Estimation Of The Carbon Stock Of Rhizophora Racemosa G.F.W.Mey. (Rhizophoraceae) In The Mangroves Of Azagny And Îles Éhotilé National Parks (Southern Côte d'Ivoire).

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Abstract: The assessment of the carbon stock of ecosystems is one of the main recommendations of the United Nations Framework Convention on Climate Change in 1994. Allometric equations, which represent a precise method of carbon quantification, were used to assess the carbon stock of mangroves in two national parks, Azagny and Îles Ehotilés. To this end, forty (40) plots, twenty (20) in each park, were set up in which measurements of diameter at breast height and height at the top were taken. In the Ehotilés Islands National Park, the biomass values are higher than those measured in the Azagny National Park. Obviously, carbon stocks and CO_2 emission rates follow the same trend. This difference could be explained by the fact that the mangroves in these two parks do not experience the same level of anthropogenic aggression.

Keywords: Biomass, Carbon, Mangroves, Protected areas, Côte d'Ivoire.

1. Introduction

Since the beginning of the use of fossil fuels in industry, anthropogenic carbon emissions into the atmosphere have increased considerably [17]. The various projections for the evolution of these concentrations during the 21st century show no decrease, despite the growing development of alternative energies to fossil fuels. Industrial activities are generating an increase in greenhouse gas emissions and, consequently, a marked rise in their concentrations in the atmosphere. These anthropogenic emissions increased by 80% between 1970 and 2004 [18]. The use of fossil fuels and deforestation are the main causes of CO_2 emissions into the atmosphere. In response to the problems caused by excessive CO_2 emissions, the Kyoto Protocol was adopted under the United Nations Framework Convention on Climate Change (United Nations, 1998). This treaty aims to stabilise and reduce greenhouse gas emissions into the atmosphere by the signatory countries. The partial pressure of CO_2 in the atmosphere is essentially controlled by physico-chemical and biological processes of carbon storage and transfer between the various existing pools or reservoirs [2], [16]. Many scientific studies have focused on the mechanisms governing carbon flows at both spatial and temporal scales. These studies are mainly based on the potential of these ecosystems to store or release CO_2 into the atmosphere. Furthermore, it is necessary to understand and quantify the role of these ecosystems in the global carbon cycle in order to estimate and predict their responses to known global environmental changes. Among these ecosystems, coastal zones are of particular importance. They represent about 7% of the global ocean surface and are considered the most biologically active areas of the biosphere [15]. Coastal areas are characterised by a great diversity of ecosystems such as estuaries, macrophytic communities, mangroves, coral reefs and continental shelves. Among these ecosystems, mangroves are recognised as an excellent carbon sink [9]; [21]. This specificity results from the combination of several factors, including a very high primary production [4], a high sequestration capacity [5], and very anoxic soil conditions that decrease the rate of organic matter degradation (Kristensen et al., 2008). Mangroves are known for their dual capacity as a sink for CO_2, storing it in organic form in both biomass and sediments, and as a source of dissolved and particulate organic carbon for adjacent coastal waters [4] ; [20]. It therefore seems natural to think that mangroves are a major component of the global carbon cycle. However, they remain an understudied and relatively unknown ecosystem, particularly in terms of biogeochemical cycles. In the case of Côte d'Ivoire, various studies have been conducted on mangroves [11], [1]; [12]; [13]. These studies show a progressive decrease in mangrove areas in Côte d'Ivoire. However, these studies have not yet addressed the issue of carbon flows between mangroves and contiguous ecosystems. It is thus opportune to know the contributions of mangroves present in Côte d'Ivoire in carbon sequestration in order to apprehend the potential impacts of the destruction of mangroves in the atmospheric releases of CO_2. The objective of this work is to estimate the carbon stocks in the mangroves present in the Azagny and Éhotilés Islands National Parks.

2. Material and methods

2.1. Study site

The intervention area includes the Grand-Lahou lagoon complex with the Azagny National Park and the Aby-Sud Lagoon with the Îles Éhotilé National Park (Figure 1).

