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Bombetoka mangrove and climate: carbon stored in living *Avicennia marina*

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Abstract :

Mangroves offer many services, the most important of which is the mitigation of climate change, more specifically those of Bombetoka. These are almost monospecific, with the *Avicennia marina* species occupying the entire space. This species is much used by humans and even wildlife. The aim is to determine the carbon storage capacity of the living *Avicennia marina* species. In the field, botanical surveys were carried out in this ecosystem to identify the location of surveys in the mangroves. Biometric measurements were taken using ecological surveys to identify the species present and their biometric measurements. To assess carbon sequestration potential, the Malagasy Rakotomavo method was applied to determine the biomass of the living *Avicennia marina* species. Satellite images were used to locate the study area. As results, for a survey made, the species *Avicennia marina* living in the mangroves of *Moraharivа* and *Tambohobe* have a high biomass. This is due to the presence of large-diameter and very tall individuals, as well as the number of these individuals. For a given area, 0.01 hectare, there are fewer individuals present. As a result, the biomass is high for mangroves such as *Tambohobe*, *Marofisonko* and *Anglais*. So, to achieve sustainable management of mangroves and mitigate climate change, we need to make people aware that these mangroves are very valuable, and apply and update the laws on mangroves.

Keywords: *Avicennia marina*, Bombetoka, biomass, carbon, climate change, sustainable development

I. Introduction

Madagascar has a surface area of 592,000 km (Ministry of Water, 2006). The Big Island, the fifth largest island in the world according to Allorge (2007), is a remnant of the former great austral continent of Gondwana (IUCN, 2007 and Rabinowitz et al. 1983). Mangroves occupy 3,270 km^2 of this surface area, including tans and vegetation (Rasolofo 1997), i.e. 2% of the world's mangroves. The west coast has 98% of the mangrove area and the remaining 2% is on the east coast of the country (Andriamanantena *and al.*, 2018 and FAO, 2003).

Mangroves are very important for planet earth. They offer many services, the most important of which is the mitigation of climate change, more specifically those of Bombetoka. This maritime marsh is virtually monospecific, with the species *Avicennia marina* occupying the entire space. This species is much used by humans and even wildlife. So the question arises: "Does *Avicennia marina* store carbon? To answer this question, the study involves assessing the carbon stock of the *Avicennia marina* species living in the Bombetoka maritime marsh. The objectif is to determine the carbon status of the living *Avicennia marina* species.

II. Materials and methods

Materials and methods were used during the study.

II.1 Materials

The materials are divided into two categories: biological materials and study materials.

II.1.1. Biological materials

The species *Avicennia marina* is classified as :

Kingdom	: Plantae
Sub-region	: Tracheobionta
Division	: Magnoliophyta
Class	: Magnoliopsida
Order	: Lamiales
Family	: Avicenniaceae
Genus	: *Avicennia*
Species	: *Avicennia marina* (Forssk.) Vierh.
Common names	: Palétuvier blanc, *afiafy*

Source: APGIII, 2009

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II.1.2 Study equipment

The following equipment was used during the study, the most important of which were the stilt-walker, metric tape, ropes, flags, markers, decametre, stakes, Global Positioning System (GPS) and survey sheet.

II.2 Methods

II.2.1. Bibliographic and webographic analyses

Bibliographic and webographic analyses were carried out. In addition, an initial botanical survey (pirogue, foot, car) was carried out. These two methods are all preliminary to this study. The aim of this study is to obtain information about the subject under study, the location of the study area and the methods to be used. In this case, documents and books as well as websites were consulted in the documentation centre as well as by visiting websites relating to the themes studied. (Andriamanantena, 2019)

II.2.2. Choice of study sites

The Bombetoka maritime marsh is rich in mangroves. This mangrove area belongs to the Boeny Region, in the north-west of Madagascar, more precisely on the west coast and in the heart of the Betsiboka River. This marsh is surrounded by three districts (Figure 1, below):

- To the north-east, the district of Mahajanga II
- From east to south-west, the district of Marovoay
- And to the west, the district of Mitsinjo (Andriamanantena, 2019).

