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RESEARCH PAPER

Estimating the stock of carbon sequestered by woody species in Yapo-Abbe classified forest

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Abstract

The constant increase in atmospheric pollution due to greenhouse gas emissions requires humanity to adopt a strategy of absorption and sequestration of these emitted gases. One of the alternatives to the damage caused is, in addition to reducing their emission, their sequestration by ecosystems. The general objective of this study was to estimate the biomass and the amount of carbon sequestered by woody plants in the different biotopes in the classified forest of Yapo-Abbé. Surface surveys and statistical analyses performed on the dendrometric parameters have shown that this forest stores a biomass estimated at 22.26 t/ha for a sequestration of 10.45 t/ha of carbon. Most of this gas is sequestered by the Yapo block, especially by its secondary forest biotope. The least anthropized and least disturbed environments have a greater storage capacity. The amount of atmospheric carbon dioxide (CO_2) sequestered by the classified forest of Yapo-Abbé is on average 39.53 t/ha of atmospheric carbon, or 1,201,988.71 t/ha of CO_2 sequestered. This study testifies to the importance of the conservation of forests in Côte d'Ivoire and their importance in the process of reducing greenhouse gases in the troposphere, thus reducing global warming.

Keywords: Carbon stock, Sequestrated, Woody species, Yapo-Abbé classified forest

Introduction

Climate change is a calamity for the world and much more for the people. Il is the consequence of the general warming of the planet earth due to greenhouse gas emissions (Lal, 2002) caused by the use of fossil fuels in industries, the increase in livestock farming and deforestation. The disturbances caused lead to extreme climatic phenomena (storms, droughts, confusing seasons, rising oceans), causes of environmental degradation.

Climate change is already affecting agriculture, health, terrestrial and ocean ecosystems, water supply and the livelihoods of certain populations (Anon, 2001; 2002; Alamgir 2008; Mooney et al., 1999). What is striking about the observed impacts of these changes is that they occur from the tropics to the poles, from small islands to large continents and from the richest to the poorest countries (IPCC, 2013). .

The constant increase in atmospheric pollution due to greenhouse gas emissions requires humanity to adopt a strategy of absorption and sequestration of these emitted gases. One of the alternatives to the damage caused is, in addition to reducing their emission, their sequestration by ecosystems.

Tropical forests represent 60% of the world's forests. They play a key role in the carbon cycle (C) both in terms of flux and the volume of carbon stored (FAO 1998, 2002). According to the IPCC special report on LULUCF activities, 2000; then Alamgir (2008), forests are one of the best sinks for carbon storage in addition to providing a unique environmental service by regulating atmospheric carbon dioxide (CO_2). The work of Negi et al. (2003) showed that one hectare of forest can sequester up to 5 tonnes of carbon per year.

Cote d'Ivoire is committed to the international mechanism for Reducing Greenhouse Gas Emissions due to Deforestation and Forest Degradation (REDD ±) since 2010, in order to contribute to the fight against climate change , but also for the sake of sustainable management of its forest cover. However, very little data exists on the biomass and on the emission factors specific to the country, in particular for the development of the reference level for REDD ± and for the operationalization of the National System of Monitoring of Forests. The general objective of this study in the classified forest of Yapo-Abbé, a benchmark in biodiversity conservation for the Forest Development Corporation (SODEFOR), is therefore to assess the biomass and the amount of carbon sequestered by woody plants in the different biotopes of this forest massif (natural forest, managed forest, forest plantations and fallows). Specifically, it will be:

- to assess the above-ground biomass and the quantity of carbon sequestered by the Yapo-Abbé classified forest and its biotopes;
- to estimate the quantity of atmospheric carbon dioxide (CO_2) sequestered.

Study area

Covering an area of 28,790 ha, the classified forest of Yapo-Abbé is located in the Department of Agboville, precisely in the Sub-prefecture of Azaguié (Figure 1) in south-east of Côte d'Ivoire, between 5 ° 35 'and 6 ° 15' north latitude and 3 ° 55 'and 4 ° 40 'west longitude. It is composed of four biotopes: natural forest, managed forest enriched with commercial species, forest plantations of main species for the production of timber, fallows. Of all these biotopes, the natural forest remains the most important today.

