**CARBON SEQUESTRATION BY RHIZOPHORA RACEMOSA IN THE MANGROVES OF THE SOUTH-EAST OF AZAGNY NATIONAL PARK (CÔTE D’IVOIRE)**

**Abstract**

This study assesses the carbon sequestration capacity of Rhizophora racemosa in mangroves located on the southeastern periphery of Azagny National Park, Côte d'Ivoire. In the global context of combating climate change, mangroves, although they occupy a relatively small area, play a crucial role as carbon sinks. The methodology adopted is based on measurements of above-ground and below-ground biomass in several types of mangroves (conserved, degraded, slightly degraded and islands). These measurements were carried out using appropriate sampling plots and the allometric equation of Kauffman (2010). The results indicate that conserved mangroves have the highest storage capacity, representing 39% of the total carbon), followed by slightly degraded (30%), degraded (25%) and islands (6%) mangroves. The entire study area sequesters approximately 23,486.79 tCO₂/ha. These results show that mangrove degradation significantly reduces their carbon sequestration capacity, highlighting the importance of their conservation to mitigate greenhouse gas emissions.

**Keywords** : Carbon stock, *Rhizophora Racemosa* , Azagny National Park, Côte d’Ivoire

**INTRODUCTION**

Tropical forests, which account for 40–50% of terrestrial carbon, play a crucial role in the global carbon cycle (Pan et al.*,* 2011). Mangroves, although constituting a small part of these tropical and subtropical forests, are recognized as one of the most productive and biologically significant ecosystems (Giri etal., 2010). These forests play a major ecological and socioeconomic role, including filtering nutrients between land and ocean, protecting coastal areas, and providing essential resources for fisheries and fish production. They also contribute to air and water purification, while helping to combat climate change through their carbon sequestration capacity (Ajonina et al.*,* 2014; Chaudhari and Pachpande, 2015). In the context of climate change, the rise in concentrations of carbon dioxide and greenhouse gases, such as methane and nitrous oxides, is a key factor (Chave, 2019). Deforestation and degradation of tropical forests generate between 10% and 15% of annual global greenhouse gas emissions (van der Werf et al.*,* 2009). To address this, the United Nations Framework Convention on Climate Change established the REDD+ initiative (Reducing Emissions from Deforestation and Forest Degradation). This mechanism encourages developing countries to preserve their forests through financial compensation from carbon credits (Angelsen et al., 2013). However, this process requires precise quantification of carbon stocks, particularly in mangroves. In Africa, studies on mangrove carbon stocks remain insufficient. Available data focus mainly on terra firma forest ecosystems and concern the carbon of living trees and dead wood. Yet, mangroves, with their exceptional capacity to sequester carbon, are among the most effective natural solutions against global warming. Their leaves, stems and roots capture atmospheric CO2, while their sequestration capacity in sediments varies according to their age. On average, mangroves trap 1.4 gigatonnes of carbon per square kilometer per year (Laffoley and Grimsditch, 2009), and absorb 14% of global ocean sequestration annually, despite a land cover limited to 0.7%, or approximately 13.5 gigatonnes of CO2 . In Côte d'Ivoire, the carbon sequestration capacity of mangroves is poorly documented. It is in this context that this study was initiated. The general objective is to assess the carbon stock efficiency of Rhizophora racemosa trees in mangroves mainly in the departments of Jacqueville and Grand-Lahou. More specifically, the first step is to measure the aboveground biomass of r*acemosa* stands and calculate its carbon stock capacity.

**I. METHODOLOGY**

**1.1 Presentation of the study area**

The study was carried out in the south of Côte d'Ivoire, within the Grands-Ponts region, covering the departments of Jacqueville and Grand-Lahou. The study area is delimited by latitudes 5°09' to 5°16' north and longitudes 4°48' to 4°58' west (Lauginie, 2007). It covers an area of approximately 550,000 hectares and has an estimated population of 29,389,150 inhabitants according to the 2021 General Population and Housing Census (RGPH, 2021). The localities covered by the study include Tiemien, Toukouzou-Hozalem, Gboyo, Téffrédji, Avadivry, Niangoussou, Azagny and Gbéhiri.