The choice of location for the surveys was the same for all the areas selected. This choice was made according to accessibility, homogeneity, the level of degradation of the mangrove, the physiognomy of the vegetation, the location of the pseudo-islets in relation to the land and the sea and their duration of appearance, the position of the hydrography (near the coast, rivers or channels), the place of reforestation, the tides and the proximity or absence of villages. According to these criteria, two different environments on the foreshore and ten pseudo-islands were selected, including Anglais, *Batribe*, *Lagera*, *Tsalopy*, *Manitomany*, *Tavoahangy*, *Marofisonko*, *Betaikary*, *Tambohobe* and *Ambanikely*...

II.2.3. Ecological surveys

Transects of the Duvigneaud and Braun-Blanquet plots were carried out.

The survey sites were chosen according to accessibility. The transect follows a line 10 m x 100 m extended through the vegetation, subdivided into contiguous squares of 10 m x 10 m. (Duvigneaud, 1980 and 1946). It is perpendicular to the channel and the sea. The plot method makes it possible to assess the growth dynamics of individuals and also to determine the species associated with the target species in a homogeneous area over a surface of (50m x 20m) subdivided into 10 plots of 10 m x 10 m (Braun-Blanquet *and al*., 1952).

II.2.4. Carbon stock assessment

The quantity of carbon between the atmosphere and a forest ecosystem cannot be measured directly. To know the carbon sequestered by the forest for a given time, it is necessary to measure the quantity present in the biomass over the whole of the survey carried out at each site and over an area of 0.01 ha. In addition, ecological factors such as individual density, surface area and Diameter at Breast Height are used to analyse the potential of the living *Avicennia marina* species.

II.2.4.1. Calculation of the biomass of living wood

The carbon stock in mangroves is calculated using the dendrometric characteristics of individuals, such as diameter at breast height and total height. To estimate the biomass of living wood, the allometric equation developed by Rakotomavo in 2018 was applied, the formula of which is (Rakotomavo, 2018):

$$\boxed{\text{Biomass (t/ha)} = 0{,}1340 \times \text{DBH}^{2{,}399}}$$

With :

0.1340: Shape coefficient

DBH: Diameter at breast height (cm)

III.2.4.2. Calculation of carbon stock

Calculation of the biomass made it possible to determine the carbon stock by applying the following relationship (WINROCK INTERNATIONAL, 2005):

$$\boxed{\text{Carbon rate} = \text{Biomass} \times 0{,}5}$$

This stock is expressed in tonnes per hectare (t/ha).

III. Results

III.1 Carbon potential

III.1.1. By survey

The biomass of living wood was calculated from the floristic inventory data for each site. Table I shows the total biomass of living wood and the carbon rate per survey conducted at each site, with their standard deviation and the average quantity of these variables.

According to Table I, with a total survey area of 1.13 hectares, the biomass of live *Avicennia marina* species is 6.94.10+01 tonnes per hectare and the total value of carbon stored is 3.47.10+01 tonnes per hectare. The *Morahariva* mangrove has the highest biomass at 6.50.10+1 tonnes per hectare. This mangrove also has the highest capacity to retain and store carbon, with 3.25.10+02 tonnes per hectare. This environment has the largest area surveyed, i.e. 0.69 ha, followed by the *Tambohobe* mangrove with an area of 0.05 ha, a total biomass of 1.32 t/ha and a total carbon stock of 6.58.10-01 t/ha.

III.1.2. For an area of 0.01 ha

The biomass of living wood and the carbon rate in a well-defined and precise area are presented in Table II.

According to this table II and as the survey area is well defined and similar, the mangrove at *Tambohobe* has the highest biomass, which is 6.79.10-02 tonnes per hectare. This mangrove also has the highest capacity to retain and store carbon, at 3.39.10-02 tonnes per hectare.