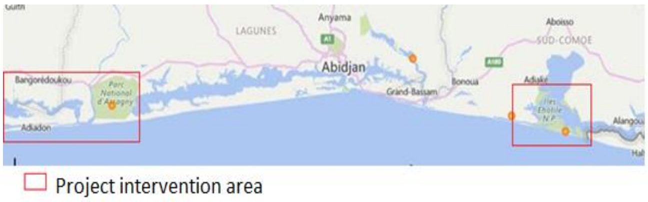

Figure 1: *Presentation of the study area*

The lagoon complex of Grand-Lahou includes the lagoons Nyouzomou, Tagba, Maké and Tadjo. It has an area of about 230 km^2 [11]. In this part of the ivorian coastline, mangroves extend from the Azagny canal to Ebonou. The Azagny National Park (ANP) is located on the eastern bank of the Bandama river mouth. It lies between latitudes 5°9' and 5°17' North and longitudes 4°47' and 4°57' West. The park is bounded to the west by the Bandama River, to the south-east by the Ebrié Lagoon and to the south by the Azagny artificial canal dug in 1920 [3]. The most widespread forms of vegetation are forest formations. These can be found in several forms. Dense evergreen forests are found in the northern parts of the park. Swamp forests are generally dominated by Hallea ledermannii. There are also littoral forests, also known as coastal forests [22]. These forests are characterised by the presence of species such as Sacoglottis gabonensis, Cola lateritia, Uapaca guineensis, Lophira alata, Chrysobalanus icaco [26]. Mangroves and other aquatic formations border lagoons and rivers, the banks of the Azagny canal as well as the backwaters within the park where they can form floating mats [24]. The characteristic species of the park's mangroves is Rhizophora racemosa G.F.W.Mey (Rhizophoraceae). The Aby lagoon complex which contains the Ehotilé Islands National Park (EINP) is located between longitudes 2° 51' and 3° 21' on the one hand and latitudes 5° 05' and 5° 22' on the other. The Îles Ehotilés National Park is located in the Aby-Sud lagoon, in the department of Adiaké, in the southeast of Côte d'Ivoire. It is located between 3°16'42" and 3°18'52" West longitude, and between 5°9'24" and 5°11'13" North latitude. Several localities belonging to the sub-prefectures of Adiaké, Assinie Mafia and Etuéboué surround it. The Park consists of six islands with a total area of 550 ha. of these islands, five are located in the deltaic zone of the Aby-Sud: Assokomonobaha (327.5 ha), Baloubaté (75 ha), Niamouan (47.5 ha), Méha (45 ha), Elouamin (22.5 ha); and one Bosson Assoun (32.5 ha), located in the Tendo Lagoon, off the village of Mbraty. The mangrove exists in dense stands especially around the islands in the deltaic zone. It extends to the east towards Tendo Lagoon. In the northern part, although the tide is felt, only a few scattered mangrove trees remain, "smothered" by the rainforest.

2.2. Data collection

The surface survey method was used to characterise the vegetation in the mangroves. The surface survey, also known as the « quadra technique », consists of identifying and measuring the diameters of all individuals of plant species (lianas, shrubs and trees) of more than 5 cm in diameter at breast height (DBH) on fixed surface plots. In this study, the surface survey consisted of delineating 20 survey plots in the mangroves in each project area. Each plot was 25 metres long and 20 metres wide, i.e. an area of 500 m².