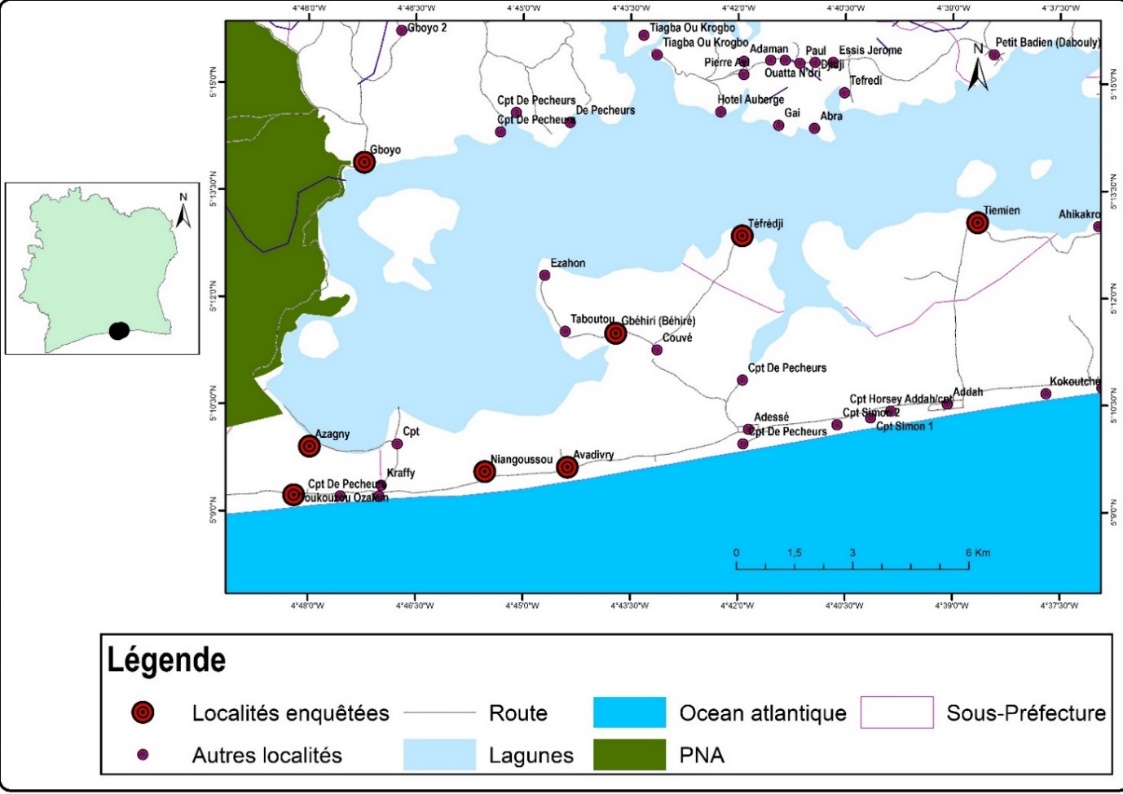
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Figure 1 : Location map of the southeastern periphery of the Azagny National Park (PNA)

**1.2 Data collection**

**1.2.1 Experimental device**

The study was conducted in the heart of mangrove forests, using carefully installed rectangular plots to address the unique characteristics of these ecosystems. Due to their exceptional density of stilt roots and their imposing heights, mangroves present access challenges, thus justifying the choice of this type of plots and their adapted dimensions. As part of this research, three categories of mangroves were distinguished: well-preserved mangroves, extending around the village of Azagny and along the park; degraded mangroves, located between Avadivry, Toukouzou and Gboyo; and finally, scattered mangrove islands, identified in the localities of Gbéhiri, Téffrédji and Tiemien. The dimensions of the plots, for their part, were determined according to the configuration of the stands. For areas where mangroves extend continuously over a long distance, 10 m × 10 m plots were established (see Figure 2). In contrast, in areas where stands were more discontinuous, such as in Tiemien, Téffrédji and Gbéhiri, 20 m × 10 m plots were preferred (see Figure 3), following the methodology recommended by Donato and Kauffman (2012). Within the park, the experimental design was adjusted to the specific configuration of the stands. The plots were positioned vertically and continuously, starting from the edges facing the village of Azagny and progressing towards the interior of the park, in accordance with the experimental design illustrated in Figure 4.

