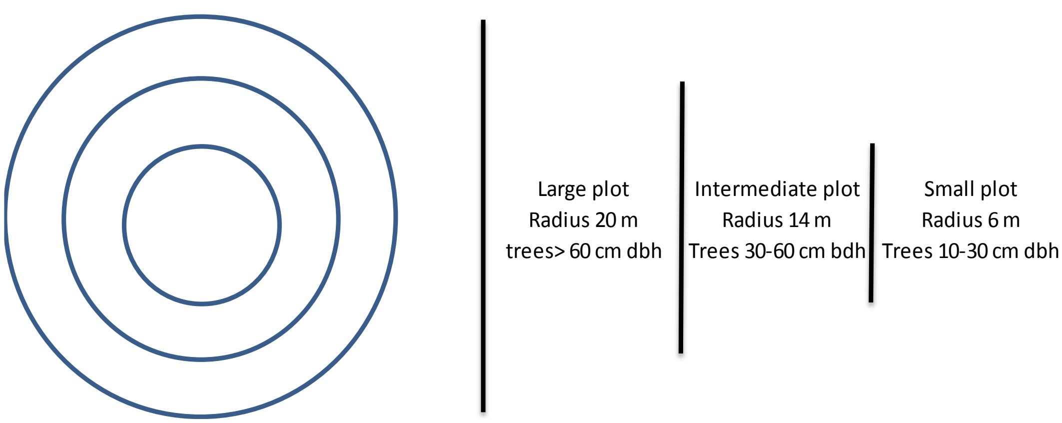

Figure 2: Nested circular plots installed on the ground

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It is good practice to design fixed size circular plots since they are easy to establish, preferably with distance measuring equipment (DME). With DME the boundary of the plot does not need to be marked. Nested plots are cost efficient and scientifically robust for most vegetation types with trees (Walker *et al.* 2012).
Large tree palms (≥ 10 cm DBH) palms were not included in this inventory as well as lianas, small trees (< 10 cm DBH). The others pools of carbon (Dead wood debris, below ground, herbaceous) were not measured in this forest ecosystem.

Calculating carbon stock in above-ground trees from allometric equations

The calculation of aboveground biomass was done using the pan tropical equation developed by Chave *et al*. (2005) for moist forests. This equation was calibrated on an extensive dataset of 2410 trees ≥ 5 cm diameter from 27 study sites across the tropic but none in Africa. In their study in central Africa, Fayolle *et al.* (2013) conclude that the pan tropical multi-species allometric equation can be used to produce accurate estimates of biomass and carbon stocks from diameter measurements in the forest inventory data and from external information on wood specific gravity at species level.

$$B = \rho.exp(-1.499 + 2.148\ln(D) + 0.207(\ln(D))^2 - 0.0281\ (\ln(D))\hat{}3)$$

B= dry biomass (in kg),
D is dbh (in cm),
ρ is wood density (in $g.cm^{-3}$)

Carbon stock ($tC.ha^{-1}$) was obtained by multiplying dry biomass (in kg) with 0.47 (GIEC, 2003).
Woody density of each species was obtained on the website http://datadryad.org/repo/handle/10255/dryad.235.
During the data treatment, we considered the default woody densities of 0.60 $g.cm^{-3}$ for species for which there was no published data of wood density (Henry *et al*. 2010). And to obtain the stock of carbon per hectare, we divided the sum carbon stock per tree by the plot area (m^2) converted into hectare.

Relationship between type of forest, species and aboveground biomass

Cette étude a été faite on ne considérant que tous les arbres de diamètres > 60 cm enregistrés dans la parcelle circulaire de rayon 20 m. Nous avons considéré ce diamètre, parce que les arbres ayant ce diamètre sont ceux qui participent le plus a la biomasse aérienne. Le tableau croisé dynamique d'excel a été utilisé afin de suivre la relation entre le nombre d'espèce végétale par zone ou type de foret, leur nombre ainsi que la contribution de chaque espèce dans la biomasse totale aérienne. Ensuite les espèces sont discriminées suivant leur appartenance à tel ou tel type de foret. Les arbres de diamètres > 60 cm ont été repartis suivant leurs espèces et le nombre d'individus par espèces à leur contribution en termes de biomasse.