III.2 Biomass potential

III.2.1. By survey conducted

Figure 2 shows the impact of ecological factors such as the density of living *Avicennia marina*, the total area of the survey and the diameter at breast height of each individual on the biomass values obtained.

The decreasing straight lines in Figure 2.1 and the increasing straight lines in Figure 2.2 indicate that the greater the surface area of the survey, the greater the abundance of individuals. This trend leads to an increase in biomass for the large survey, including the *Morahariva* mangrove, followed by *Tambohobe*. By relating biomass and dbh in Figure 2.3, the mangrove sites with the largest individuals have the highest biomass.

III.2.2. For an area of 0.01 ha

Since the area is very precise, i.e. 0.01 ha, Figure 3 shows the impact of ecological factors such as the density of living individuals of the species *Avicennia marina* and the mean diameter at breast height of each individual on the biomass values obtained.

Compared with the trend results in Figure 2, the decreasing line in Figure 3.1 shows that the lower the number of individuals, the higher the average biomass and the carbon stock depends on this biomass value obtained. If we relate this to the average dbh, even if there are fewer individuals, the average biomass is still high (Figure 3.2). These mangroves are *Tambohobe*, *Marofisonko* and Anglais.

IV. Discussion

Mangroves are very different from forests. Access to them is difficult. Even with this difficulty, research into mangroves is constantly increasing, as in Madagascar with the studies by : Andriamanantena (2019), Andriamalala (2007).........

With regard to ecological methods, like all forestry studies, the Duvigneaud method and the Braun-Blanquet method were used to acquire data in the field.

In order to analyse and assess the carbon stock in the mangroves of the Bombetoka maritime marsh, the Rakotomavo equation was applied in 2018. This equation is more recent than the other models previously used. This analysis provides results on the biomass of living wood and the carbon stored in the *Avicennia marina* species. As the Bombetoka maritime marsh is virtually monospecific, this species was chosen for the assessment.

Different results were observed between the carbon potential per survey carried out and those for an area of 0.01 ha. These differences relate to the parameters to be monitored in the field during the choice of study site, such as accessibility above all. Access will determine the length of the survey. The very high biomass on these two results depends on the characteristics of the individuals in the mangroves and the length of the survey. These individuals have a large diameter and are taller than at the other sites. For this length of survey, the number of individuals varies. For a given area of 0.01 ha, the lower the number of living *Avicennia marina* individuals, the better they develop. This development is observed in the following mangroves: *Tambohobe*, *Marofisonko* and Anglais.

V. Conclusion

In conclusion, mangroves are a very complex ecosystem. The Bombetoka maritime marsh has very specific characteristics. The study focuses on assessing the carbon stock of the living *Avicennia marina* species. The biometry taken and the survey area are highlighted. In addition, this study showed that the values of these mangroves are to store carbon.

To know the carbon stored in the living species, the application of a proven allometric equation is necessary. Moreover, the most important is the most recent equation. By properly specifying the surface area at each site, differences are observed in relation to the quantification of carbon in a survey carried out according to access and other field conditions.

Mangroves play an important ecological and socio-economic role. It sequesters carbon and thus contributes to climate change mitigation. So, in order to achieve sustainable development, it is necessary to enrich mangroves and raise people's awareness of the benefits of mangroves. Data on the carbon stock in mangroves needs to be updated.