**Figure 2** : Placette continue (Donato et Kauffman, 2012)



**Figure 3** : Discontinuous plot at the level of mangrove islands (Donato and Kauffman, 2012)

10 m

**Figure 4** : Vertical plot of the Azagny National Park

**1.2.2. Data collection**

Data collection was carried out within each sampling plot according to a specific protocol. It began with the counting of mangrove individuals, followed by the measurement of the diameter at breast height (DBH) of the main stem, as well as the total height of the tree and crown, using a laser rangefinder. Diameters were recorded above the highest stilt root, as recommended by Clough and Scott (1989) and Komiyama et al. (2005). All trees reaching a minimum height of 1.30 m were identified, marked, and then measured. For the purposes of this study, it should be noted that the species Rhizophora racemosa locally has stilt roots rising above 1.30 m. Therefore, circumference measurements were made by climbing the tree, from the point where the trunk adopts a cylindrical shape, approximately 0.30 m above the highest stilt root.

**1.3 Data analysis**

**1.3.1. Estimation of plant biomass and carbon stock**

According to IPCC (2003), estimating carbon stock in forest ecosystems requires assessing biomass, which can be separated into aboveground biomass (stems, branches, leaves) and belowground biomass (roots). Concerning our study, it is a question of assessing only the rate of CO 2 sequestered by *Rhizophora Racemosa* . For this purpose, the rate of CO 2 sequestered was calculated in the different defined biotopes. There are several models for calculating biomass in tropical forests, wetlands and in particular mangroves. As an example, we have firstly the model of **Fromard *et al* .** (1998 **) which concerns the three** *Rhizophora* species *sp* , *Avicennia germinans* and *Laguncularia racemosa* . This model allows biomass to be estimated from DBH measurements. The application of this model should remain limited to DBHs less than 42 cm for *Avicennia germinans* and 32 cm for *Rhizophora mangle* **(Bourden, 2013).** This model cannot be used because not only are the DBH sometimes greater than 32 cm and 42 cm and it is not *Rhizophora Racemosa.* Second, the allometric equation used is that of **Komiyama *et al.* (2005)** . This model allows biomass to be estimated from DBH measurements and specific wood density. This density used is based on *Bruguiera gymnorrhiza* and *Rhizophora apiculata* Blume (Rhizophoraceae).Therefore, the application of this model recommends using the specific density of the species considered, but the study only concerns *Rhizophora Racemosa* . All these equations are not consistent for this study, which is why we used the allometric equation of **Kauffman (2010).** This equation is justified by the date which is recent (2010) compared to that of 2005 and the fact that the formulas are usable in relation to the data collected in the field. This formula translates into wood biomass, leaf biomass and root biomass. The wood biomass is used by the following formula: **AGB (wood)** = Vol (wood) \* Sg \* 1000 and **Flight (wood)** = 0.0000695(D)^2.64

**AGB (wood):** Wood biomass; **Sg:** Specific density (g/cm3) of Rhizophora sp=0.96; **Vol (wood):** Wood volume; **D:** wood diameter.

The biomass of the leaf is translated by the following mathematical expression: **AGB (Leaf) =** 10^ (-1.8571+2.1072\*log(D)

With **AGB (Leaf):** Leaf biomass and **D:** Wood diameter

Finally, the root biomass is expressed by the following formulas according to the diameter measurements:

D≤5, 0 cm AGB **(Root)** =AGB **(Wood)** \* 0, 101

D>5, 0≤10 cm AGB **(Root)** =AGB **(Wood)** \*0, 204

D>10≤15, 0 cm AGB **(Root)** =AGB **(Wood)** \*0, 356

D>15≤20, 0 cm AGB **(Root)** =AGB **(Wood)** \* 0, 273

D>20 cm AGB **(Root)** = AGB **(Wood)** \* 0, 210

Total biomass and total carbon were calculated by summing the above-ground and below-ground parts, resulting in the following formula: **AGB(Tot)** = AGB (wood) + AGB (leaves) + AGB (roots).