Results

Variability of the AGB along the transect

Aboveground carbon stock highly varies in this study from 82 $MgC.ha^{-1}$ to 409.6 $MgC.ha^{-1}$ considering the five transects where we established plots with an average of 223 $MgC.ha^{-1}$ (**Table 2**). Inside each transects (Bondoki, Bondzale, Ekolongoma, Itanga, Mbala), we have noticed a high variability of the AGB. In certain plots like in Mbala, Bondzale, Bandoki). The stock of carbon could vary from simple to double or more (Figures 3).

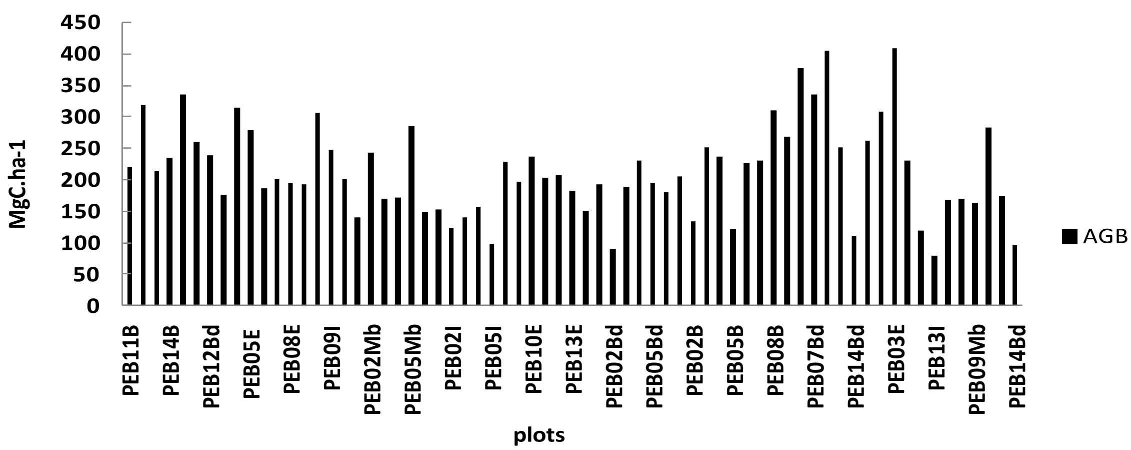

Figure 3: Trends of aboveground biomass along the transect.

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We found also that the above ground biomass varies greatly between the different types of forest

The test of multiple comparisons of means of Turkey shows that there is a significant difference between the seasonally flooded forest carbon stock and the forest on terra firma. A difference of 8.61 MgC.ha^{-1} was noted between these two forests. We obtained also a significant difference of Cstock of 51.80 MgC.ha^{-1} between FTF and FF between FSF and FF there is a significant difference of 60.42 MgC.ha^{-1}. But there is no significant difference between seasonally flooded forests and flooded forests.

Influence of the class of diameter on the aboveground biomass

Analysis of the data indicates the existence of a fairly wide range of diameter class in this study area. Indeed it varies from the class [10 - 19.99] to the diameter class [140 - 149.9].

The results obtained in our study showedlarge trees, through less abundant than small trees, stored a greater proportion of the plot biomass than small trees. The tree population with diameter ≤ 60 cm was more important (79 % of total tree censed) than the tree population above that diameter (Figure 3). However, trees with DBH > 60 cm represented 91 % of the mean of AGB in the five transects censed. Considering trees with d.b.h ≥ 60 cm, the most important stock of carbon has been recorded in the FFFTF with 103 MgC.ha^{-1}. In the two others forest we obtained respectively 73 and 67 MgC.ha^{-1} in the FSF and FF.

Relationship between species and aboveground biomass

Linear regressions were made to check the link between the number of species and the amount of aboveground biomass in different plots (figure 4). It notes that there are linear regressions between these two parameters, but the correlation is weak ($r^2 = 0.25$, FSF; $r^2 = 0.39$, FF; $r^2 = 0.24$, FFF) (figure 5).

Also if we consider trees with diameters ≥ 60 cm, the relationship indicates a better correlation ($r^2 = 0.65$).