According to climatological data from SODEXAM (2018), for the period 1996 to 2013, the Department of Agboville remained subject to four seasons: a long dry season from December to February, a long rainy season from March to June, a short dry season from July to August and a short rainy season from September to November with average annual temperatures of 27 ° C.

The relief, in the Department, is characterized by numerous small hills and by shallows (SODEFOR, 1999). The soil profile in the forest massif presents a horizon rich in coarse elements with quartz gravels and gravel (Beaufort, 1972).

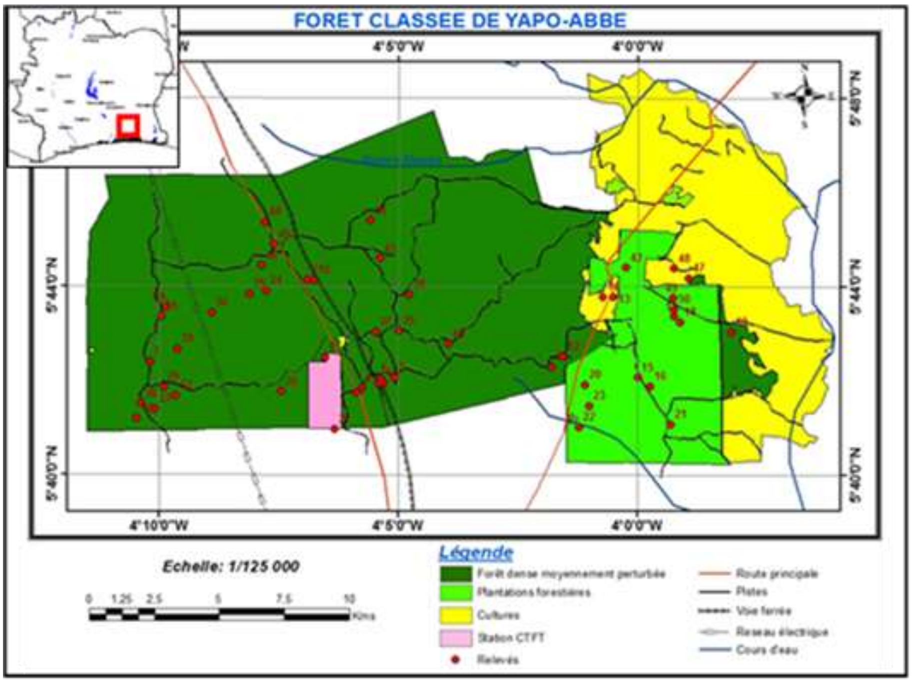

Figure 1: Location of the Yapo-Abbé classified forest

Methods

Data collection

To assess the aboveground biomass and the amount of carbon sequestered in the different biotopes of the classified forest, the surface survey method was adopted. 50 plots of 100 mx 50 m (5000m²) have been installed in the four biotopes. In each 500m^2 plot, all woody individuals with a diameter greater than 10 cm (dbh> 10 cm) were measured. Subsequently, each plot was subdivided into 4 plots of 25 m each, or 625 m², in which regeneration in the four biotopes was assessed, by the inventory of all individuals with a diameter less than or equal to 10 cm .

Data processing

Aerial biomass

The above-ground biomass of woody plants in the Yapo-Abbé classified forest was estimated using the allometric equation of Chave et al. (2005) for tropical rain forests. This equation integrates the dendrometric parameters of the forest inventory (diameter, height, density of wood) according to the model Ba = f (diameter, height, density of wood).

The mathematical formula is defined as follows:

Ba (t/ha) = exp (-2.557 + 0.940 ln (ρD²H)) = 0.0776 (ρD2H) 0.940,
Ba: above-ground biomass expressed in t/ha;
D: diameter measured at 1.30 above the ground in cm;
H: total height of the tree;
ρ: density of specific matter of a species expressed in g / cm^3.