2.3. Analysis of the data

2.3.1. Estimation of above-ground biomass of woody plants

Biomass refers to the total amount or mass of living matter of all species present in a given environment. [17] defines biomass as the total mass of living organisms within a given area or volume. In forestry, plant biomass comes in two forms: epigeous biomass and hypogeous biomass. The above-ground biomass is the mass of the above-ground part of the plants, while the below-ground biomass is the mass of the plants in the underground part. Biomass is expressed in kilograms, in units of tonnes (t) or in Megagrams (Mg), (1Mg = 1t = 103 kg). Biomass is used to estimate the potential amount of carbon that can be released to the atmosphere as CO_2 if the forest area is destroyed and the amount of carbon that can be captured through plantations or reforestation. Woody biomass can be calculated using allometric formulae defined by authors such as [8] and subsequently translated into carbon stock. The method used is that developed by [7]. In this method the total biomass per tree is calculated from an allometric model. This model can be used for precise "permanent plot" type inventories but also from raw forest inventory data on the condition that the data are corrected by diameter class by making assumptions on the continuous diameter distribution of the stand [10]. The allometric equations developed by [8] are the most powerful and robust. The use of these equations leads to an accuracy of 90% in biomass estimates at the 0.25 ha scale in tropical rainforests [8]. The equation of [8] used in this study is as follows:

$$\mathbf{AGB = 0{,}0673 \times (\rho D^2\ H)^{0{,}976}}$$

where AGB, ρ, D and H are respectively the above-ground biomass (in kg), the specific wood density (in g.cm-3) which is 0.92 g.cm3 for Rhizophora racemosa, the tree diameter (in cm), the total tree height (in m).

2.3.2. Estimation of total standing woody biomass

The estimation of the root biomass of standing woody plants will follow the guidelines established by [17]. According to these, the root biomass equivalence of standing woody plants is found by multiplying the value of above-ground biomass (AGB) by a coefficient R, the value of which is estimated to be 0.5. The below-ground biomass is half of the above-ground biomass. The total biomass is the sum of the above-ground biomass and the below-ground biomass. The total biomass (TB) of standing woody plants will then be estimated by summing the two values above:

$$\mathbf{TB = AGB + BGB}$$

With: TB = Total Biomass (Kg), AGB = Above Ground Biomass (Kg); BGB = Below Ground Biomass (Kg)

2.3.4 Carbon stock and carbon equivalent

Carbon stock is the amount of carbon in a reservoir or system that can accumulate or release carbon [17]. In the context of forests, it is the amount of carbon stored in a forest ecosystem, mainly in biomass and soil, but also to a lesser extent in dead wood and litter. The carbon stock expressed in tonnes of carbon per hectare (tC/ha) is obtained by multiplying the biomass by the biomass carbon rate. The carbon content of biomass varies according to species, organ and growing conditions [7]. The default value proposed by [17] in climate change studies is 50% and 47% according to [17]. The carbon stock is half of the total biomass. From the carbon stock, the carbon equivalent is deduced by the following relationship:

$$\textbf{Carbon equivalent} = \textbf{Carbon stock (tonnes)} \times 3.67$$

2.3.5. Modelling the biomass recovery trajectory

The model proposed for this study was written following a Bayesian approach. Bayesian modelling is based on Bayes' statistical theory. This modelling framework allows for the combination of information from data with a priori knowledge from either previous studies or expert opinion, in order to obtain a posteriori information [29]. The biomass recovery trajectory (BRT) was modelled with the following model, written in the Stan language [6]. This is a probabilistic programming language for specifying statistical models [6]. It provides full Bayesian inference for continuous variable models. Bayesian inference is a method of inference (an operation that moves from one or more assertions, asserted as true, called prior, to a new assertion that is the conclusion, or posterior) that allows the probability of an event to be inferred from those of other events that have already been evaluated [25]. Following Bayesian inference, the maximum likelihood is as follows:

$$AGBt = AGBmax\ (1 - e\text{-}0,(t/15,29)\ \hat{}\ 1,72)$$

AGBt is the above-ground biomass at age t, AGBmax is the maximum asymptotic biomass (estimated based on the densest plot across all surveys in this study), -0.089 is the value of the observed recovery rate (λobs) after inference, 15.29 is the value of the inflection point θ after inference, and 1.72 is the value of the parameter β that gives flexibility on the relationship between recovery rate λ and time t.