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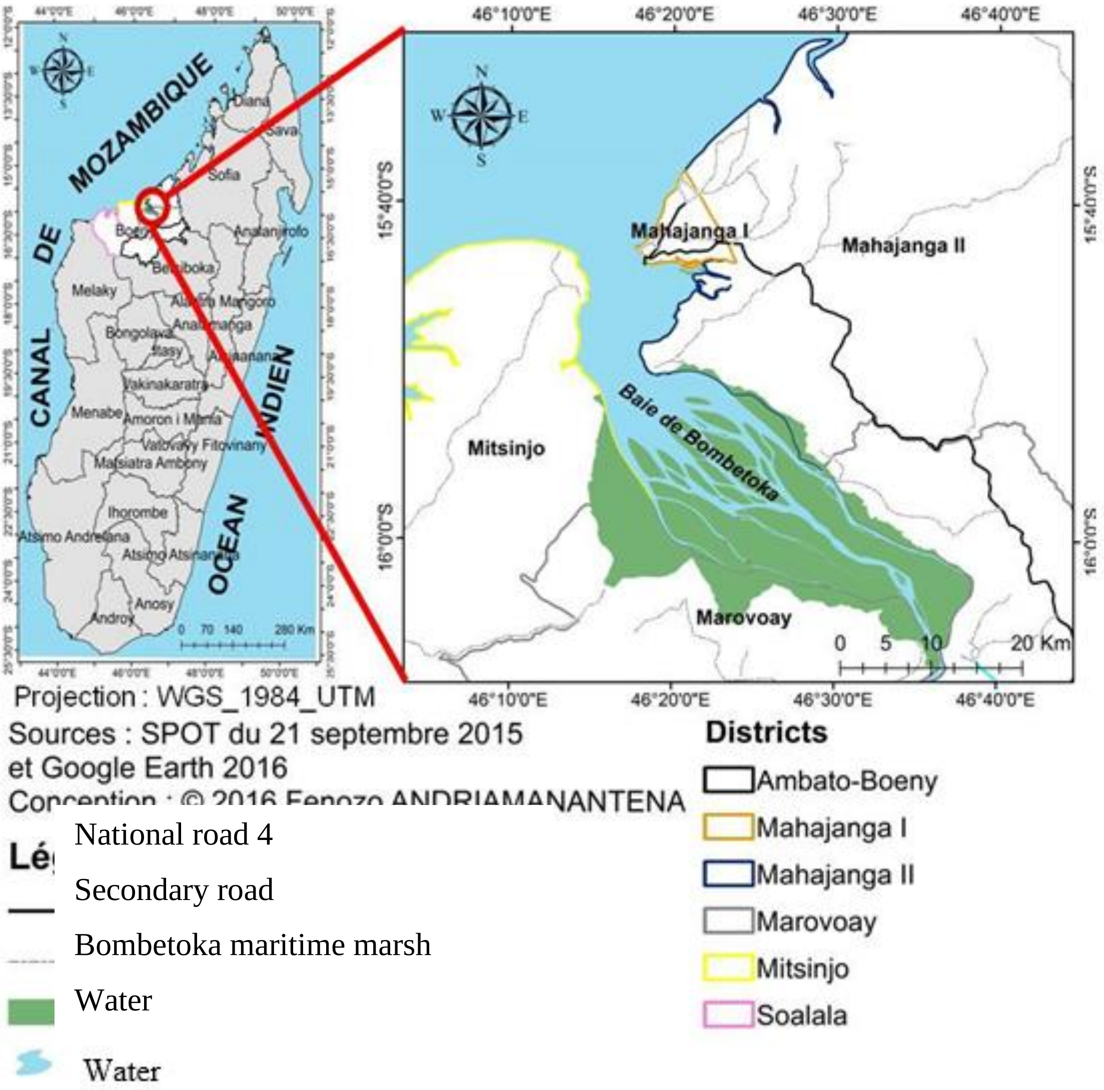

Figure 1. Location of the Bombetoka salt marsh

Table I. Total amount of biomass and carbon in the entire survey by each site on live *Avicennia marina* species