For species without available density literature, the default value for African tropical forests (ρ defect = 0.58 g / cm3) was used (Reyes et al., 1992). The above-ground woody biomass was evaluated according to different strata determined by Emberger et al. (1968), then Chatelain (1996) and distributed as follows: Lower stratum (stratum <2 m), shrub stratum (2 <stratum <8 m), tree stratum (8 <stratum <32 m) and upper stratum (32 m <stratum).

Carbon sequestration potential

The carbon sequestration potential of the classified forest was assessed by the conversion of dry matter from above-ground biomass. The sequestered carbon (C) was estimated from the product of aboveground biomass by a conversion factor (k) which is 0.47 according to the IPCC (2006) as follows:

C (t/ha) = k.Ba
C: sequestered carbon;
Ba: aboveground biomass;
k: conversion factor.

Amount of sequestered atmospheric carbon dioxide (CO_2)

The assessment of the amount of atmospheric carbon dioxide absorbed by the classified forest was made from sequestered carbon. To convert the carbon stock into the amount of sequestered CO_2, the conversion factor used is that determined by the Molecular mass / Atomic mass ratio (44/12). The value of this factor is 3.67. The equivalent atmospheric CO_2 stock is estimated by the product of the sequestered carbon stock (from above-ground biomass) by 3.67. Thus, the quantity of carbon dioxide (CO_2) is evaluated by the formula (Ecosystems Marketplace, 2016): CO_2 (t) = 3.67C. It was used by Tsoumou et al. (2016) for the estimation of the amount of carbon dioxide (CO_2) sequestered by the Dimonika model forest in the southwest of the Republic of Congo.

Statistical analyses

The comparison of the mean values of the different calculated parameters was made from an analysis of variances, to observe or not possible significant differences between the biotopes, with an error of 5% (p <0.05). This analysis was carried out with XLSTAT version 16.0 software. For values of p <0.05, the difference is significant.

Results

Above-ground biomass and carbon sequestration potential

The estimation of aboveground biomass gave an average value of 22.26 t/ha for the classified forest of Yapo-Abbé (Table 1). Between the blocks, these values are statically different (p-value = 0.003). For the Yapo block, the above-ground biomass is 25.08 t/ha, distributed among the low strata (0.08 t/ha), shrubby (0.61 t/ha), trees (16.89 t/ha) and higher (7.50 t/ha). The Mambo block follows with 22.37 t/ha, distributed between the low (0.08 t/ha), shrubby (0.54 t/ha), tree (15.26 t/ha) and upper (6, 50 t/ha). Finally, comes the Abbé block with 19.33 t/ha, distributed between 0.08 t/ha in the lower layer, 0.63 t/ha for the shrub layer, 15.41 t/ha in the tree layer and 3.21 t/ha in the upper stratum. These results show that in this classified forest, the Yapo block produces the greatest amount of above-ground biomass, especially in the tree layer.

In the different biotopes constituting the classified forest, the aboveground biomass values are also statistically different (p-value = 0.001). It is 25.07 t/ha in the secondary forest, distributed between the low (0.18 t/ha), shrubby (0.69 t/ha), tree (16.46 t/ha) and higher (7.74 t/ha). In the enriched forest, this value is 21.35 t/ha with 0.13 t/ha in the lower stratum, 0.69 t/ha in the shrub stratum, 16.46t/ha in the tree stratum and 4, 60 t/ha at the level of the emerging stratum. Within the reforested area, the quantity of above-ground biomass is 19.17 t/ha, distributed among the low strata (0.09 t/ha), shrubby

(0.77 t/ha), trees (14.34 t/ha) and higher (3.97 t/ha). Finally in the fallow, it is 16.59 t/ha, composed of 0.08 t/ha in the lower stratum, 0.56 t/ha in the shrub stratum, 14.45 t/ha for the tree stratum and 1.50 t/ha for the upper stratum. According to these results, the secondary forest produces the highest above-ground biomass, mainly in the tree layer.