2.3.6 AGB recovery rates

The observed biomass recovery rates were calculated using the maximum likelihood parameterised model and the AGBp, t biomass values of each surveyed plot. The biomass flux expressed in tonnes per hectare per year (t/h/yr) was subsequently calculated using the following formula

$$\textbf{Biomass flux} = AGB_{t2} - AGB_{t1}$$

where AGB_{t2} = predicted biomass at time t2 and AGB_{t1} = predicted biomass at time t1.

3. Results

3.1. Geographical areas of mangroves in Azagny National Park

Mangroves are concentrated along the Azagny canal in the south of the park along the canal. They are often isolated blocks with areas ranging from 0.1 to 57 hectares. The total area covered by mangroves within the park is estimated at 429.16 hectares, or 1.96% of the park's total vegetation cover. The mangrove areas outside the park are found along the edges of the Tagba lagoon, to the west of the park. The journey along the lagoon from the landing stage at Braffedon to the village of Lipiliassé allowed us to observe these mangroves along the lagoon.

3.2. Geographical areas of mangroves in the Îles Ehotilés National Park

The field survey was carried out around the various islands of the park. Mangroves are present on all the islands visited. The areas covered by mangrove blocks vary between 0.1 hectares and 42.36 hectares. These various tenants scattered over the Îles Éhotilé cover a total area of 195.99 hectares, i.e. 35.63% of the entire park.

3.3. Estimation of mangrove biomass in Azagny and Îles Ehotilés National Parks

The above-ground biomass measured in the Azagny National Park (ANP) is estimated at 1060.8 tonnes at the level of the inventory plots and 53 tonnes per hectare (Table 1). From this above-ground biomass, the below-ground biomass is deducted, which is 26.5 tonnes per hectare. The total biomass of mangroves in the ANP is estimated at 79.6 tonnes per hectare. The average biomass values for the Îles Ehotilés National Park (IENP) are given in table I. The differences between the mean biomass values are significant for both parks (U^2=20; p-value < 0.0001).

***Table 1:** Mean biomass values in the two parks*

	ANP	IENP	Statistics of the test
Average Above Ground Biomass (AGB) (t/ha)	53.04±1.9	116.5±0.6	U=20 ; p-value < 0.0001
Average Below Ground Biomass (AGB) (t/ha)	26.52±0.95	58.24±0.29	U=20 ; p-value < 0.0001
Average total biomass (TB) (t/ha)	79.6±2.85	174.7±8.75	U=20 ; p-value <0.0001

3.4. Carbon and CO_2 stocks of mangroves

The estimated carbon stock in the ANP is 39.78 tonnes per hectare in the mangrove plots, or a total of 795.6 tonnes of carbon in the park's mangroves. The CO_2 stored in the mangroves of the ANP is 146 tonnes per hectare in the mangrove survey plots (Table 2). It can therefore be said that the ANP stores about 2919.85 tonnes of CO_2 in the mangroves alone. For the IENP, the surveyed areas yielded an estimate of 87.36 tonnes of carbon per hectare. All the mangroves in the Îles Ehotilés therefore have a storage capacity of 1747.18 tonnes of carbon. These mangroves therefore have a quantity of 6412.17 tonnes of CO_2 stored. A comparison of the average carbon stock and carbon dioxide stored per inventory plot was carried out between the Azagny and Îles Éhotilés National parks. The Mann-Whitney test shows that there is a significant difference between these mean values.

Table 2: *Carbon and carbon dioxide stock values in the two parks*

	ANP	IENP	Statistics of the test
Total St C (t)	795.6	1747.18	
Average St C (t/ha)	39.78±1.43	87.36±0,44	U=0 ; p-value < 0.0001
Total St CO_2 (t)	2919.85	6412.17	
Average St CO_2 (t/ha)	146±5.24	320.61±1.61	U=0 ; p-value < 0.0001