Sites	Area (ha)	Biomass of living wood (t/ha)	Standard deviation	Carbon content (t/ha)	Standard deviation
Ambanikely	0,01	1,59.10^{-02}	4,44.10^{-04}	7,96.10^{-03}	2,22.10^{-04}
Anglais	0,07	3,10.10^{-01}	9,70.10^{-03}	1,55.10^{-01}	4,85.10^{-03}
Batribe	0,1	1,06	2,98.10^{-03}	5,32.10^{-01}	1,49.10^{-03}
Bemangoraka	0,04	2,90.10^{-01}	4,02.10^{-03}	1,45.10^{-01}	2,01.10^{-03}
Betaikary	0,02	5,01.10^{-02}	9,20.10^{-04}	2,50.10^{-02}	4,60.10^{-04}
Lagera	0,1	1,18	3,67.10^{-03}	5,92.10^{-01}	1,83.10^{-03}
Manitomany	0,01	1,40.10^{-02}	8,23.10^{-04}	6,99.10^{-03}	4,11.10^{-04}
Marofisonko	0,02	1,21.10^{-01}	7,41.10^{-03}	6,05.10^{-02}	3,71.10^{-03}
Morahariva	0,69	6,50.10^{+01}	5,73.10^{-01}	3,25.10^{+01}	2,86.10^{-01}
Tambohobe	0,05	1,32	4,42.10^{-02}	6,58.10^{-01}	2,21.10^{-02}
Tsalopy	0,02	3,22.10^{-02}	5,08.10^{-04}	1,61.10^{-02}	2,54.10^{-04}
Total	1,13	6,94.10^{+01}		3,47.10^{+01}	

Table II. Quantity of biomass and carbon in an area of 0.01 ha

Sites	Biomass of living wood (t/ha)	Standard deviation	Carbon content (t/ha)	Standard deviation
Ambanikely	$1,59.10^{-02}$	$4,44.10^{-04}$	$7,96.10^{-03}$	$2,22.10^{-04}$
Anglais	$1,60.10^{-02}$	$3,54.10^{-03}$	$8,01.10^{-03}$	$1,77.10^{-03}$
Batribe	$8,27.10^{-03}$	$3,60.10^{-04}$	$4,13.10^{-03}$	$1,80.10^{-04}$
Bemangoraka	$2,59.10^{-02}$	$1,23.10^{-03}$	$1,30.10^{-02}$	$6,14.10^{-04}$
Betaikary	$7,47.10^{-03}$	$5,49.10^{-04}$	$3,74.10^{-03}$	$2,74.10^{-04}$
Lagera	$1,20.10^{-02}$	$2,16.10^{-04}$	$6,00.10^{-03}$	$1,08.10^{-04}$
Manitomany	$1,40.10^{-02}$	$8,23.10^{-04}$	$6,99.10^{-03}$	$4,11.10^{-04}$
Marofisonko	$2,58.10^{-02}$	$2,47.10^{-03}$	$1,29.10^{-02}$	$1,23.10^{-03}$
Morahariva	$4,31.10^{-03}$	$7,32.10^{-04}$	$2,16.10^{-03}$	$3,66.10^{-04}$
Tambohobe	$6,79.10^{-02}$	$8,46.10^{-03}$	$3,39.10^{-02}$	$4,23.10^{-03}$
Tsalopy	$8,25.10^{-03}$	$2,19.10^{-04}$	$4,13.10^{-03}$	$1,09.10^{-04}$
Total	$2,06.10^{-01}$		$1,03.10^{-01}$	

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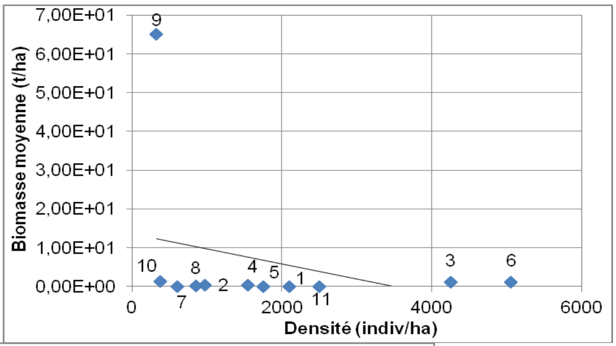