Table 1: Amount of above-ground biomass stored by each vegetation medium (t/ha)

		Upper stratum > 32 m	Tree Layer [8 - 32 m]	Shrub layer [2 - 8 m]	Low stratum <2 m	Total values
Biotopes	Secondary forest	$7,74 \pm 0,30^{a}$	$16,46 \pm 0,15^{a}$	$0,69 \pm 0,06^{a}$	$0,18 \pm 0,05^{a}$	$25,07^{a}$
	Enriched forest	$4,60 \pm 0,30^{b}$	$15,97 \pm 0,15^{a}$	$0,65 \pm 0,06^{a}$	$0,13 \pm 0,05^{a}$	$21,35^{ab}$
	Reforested area	$3,97 \pm 0,30^{b}$	$14,34 \pm 0,15^{b}$	$0,77 \pm 0,06^{a}$	$0,09 \pm 0,05^{a}$	$19,17^{b}$
	Fallow	$1,50 \pm 0,30^{c}$	$14,45 \pm 0,15^{b}$	$0,56 \pm 0,06^{a}$	$0,08 \pm 0,05^{a}$	$16,59^{b}$
	p-value	0,001	0,001	0,26	0,62	0,001
Forest blocks	Yapo	$7,50 \pm 0,01^{a}$	$16,89 \pm 0,01^{a}$	$0,61 \pm 0,01^{a}$	$0,08 \pm 0,01^{a}$	$25,08^{a}$
	Abbé	$3,21 \pm 0,01^{c}$	$15,41 \pm 0,01^{b}$	$0,63 \pm 0,01^{a}$	$0,08 \pm 0,01^{a}$	$19,33^{b}$
	Mambo	$6,50 \pm 0,01^{b}$	$15,26 \pm 0,01^{c}$	$0,53 \pm 0,01^{b}$	$0,08 \pm 0,01^{a}$	$22,37^{ab}$
	p-value	< 0,0001***	< 0,0001***	0,002**	$1,00^{ns}$	0,003***
FC Yapo-Abbé		22,26				

Threshold of significance of the tukey tests: ns> 0.05; * <0.05; ** <0.01; *** <0.001; ns: not significant
a, b and c indicate statistically significant differences

The assessment of the carbon sequestration potential showed that the classified forest of Yapo-Abbé, as a whole, stores on average 10.45 t/ha of carbon (Table 2). In the Yapo block, the amount of carbon sequestered is 11.78 t/ha, distributed between the basic (0.04 t/ha), shrubby (0.29t/ha), tree (7.93 t/ha) strata) and higher (3.52 t/ha). The Mambo block follows with 10.49 t/ha, distributed between the low (0.04 t/ha), shrubby (0.24 t/ha), tree ((7.16 t/ha) and upper (3, 05 t/ha). Finally, comes the Abbé block with 9.07 t/ha, of which 0.04 t/ha in the lower layer, 0.30 t/ha for the shrub layer, 7.23 t/ha in the tree layer and 1.50 t/ha in the emerging stratum. These results indicate that the Yapo block sequesters the most carbon in this classified forest, particularly in its tree layer.

In the biotopes, the amount of carbon sequestered is 11.55 t/ha in the secondary forest, distributed among the low strata (0.04 t/ha), shrubby (0.26 t/ha), tree (7, 67 t/ha) and higher (3.58 t/ha). It is 10.22 t/ha with 0.04 t/ha in the lower layer, 0.28 t/ha in the shrub layer, 7.48 t/ha in the tree layer and 2.42 t/ha in the level of the upper stratum in the enriched forest. In the reforested area, it is 8.69 t/ha and is distributed between the low strata (0.04 t/ha), shrub (0.29 t/ha), trees (6.78 t/ha) and higher (1.58 t/ha). Finally, in the fallow, it is 7.85 t/ha, composed of 0.04 t/ha in the lower stratum, 0.24 t/ha in the shrub layer, 6.88 t/ha for the tree stratum and 0.69 t/ha at the level of the upper stratum. According to these results, the amount of carbon sequestered in the classified forest of Yapo-Abbé is higher in the secondary forest, especially in the tree stratum.