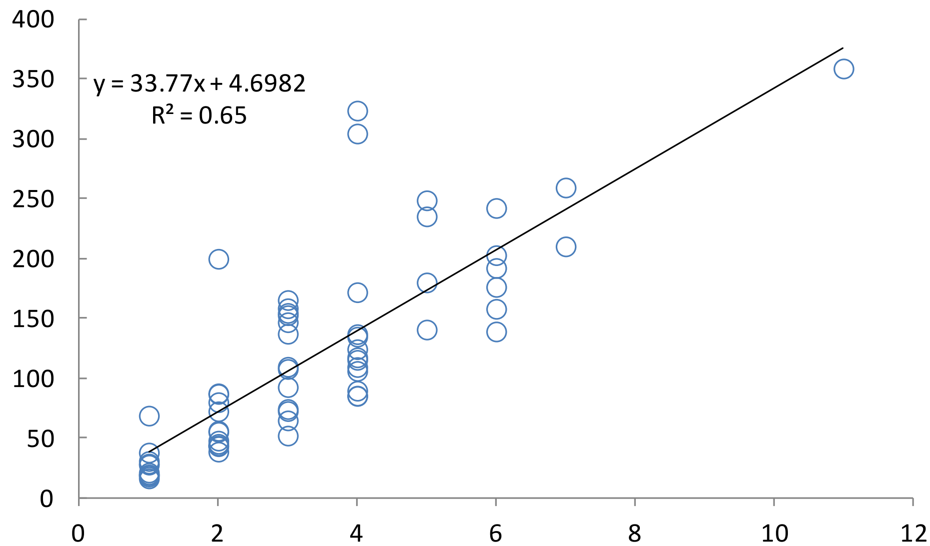

Figure 4: Relationship between number of species and aboveground biomass

Otherwise, if we consider all tree recorded, in the forest of FTF there are 116 individuals trees for a Cstock of 2179 MgC.ha^{-1} against 285 trees with diameter ≥10 cm for a total biomass of 3399 MgC.ha^{-1} for the FF. We obtained for the FSF a total biomass of 2713 MgC.ha^{-1} for 104 trees. Considering trees with dbh ≥ 60 cm-diameter trees, there is great variability in terms of representation of the number of species with more than three trees higher than 60 cm. In the FSF forest we note 6 species, while in two other types of forests there was 8 and 10 species respectively in FF-FFF forests. This result reveals that in the tropical rainforests of Likouala very few plant species are involved in the biomass of these forests. In addition, there are specific to each type of forest plant associations. Six forest species contribute to almost 50% a total biomass of the trees of diameter above 60 cm in the forest FSF, 66% in forests FFF and 61% for the FF (table 1) forests.

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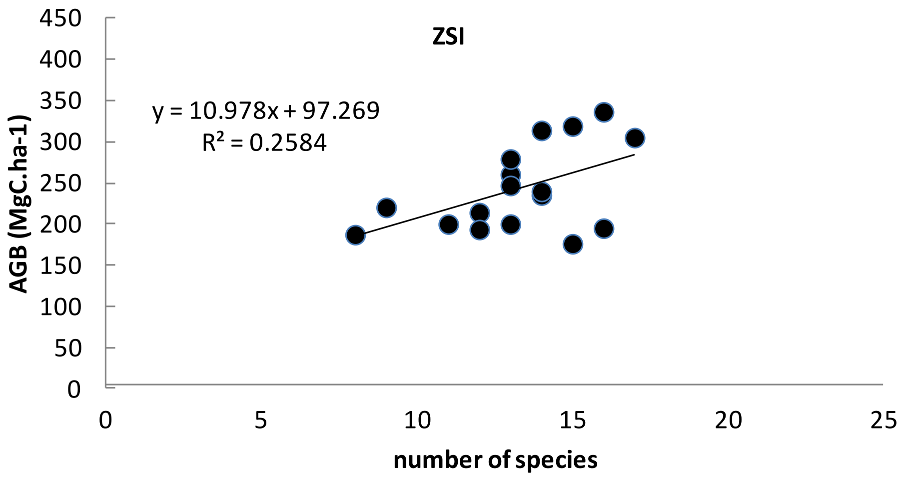
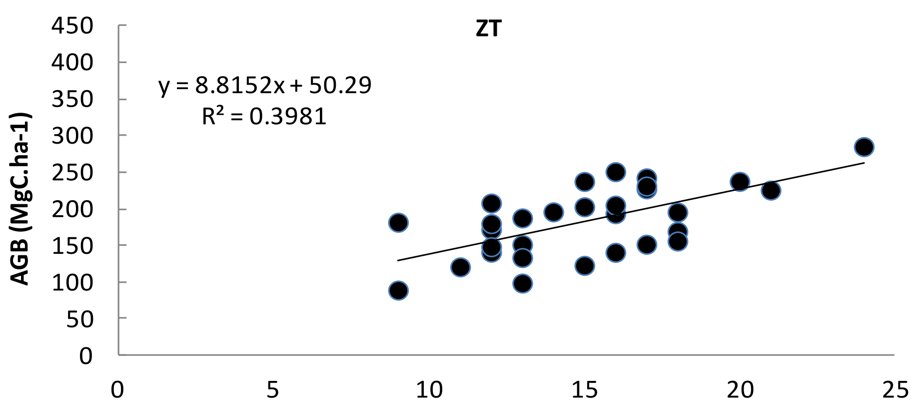
Tableau 1: Relationship between species and aboveground biomass