Total biomass is expressed in **(tot /ha).** Finally, the amount of carbon stored is estimated by multiplying the amount of biomass by the coefficient 0.5. In non-destructive studies, the most commonly used carbon coefficient is that recommended by the **IPCC (2014).** After estimating the amount of carbon (C) contained in a tree that of the equivalent carbon dioxide (CO2) was determined. The sequestered CO 2 is obtained by using the ratio of the molar masses of carbon and CO2. The mass of CO2 is calculated using the following expression: mCO 2 = C x (MCO 2 / Mc) mCO 2 = C x (44/12). In the formula, mCO2 denotes the amount of CO 2 sequestered in Kg. C denotes the amount of carbon stored in a tree in Kg. MCO 2 and Mc are respectively the molar masses of CO2 and carbon in g.mol-1. The estimation of biomass and carbon stock in the different mangrove biotopes allowed us to evaluate their capacity to sequester carbon according to their structure. In this analysis, the data being quantitative values with several variables, the comparison of the average values of the different parameters measured in the biotopes was carried out either by an ANOVA test (Analysis of variance) or by a Kruskal-Wallis test. The measured parameters are biomass and carbon sequestration potential. To do this, the normality of the data distribution was verified by the ShapiroWilk test. At the end of this test, if the data are not normally distributed, the Kruskal-Wallis test, which is a non-parametric alternative to ANOVA, is chosen for the comparison of means. Whenever the calculated probability was significant, the means are calculated through the Dunn test, in order to assess the significant differences that exist between them. If, on the other hand, the data distribution respects normality, the ANOVA test is chosen. The Tukey test is then applied for the comparison of means. The significance level is 5% (P ≤0.005).

**II. RESULTS**

**II.1. Average and total biomass of diameter classes between 5 and 10 cm (5 ≤ DHP < 10 cm).**

During this study, diameter classes between 5 and 10 cm were observed only in mangrove islets. The total biomass value is 3.48 t/ha for an average value of 1.74±0.57 t/ha (Table 1).

**Table 1** : Value of total and average biomass of juvenile individuals in mangrove islets

|  |  |  |  |
| --- | --- | --- | --- |
| **Diameter class** | **Mangrove biotopes** | **Total value (t)** | **Mean value (t)** |
| 5 ≤ DHP < 10 cm  Juvenile individuals | Mangrove island | 3.48 | 1.74±0.57 |
| **Statistical values**  **P** <0.0001 | | | |

**II.2. Average and total biomass of classes with a diameter greater than or equal to 10 cm ( DHP ≥ 10 cm).**

The average and total biomass of adult individuals were observed in the four (4) mangrove biotopes. We note that the total biomass values in degraded mangroves and slightly degraded mangroves are the same (3880.29 t) with average values that differ and are respectively 970.07±420.08 t/ha and 783.02±285.32 t/ha. The lowest value was observed in mangrove islands (791.66 t) and the highest in preserved mangroves (5003.49 t). Considering all biotopes, the total biomass is estimated at 12811.03 t/ha, or an average value of 3203.61±1305.35 t/ha ( Table 2).

|  |  |  |  |
| --- | --- | --- | --- |
| **Diameter class** | **Mangrove biotopes** | **Total biomass value (t/ha)** | **Average biomass value (t/ha)** |
| DHP≥10cm  Adult individuals | Mangrove island | 791.66 | 197.91±74.88 |
| Little degraded mangrove | 3880.29 | 783.02±285.32 |
| Degraded mangrove | 3880.29 | 970.07±420.08 |
| Preserved mangrove | 5003.49 | 1250.8±524.5 |
| **Statistical values P** <0.0001 | | | |

**Table 2** **:** Value of total and average biomass of adult individuals in all mangrove biotopes.

**II.3 Carbon and CO2 equivalent stock of the different mangrove biotopes in the South-East of Azagny National Park**

The lowest values of sequestered carbon and CO2 equivalentwere observed in the mangrove islands for juvenile individuals with respective values of 1.74 tC/ha or an average value of 0.87 ± 0.28 tC/ha. Finally, the CO2 equivalent has a value of 6.38 tCO2 /ha, or an average of 3.19±1.02 tCO 2 /ha. Unlike mangrove islands, the highest values of sequestered carbon are observed in preserved mangroves. The value is estimated at 2501.74 tC/ha, with an average of 1000.69 ± 262.27 tC/ha. The CO2 equivalent, meanwhile, is 917304.66 tCO2 /ha with an average of 3669.19 ± 961.65 tCO2 /ha (Figure 5 and Table 3).The results of the statistical analysis show that the average values of total biomass, sequestered carbon and the equivalent CO2 rate in all types of mangrove are significantly different (KW = 12.25; P = 0.002). The value of total equivalent CO 2 is 23486.79 tCO 2 /ha. For equivalent CO 2 the value is 6.38 tCO2 /ha, or an average of 3.19±1.02 tCO2 /ha.