Table 2: Quantity of carbon sequestered by each medium and by vegetation stratum (t/ha)

		Emerging stratum > 32 m	Tree Layer [8 - 32 m]	Shrub layer [2 - 8 m]	Low stratum <2 m	Total values
Biotopes	Secondary forest	$3,58 \pm 0,01^{a}$	$7,67 \pm 0,01^{a}$	$0,26 \pm 0,01^{a}$	$0,04 \pm 0,01^{a}$	$11,55^{a}$
	Enriched forest	$2,42 \pm 0,01^{b}$	$7,48 \pm 0,01^{a}$	$0,28 \pm 0,01^{a}$	$0,04 \pm 0,01^{a}$	$10,22^{a}$
	Reforested area	$1,58 \pm 0,01^{c}$	$6,78 \pm 0,01^{b}$	$0,29 \pm 0,01^{a}$	$0,04 \pm 0,01^{a}$	$8,69^{b}$
	Fallow	$0,69 \pm 0,01^{d}$	$6,88 \pm 0,01^{b}$	$0,24 \pm 0,01^{a}$	$0,04 \pm 0,01^{a}$	$7,85^{b}$
	p-value	< 0,0001	< 0,0001	0,07	1,00	0,02
Forest blocks	Yapo	$3,52 \pm 0,01^{a}$	$7,93 \pm 0,01^{a}$	$0,29 \pm 0,01^{a}$	$0,04 \pm 0,01^{a}$	$11,78^{a}$
	Abbé	$1,50 \pm 0,01^{b}$	$7,23 \pm 0,01^{a}$	$0,30 \pm 0,01^{a}$	$0,04 \pm 0,01^{a}$	$9,07^{b}$
	Mambo	$3,05 \pm 0,01^{a}$	$7,16 \pm 0,01^{a}$	$0,24 \pm 0,01^{b}$	$0,04 \pm 0,01^{a}$	$10,49^{ab}$
	p-value	< 0,01	< 0,06	0,006	1,00	0,04
FC Yapo-Abbé		10,45				

Threshold of significance of the tukey tests: ns> 0.05; * <0.05; ** <0.01; *** <0.001; ns: not significant
a and b indicate statistically significant differences

Atmospheric carbon dioxide (CO_2) sequestered by the CF of Yapo-Abbé

The amount of atmospheric carbon dioxide (CO_2) absorbed by the classified forest of Yapo-Abbé varies between the three forest blocks. Of the 18 plots installed in the Yapo block, 13 sequester CO_2 quantities varying between 45 and 65 t/ha and the other five absorb between 25 and 45 t/ha. The average amount of atmospheric CO_2 absorbed in this block is 49.44 t/ha, or 41.68% over all three blocks (Table 3). In the 19 plots in the Mambo block, four capture 45 to 65 t/ha of CO_2, 13 sequestrate from 25 to 45 t/ha and the other two from 15 to 25 t/ha, an average of 37.63 t/ha (31.72%). As for the 13 plots in the Abbé block, 10 absorb between 25 and 45 t/ha and the last three plots, between 15 and 25 t/ha, an average of 31.54 t/ha of CO_2 sequestered by this forest block.

Table 3: Amount of atmospheric carbon dioxide (CO_2) sequestered by the three forest blocks of the CF of Yapo-Abbé

Forest blocks	Number of plots	Quantity ranges CO_2 (t/ha)	Average CO_2 values (t/ha)	Proportion (%)
Yapo	- 5 13	15 - 25 25 - 45 45 - 65	49,44	41,68
Mambo	2 13 4	15 - 25 25 - 45 45 - 65	37,63	31,72
Abbé	3 10 -	15 - 25 25 - 45 45 - 65	31,54	26,59
FC Yapo-Abbé			39,53	

The evaluation of the quantity of atmospheric carbon dioxide sequestered by the various plots installed made it possible to characterize its variation over the whole of the classified forest (Figure 2). From the Yapo block to the Abbé block, via the Mambo block, the amount of atmospheric CO_2 absorbed decreases. It varies from 45 to 65 t/ha in the Yapo block, from 25 to 45 t/ha in the central Mambo block and then from 15 to 35 t/ha in the Abbé block. These results indicate that the Yapo block is the one that absorbs large quantities of atmospheric carbon dioxide.