type of forest	n (d > 60 cm)	d>60 cm AGBtot	Species with n<2	Species with n>2	AGBtot Species for n>2
FSF	61	2176	25	6	1013
FF	71	1753	18	8	1076
FFF	77	3281	22	10	2164





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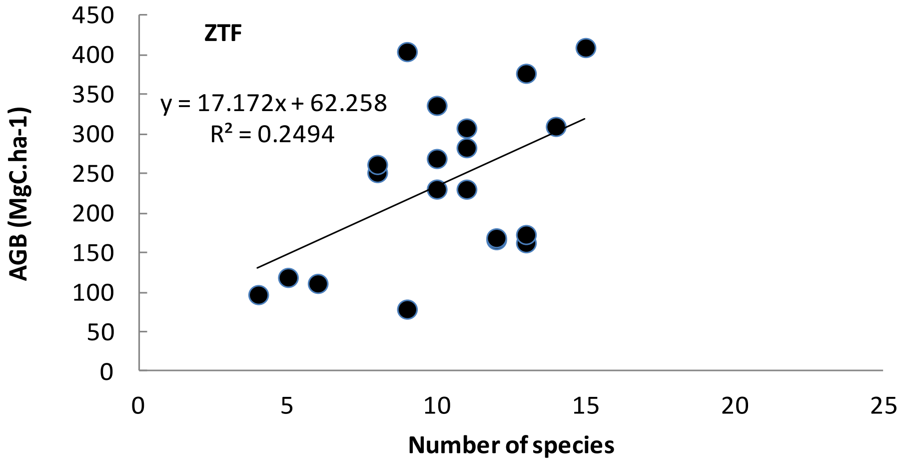

Figure 5: relation between number of species and aboveground biomass for trees above> 60 cm.

Discussion

Variability of the aboveground biomass

The means values of biomass obtained in the different forest in this study was higher than the mean value published by the report of GIEC (2003) for dense tropical forest for Africa (310 tMS.ha^{-1} or 138 MgC.ha^{-1}.). However, the results obtained in this study are closed to those obtained by others authors (Table 7) and were below in comparison with those published by Nascimento *et al* (2002) and Brown *et al.* (2004). Indeed Brown *et al*. (2004). in their study on the impact of selective logging on the carbon stocks of tropical forests in Republic of Congo from 10 plots in mature unlogged forest with the same protocol as used in our study, their found a mean stock of carbon of 276.7 MgC. ha^{-1}± 103.9 (n = 10, mean ± 95 % confidence interval). Many factors could explain the high variability of aboveground biomass (soil fertility, big trees density, wood density, high diameter, etc). According to results obtained, we noted high variability of AGB inside each type of forest as noted we have swamp forest, terra firma forest and seasonally flooded forest. The lowest biomass in the flooded forest could be explained by the presence of water that does not facilitate the growing of trees.

Influence of type of forest on AGB

Guitet *et al.* (2005) noted in French Guiana forest that the biomass varied significantly between primary forest and swamp forest. Aboveground biomass was lower in the swampy forest than in the terra ferma with 290 ± 30 tMS.ha^{-1} against 350 ± 25 tMS.ha^{-1} respectively.

Brown *et al* (1997) argue that in the old tropical forest aboveground biomass of trees range from 220-260 MgC.ha^{-1} with trees > 70 cm in diameter accounting for 30% of the AGB. But Baishyal *et al.* (2009) found in their study that about 49% of the AGB was explains by trees with DBH> 60 cm, while Serura & Kanninen (2005) discovered in the forest of Northern Costa Rica that DBH ≥ 60 cm, represented, 41 and 50 percent of the AGB. Brandeis *et al.* (2006) stated that even in the dry tropical forest, the large diameter influences greatly the value of the aerial biomass of trees. Terakunpisut *et al*. (2007) reported that the potential of forests to sequester carbon depends on the forest type and size of forest age class of trees. Regarding the age, no data could allow us to determine the age of the trees in the area where our data were collected. But following results obtained in terms of the proportion of trees in relation to their diameter classes, classes with diameters less than 60 cm are most important. The number of large trees per unit area is an important indication that this forest is an old forest or not. Low representation of individual large diameters could be explained by soil nutrient concentration, understory vegetation, but also by dynamic growth of tropical forest (Holl and Zahawi, 2014).