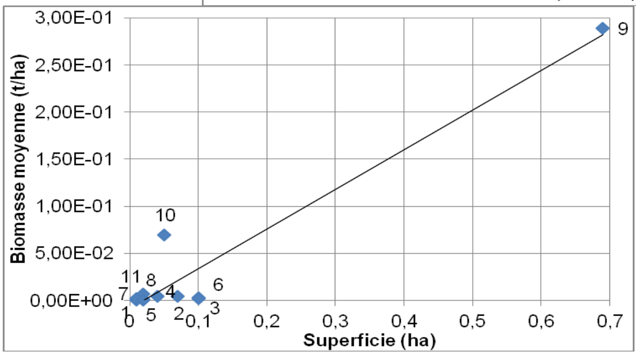

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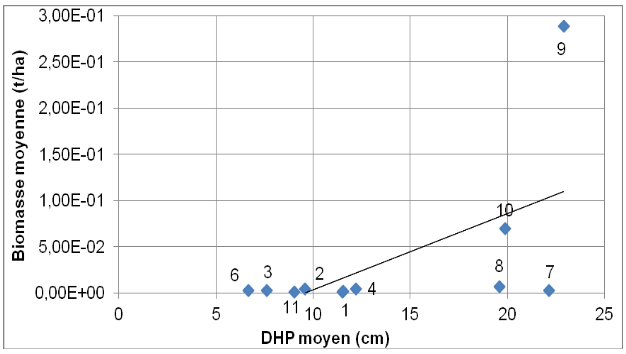

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Mangrove legend : 1) *Ambanikely*, 2) Anglais, 3) *Batribe*, 4) *Bemangoraka*, 5) *Betaikary*, 6) La Guerre, 7) *Manitomany*, 8) *Marofisonko*, 9) *Morahariva*, 10) *Tambohobe*, 11) *Tsalopy*

Figure 2. Correlation between: 1- average biomass and density; 2- average biomass and surface area; 3- average biomass and Diameter at Breast Height (DBH)

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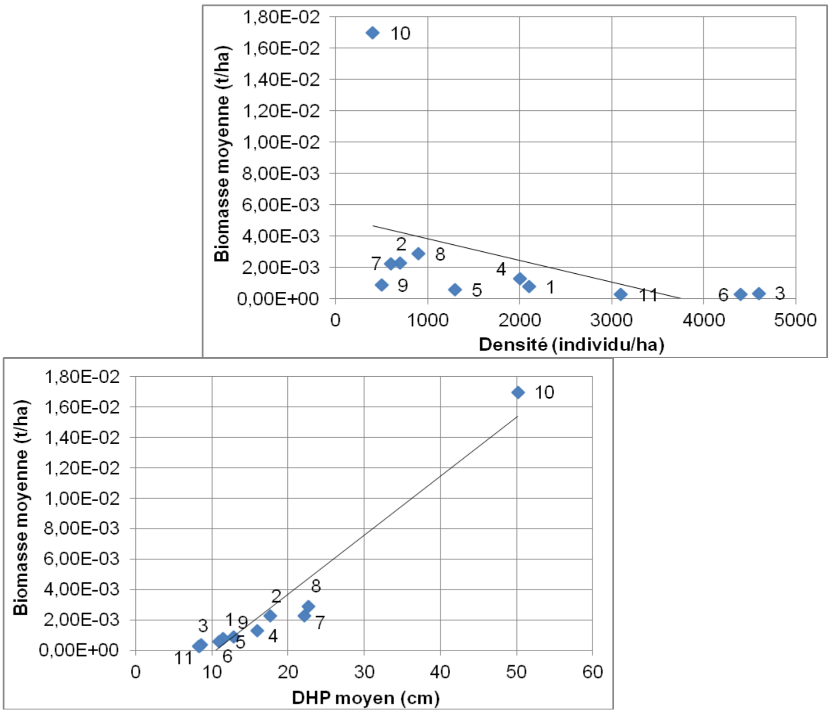

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Mangrove legend : 1) *Ambanikely*, 2) Anglais, 3) *Batribe*, 4) *Bemangoraka*, 5) *Betaikary*, 6) La Guerre, 7) *Manitomany*, 8) *Marofisonko*, 9) *Morahariva*, 10) *Tambohobe*, 11) *Tsalopy*

Figure 3. Correlation between: 1- average biomass and density; 2- average biomass and Diameter at Breast Height (DBH).