3.5. Evolution of biomass in mangroves

Based on the scenarios developed by Carpentier et al. (2017), the following predictions are obtained. The gain in total above-ground biomass in Azagny National Park is estimated at 12879.38 tonnes in a 2.5 year period (Table 3). This prediction amounts to 12886.09 tonnes over a period of 5 years. The biomass gain over a 2.5 year interval is 4.53 tonnes. The biomass flux is therefore 90.51 tonnes/hectare/year in the mangroves of Azagny National Park. The total biomass gain in Azagny National Park is estimated to be 26756.46 tonnes over the whole park in 2.5 years. When the same predictions are made over a 5-year period, the biomass gain is 26770.4 tonnes over the whole park's mangroves. The biomass gain over a 2.5 year interval is 9.4 tonnes for the park. The biomass flux obtained is 188.04 tonnes/hectare/year in the mangroves of the Îles Éhotilés National Park.

4. Discussion

The above-ground biomass values obtained for the two parks studied are higher than those obtained by different authors for other regions of the humid tropical world, such as [14] in Panama (30 t) and by [28] in Guatemala (40 t). The growth of above-ground biomass is generally due to floristic and structural evolution. During this evolution, there is first a predominance of pioneer species that settle and grow rapidly after a cultivation episode.

Table 3: *Total above-ground biomass flux values in the two parks*

Période (years)	AGB_{max}	AGB_t ANP	AGB_{max}	AGB_t IENP
1	56.8	12874.85	118	26747.05
1.5	56.8	12876.41	118	26750.28
2	56.8	12877.92	118	26753.42
2.5	56.8	12879.38	118	26756.46
3	56.8	12880.8	118	26759.41
3.5	56.8	12882.18	118	26762.28
4	56.8	12883.52	118	26765.07
4.5	56.8	12884.82	118	26767.77
5	56.8	12886.09	118	26770.4

These species constitute the most important part of the biomass [19]. As the level of floristic and structural evolution increases, the number of pioneer species decreases. At the same time, diverse species including longer-lived species capable of reaching larger diameters such as Piptadeniastrum africanum, Parkia bicolor, Ceiba pentandra, Balanites wilsoniana increase their biomass to equal and then exceed that of the pioneer species [19]. Moreover, the fact that the total biomass is higher in the Îles Ehotilés National Park (IENP) than in the Azagny National Park (ANP) could be explained by the fact that the mangroves of the IENP are more preserved than their counterparts of the ANP. Indeed, in the PNIE, mangroves are concentrated on isolated islands that are difficult to access by local populations. This isolation would be a factor in the conservation of mangroves in the IENP, whereas in the ANP the mangroves, although scattered, are very close to the villages surrounding the Park. As a result, they are more subject to anthropisation. Thus, for the communities living along the ANP, the exploitation of natural resources in this protected area is a matter of survival. Their livelihoods depend on free and easy access to a wide variety of biological resources for food, fuel, medicine, materials and economic security. Our findings are consistent with those of [27]. In his work, the author argues that people in localities near or within 15 km of a protected area are sources of threats to the sustainability of protected areas. These protected areas become their source of medicinal food and construction products. However, the fact that the Îles Éhotilés National Park shows higher values per hectare than the Azagny National Park could be linked to the greater harvesting of energy wood in the mangroves of the Azagny National Park.

5. Conclusion

The mangrove ecosystem is a carbon store in its own right, whether through its vegetation or its soil. This ecosystem also provides humans directly and indirectly with various benefits, the most important of which is its carbon storage capacity. A study was carried out in the mangroves of two national parks in Côte d'Ivoire, Azagny and Îles Ehotilés, and highlighted the role of these mangroves in carbon sequestration. For this purpose, the equations of [8] were used. The mangroves in the Îles Ehotilés National Park have an average total biomass of 174.7±8.75 t /ha, which represents 1747.18 t of carbon and an emission rate of 6412.17 t of CO_2. In Azagny National Park, the average total biomass is 79.6±2.85 t/ha, which represents 795.6 t of carbon and an emission rate of 2919.85 t of CO_2. These lower values in Azagny National Park indicate that protection measures should be further emphasised in this park.

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