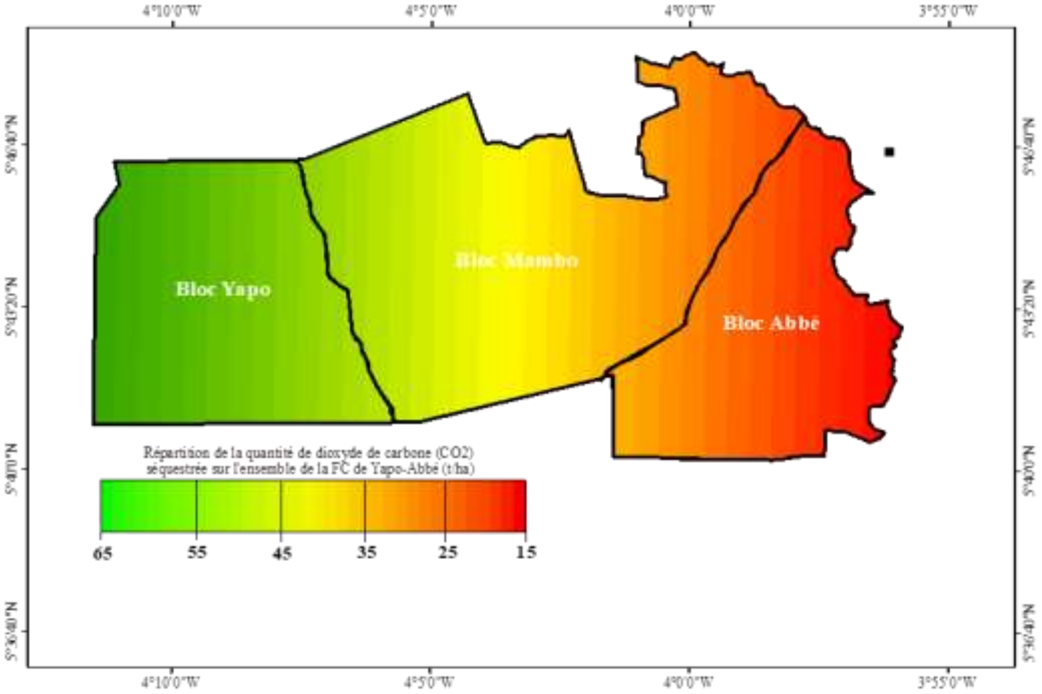

Figure 2: Potential evolution of the amount of atmospheric CO2 sequestered by the Yapo-Abbé classified forest

Discussion

Above-ground biomass and carbon sequestration potential

The evaluation of the aboveground biomass and the carbon sequestration potential of the classified forest of Yapo-Abbé shows that it is 22.26 t/ha on average for the biomass and 10.45 t/ha for the carbon. This result shows the importance of this Yapo-Abbé classified forest in regulating the carbon cycle both in terms of flux and the volume of carbon stored. Biomass and sequestered carbon are higher in the Yapo block, mainly in secondary forest (biomass, 27.07 t/ha and carbon, 11.55 t/ha), especially in the tree layer (8 to 32 m height) .The explanation would come from the high density of the woody and the high circumference of the individuals in this biotope. Auclair and Bige (1984) and Brown (2002) have shown that tropical forest trees are the dominant element in aboveground biomass. For these authors, 57% of the above-ground forest biomass comes from the upper stratum with diameters greater than or equal to 30 cm. Indeed, the allometric equation of Chave et al. (2005) used includes in addition to density and total height, the diameter of the trees. Thus, large diameter trees will obviously have the highest values of above-ground biomass and sequestered carbon.

These results can still be supported by the studies of Novak and Crane (2002) for which, the biomass and the carbon are influenced by the diameter of the tree at maturity. The work of Konan (2016) had shown that the Yapo block was, unlike the Abbé and Mambo block, less disturbing, anthropized and less developed as a whole. Dubé et al. (2006) have also shown that the size of the trees has a strong impact on the above-ground biomass and the amount of carbon captured. The amount of carbon sequestered is also always greater in the secondary forest at Yapo-Abbé. In a forest ecosystem, the increase in biomass is linked to the carbon sequestration of the atmosphere thanks to the photosynthetic fixation process of the crown (Dubé et al., 2006). Photosynthesis allows trees to capture atmospheric carbon during their growth, which is then stored in biomass. Thus, the intensification of wood removals could reduce the rate of carbon sequestration in forest ecosystems (Andreux and Choné, 1993). Abuse is believed to be the cause of the low carbon value sequestered in highly disturbed environments such as fallow and the Abbé block.