Our results showed that the number of large tree decrease swiftly from 60 cm of diameter to 100 cm of diameter. We recorded 71 trees with diameter above 60 cm against 3 trees with diameter above 100 cm, while in the two others type of forest, we noted in the terra firma forest we had 77 trees with diameter above 60 cm against 15 trees with diameter above 100 cm

Lutz *et al*. (2012) reported that large-diameter trees contribute disproportionately to reproduction, and influence the rate and pattern of tree regeneration and forest succession. However large tree density (DBH≥70 cm) accounted for 69.8% of pan-tropical variation but also explain the great difference we observe between Neotropical and pantrocical forest (Silk *et al*. 2013). The impact of big trees on AGB also follows from the fact that they stored on average 25.1, 39.1 and 44.5% of AGB in South America, Southeast Asia and Africa, respectively, but represented only 1.5, 2.4 and 3.8% of stems larger than 10 cm DBH in these three respective regions (Slik *et al*. 2013). In our study DBH up to 70 cm represent site by site from 0,36 % to 1,57 % of the tree population.

Biomass and woody density

Although the wood density it is an important parameter, this cannot explain itself trends of mean AGB observes in the study site. Wood density is with the diameter the most important parameters used to calculate aboveground biomass. Between the two parameters, diameter revealed to be the most important factor with a correlation R^2 = 0.82. We noted that woody density do not contributed a lot to the prediction of aboveground biomass.

This result confirm the fact that diameter is the most important parameter to estimate AGB of this forest. Although the biomass of a forest is affected by variety of factors such as age of standing trees, species composition, topography, environmental heterogeneity, and natural and anthropogenic disturbance (Chave *et al*. 2005). This author attested that wood density, diameter at breast height (DBH or D) and plant height (H) are the common exogenous variables that individually or in combination explain biomass with deviations greater than 16 % of the average measured tree aboveground.

The analyses of the results of woody densities obtained indicate an average density of wood of 0.66 $g.cm^{-3}$ on all of the sites studied. However this woody density ranges from 0.23 $g.m^{-3}$ to 1.01 $g.m^{-3}$. The variation of woody density varies from site to sites across the tropical forest of this studying area. In south-eastern of Cameroon, Falloye *et al*. (2013) finds that woody density range from 0.284 to 1.152 $g.cm^{-3}$ for the tree with a highest and densest wood based on sampled of 138 trees with diameter between from 5.30 to 192.50 cm.

In our study we censured 828 trees. It is important to note that the range of variation of the wood density values in tropical forests is a very important aspect which can also help us to learn more about the structure of the humid forest, the dynamics of these forests, and may also learn about the pedo-climate parameters which appears during the development of these forests.

Stegen *et al*. (2009) affirm that when forest biomass is dominated by low wood density species, total basal area declines with community. It seems that with the age, tree woody density increase as well. In this way, Zimmerman *et al*. (1994) in Stegen *et al*. (2009) found that high wood density species preferentially survived the 1989 hurricane that disturbed the Luquillo forest, which should have resulted in above-ground biomass being primarily held in high wood density trees. Wood density, and if this relationship is steep enough forest biomass will also decline with community wood density. The department of Likouala where our data was collected is characterized by a very high rainfall and strong winds during the season of heavy rains. All these phenomena do not cause the destruction of tropical forests in this region. Indeed we have not noted a lot dead wood debris on the ground of these forests (Ifo et al. in preparation).

Conclusion

Humid tropical forest in the North of Congo Brazzaville contains a high value of above ground biomass with significant variability between plots using the pan tropical equation. This study demonstrates the importance of large trees in the structure of this humid tropical forest but also the influence in the estimation of aboveground biomass. Diameter up to 90 cm explains about 89% of AGB. AGB was different in the tree types of forest identified in the study area and present a slightly different with the lower value obtained in the peat land forest. Our results revealed the importance to collect ground data in the context of REDD+ in which Congo RC is committed.

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