**Figure 5** : Histogram of carbon stock values of mangroves on the southeastern periphery of Azagny National Park

**Table 3** : Comparison of CO2 equivalent of the different mangrove biotopes in the South-East of the Azagny National Park.

|  |  |  |  |
| --- | --- | --- | --- |
| **Diameter class** | **Biotopes** | **CO2 equivalent​** | |
|  |  | **Total values (t)** | **Average values** |
| **Diameter class** | **Biotopes** |  |  |
| 5 ≤ DHP < 10 cm  Juvenile individuals | Mangrove island | 6.38 | 3.19±1.02 |
| DHP≥10cm  Adult individuals | Mangrove island | 1448.33 | 362.81±137.28 |
| Little degraded mangrove | 5743.83 | 1435.53±523.08 |
| Degraded mangrove | 7113.84 | 1778±770 |
| Preserved mangrove | 917304.66 | 3669.19±961.65 |
| **Statistical values** | | P > 0.0001 | |

In the southeastern periphery of Azagny National Park, according to Figure 6, preserved mangroves store 39% of carbon. As for the less degraded and degraded mangrov6s, they store 30% and 25% of carbon respectively. Mangrove islands store only 6% of carbon in this area (Figure 6).

**Figure 6** : Diagram of the percentages of carbon stock in mangroves on the south-eastern periphery of Azagny National Park

**III. DISCUSSION**

Mangrove degradation has a significant impact on the structure of the flora, as evidenced by the average biomass observed. The low-degraded mangroves (LDM) have a biomass of 783.02 t/ha, or 626.42 tC/ha, compared to 970 t/ha, or 485.03 tC/ha for the degraded mangroves (DM). These results are much higher than those obtained during a study in Madagascar, in the Maintirano mangrove, where the biomass was 74 t/ha (37 tC/ha) for the low-degraded mangroves and 68 t/ha (34 tC/ha) for the degraded mangroves (Ajonina et al., 2013). Similarly, the values recorded in this study exceed those of the mangroves of the large Ganges River delta in Sunderbans, Bangladesh. The latter account for a total biomass of 278.0 t/ha, divided between an above-ground component of 83.7 t/ha (30.1%) and an underground component of 194.9 t/ha (69.9%). In Central Africa, degraded mangroves have an average biomass of 925.4 t/ha, while undegraded mangroves reach 1520 t/ha (Ajonina et al., 2013), results that are consistent with those obtained in this research. Furthermore, the data from this study are lower than those reported by Kauffman et al. (2011) in the Western Pacific (184 tC/ha) and Bourden (2013) in Amazonian mangroves dominated by Rhizophora sp (119 tC/ha). Mangrove biomass varies considerably depending on the species. For example, *Rhizophora apiculata* dominates in Malaysia with a maximum biomass of 460 t/ha, while in Florida, *Rhizophora manglae* generates only 7.9 t/ha. As for *Avicennia marina* , it has an aboveground biomass of 341 t/ha, according to Mackey (1993). In Côte d'Ivoire, research on the carbon stock of *Rhizophora racemosa* was conducted by Badji (2017), revealing values of 7.87 ± 4.77 tC/ha in Anna and 21.63 ± 16.58 tC/ha in Eloka-To. These results differ significantly from those obtained in the south-east of Azagny National Park. However, no carbon stock study on *Avicennia germinans* has yet been conducted. These observed variations in mangrove biomass can be explained by natural morphological differences within species of the genus Rhizophora, but also by specific ecological conditions. According to the model of Twilley et al. (1992), variations in biomass of this genus can be explained, apart from anthropogenic impacts, by climatic and edaphic factors influenced by the latitudinal gradient (Guiral, 1999). The various allometric models used and sample sizes can also influence biomass estimates. Conserved mangroves located on the southeastern periphery of Azagny National Park show a remarkable capacity to store carbon, recording a capacity 10 times greater than that of mangrove islands. These results also exceed those obtained by Sié Ouattara et al. (2021), who observed an average of 35.08 ± 48.72 tC/ha for the secondary forest of the Yapo-Abbé forest massif. In comparison, the mangrove islands in this study store 5 times more carbon, and the well-preserved mangroves 28 times more.

**CONCLUSION**

At the end of this study, we note that the total biomass value of the southeastern periphery of the Azagny National Park is estimated at 12,811.03 t/ha. The highest biomass value and carbon rate was recorded in the conserved mangrove, estimated at 5,003.49 t/ha, with a carbon stock of 2,501.74 tC/ha. Conserved mangroves store 5 times more carbon than mangrove islands and 28 times more carbon than mainland forests. The degradation of the mangrove therefore has an impact on its structure. Protecting them would be a means of mitigating global warming.

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