Amount of atmospheric carbon dioxide sequestered by the Yapo-Abbé Classified Forest

The amount of atmospheric carbon dioxide (CO_2) sequestered by the classified forest of Yapo-Abbé varies from 15 to 65 t/ha, or on average 39.53 t/ha of sequestered atmospheric carbon. Reduced to the total area (30,407 ha), the classified forest would sequester 1,201,988.71 tonnes of atmospheric carbon. This amount of CO_2 absorbed indicates that the forest is effectively participating in the reduction of greenhouse gases, including carbon dioxide. Indeed, according to 2010 data reported by the World Bank on greenhouse gas emissions, each inhabitant of Côte d'Ivoire emits approximately 300 kg of CO_2 per year. Relating this quantity to the entire population (24,507,337 inhabitants) in 2018, the Ivorian population would release 7,352,201,100 kg into the atmosphere, or 7,352,201.1 tonnes of CO_2 per year. The classified forest of Yapo-Abbé with the 1,201,988.71 tonnes of sequestered CO_2 contributes 16.34% to the reduction of greenhouse gases in Côte d'Ivoire. This testifies to the compensatory role of the forest massifs, in the emissions of carbon dioxide on the national and international plan; hence the importance of enriching, reforesting, reforesting degraded areas and managing them sustainably.

In this forest, the largest amount of sequestered atmospheric carbon dioxide comes from the Yapo block, with 49.44 t/ha. On the other hand, in the Abbé block, it is reduced to 31.54 t/ha. The significant amount of CO_2 sequestered by the Yapo block could be explained by its relatively good conservation. At the Abbé block, very disturbed by anthropogenic actions, there is a loss of 17.90 t/ha of sequestered CO_2, or 36.20%. This amount would be released into the atmosphere, thereby contributing to global warming. Disturbances in forest cover over large areas would increase the amount of carbon dioxide in the atmosphere. It is very likely that in the coming decades, these emissions will continue and certainly intensify in the classified forest of Yapo-Abbé if anthropogenic activities persist. IPCC (2013) estimates that 10 to 20% of the CO_2 released into the atmosphere derive from the change in land use, in particular from the degradation and reduction of the tropical forest. Berg and Karjalainen (2003) reported that logging operations for the removal of $95m^3$ release almost 3.5 tonnes of CO_2 into the atmosphere. The protection and reduction of logging in our forests, in particular classified forests, should significantly contribute to the reduction of greenhouse gas emissions due to deforestation and the degradation of Ivorian forests (REDD ±).

Conclusion

The evaluation and quantification of the biomass and the quantity of carbon sequestered by the woody species of the classified forest of Yapo-Abbé showed that this forest stores an estimated biomass at 22.26 t/ha for a sequestration of 10.45 t/ha of carbon. It highlights the role of classified forests in Côte d'Ivoire and of all forests in general in the carbon cycle and in the fight against greenhouse effects. Most of this gas is sequestered by the Yapo block, especially by its secondary forest biotope. The least anthropized and least disturbed environments have a greater storage capacity. The quantity of atmospheric carbon dioxide (CO_2) sequestered by the classified forest of Yapo-Abbé is on average 39.53 t/ha of atmospheric carbon, or 1,201,988.71 tonnes of CO_2 sequestered. The fallow caused by the exploitation of forest species and the installation of clandestine agricultural plots in this forest cause the release of more than 32% of carbon dioxide into the atmosphere. This study shows the harmful effects of anthropogenic activities on the significant increase in greenhouse gas emissions in the troposphere, and therefore of global warming. The conservation and sustainable management of our forests remains, in doubt, an imperative.

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