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Original paper

A PILOT STUDY FOR THE ESTIMATION OF ABOVE GROUND BIOMASS AND LITTER PRODUCTION IN *Rhizophora mucronata* DOMINATED MANGROVE ECOSYSTEMS IN THE ISLAND Of MAURITIUS

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ABSTRACT

Estimation of the above ground biomass of mangroves is an important issue because of its relevance to nutrient turnover and the potential to store carbon. Productivity, as indicated by litter fall rates is important to determine the rate at which mangroves produce new biomass. The aim of the current study was to estimate the above ground biomass and quantify litter fall in two Rhizophora mucronata dominated mangrove ecosystems of Mauritius located at Trou D'eau Douce (eastern side), and at Petite Riviere Noire on the (western-side) of the island. Field studies were conducted from September 2011 to January 2012. Quadrats of 5 × 5 metres were set up in each site and 200 mature trees were surveyed. Sixteen litter traps were constructed and installed at the two sites for litter collection. To estimate the above ground biomass, allometric equations were used. The total above ground biomass for Trou D'eau Douce and Petite Riviere Noire were 26.96 t ha^{-1} and 16.63 t ha^{-1}, respectively. The mean rate of litter fall for Trou D'eau Douce and Petite Riviere Noire were 3.2 ± 0.44 g DW m^{-2} day^{-1} and 4.07± 0.95 g DW m^{-2} day^{-1}, respectively. This study is among the first to provide information on the estimation of above ground biomass for mangroves of Mauritius. It is also the first to provide data on the litter production in mangroves at Petite Riviere Noire and Trou D'eau Douce.

Keywords : *Rhizophora mucronata*, above ground biomass, productivity, allometric equations, Mauritius

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INTRODUCTION

Mangrove forests are traditionally considered as one of the world's most productive ecosystem (Kathiresan and Qasim, 2005). One of the major challenges in ecology today is to determine the actual values of carbon which is trapped in lived mangrove vegetation, and also how fast the mangrove vegetation is able to produce new biomass. Standing biomass studies should provide important information on the amount of carbon which is stored in lived mangrove vegetation while litterfall studies should focus on the rate at which mangrove produces new biomass.

The estimation of mangrove biomass is important to various stakeholders of the ecosystem. This includes the foresters who are interested in obtaining the yield of mangroves wood as a function of age and other factors (Tamooh et *al.*, 2008). The ecologists who are interested in obtaining relevant information on stand biomass, useful information on nutrient turnover, stand structure and function, and competition. The ecophysiologists whose aim are to consider how stand biomass can be a major indicator of atmospheric and soil pollution input and forest health (Komiyama et *al.*, 2002). However, in recent years one of the crucial areas of importance of the ecosystem has been the focus on carbon sequestration. Deforestation and burning of fossil fuels are causing a significant increase in the atmospheric concentration of CO_2 (IPCC, 2005). To mitigate these increases, one option can be to absorb the increasing amount of CO_2 into long lived vegetation (Eamus *et al.*, 2002). As Mitra *et al.* (2011) point out, due to the phenomenon of global warming there has been in recent years an interest in understanding the carbon-storage ability of mangroves. The carbon sequestration ability is a function of the biomass production capacity.

In Mauritius, so far, published research work on mangroves have focused on organisms inhabiting the ecosystem (Appadoo and Roomaldawo, 2005) and only one study on the litter production and litter associated organisms exists (Mohit and Appadoo, 2009). Very little is known on the above ground biomass of mangrove ecosystems in Mauritius and the aim of this study was therefore to estimate the above ground biomass of two mangrove ecosystems in Mauritius and also to estimate litter production.

In the Western Indian Ocean, *Rhizophora mucronata* is one of the most common mangrove species (UNEP, 2008). In Mauritius mangroves are mostly found in estuaries and sheltered lagoons. There are only two species of mangroves, *Rhizophora mucronata* Lam. and *Bruguiera gymnorrhiza* (L.) Lam. The majority of mangroves in Mauritius belong to the *Rhizophora mucronata* species as reported by Fagoonee (1990). According to Kathiresan and Rajendran (2005), *Rhizophora mucronata* and *Bruguiera gymnorrhiza* are cosmopolitan species with wide distribution in Indian Ocean. There has been no specific study to highlight why *R. mucronata* became the dominant species of the two, in Mauritius. However, according to Hogarth (1999) there is a difference in survival and environmental conditions: *R. mucronata* occurs in habitats flooded at all tides while *B. gymnorrhiza* grows best in region of low inundation frequency and high salinity. The *Bruguiera gymnorrhiza* species occurs only in small patches at Pointe la Fayette, Trou D'eau Douce, Ferney and Mahebourg (Appadoo, 2003) as possibly there has been no place or appropriate environmental conditions for them to survive. The aims of the current study are to investigate the above ground biomass and litter production is *Rhizohora mucronata* stands.

MATERIALS AND METHODS

Study sites

Two geographically different sites, Trou D'eau Douce (20˚15"25‟S, 57˚47"38"E) and Petite Riviere Noire (20˚23"38‟S, 57˚22"31"E) were selected from the eastern and western regions of Mauritius respectively (**Fig. 1**). The estimated mangrove coverage in the region of Trou D'eau Douce/Ile Aux Cerfs is 10,000 m^2 making it the second largest natural mangrove forest in Mauritius.

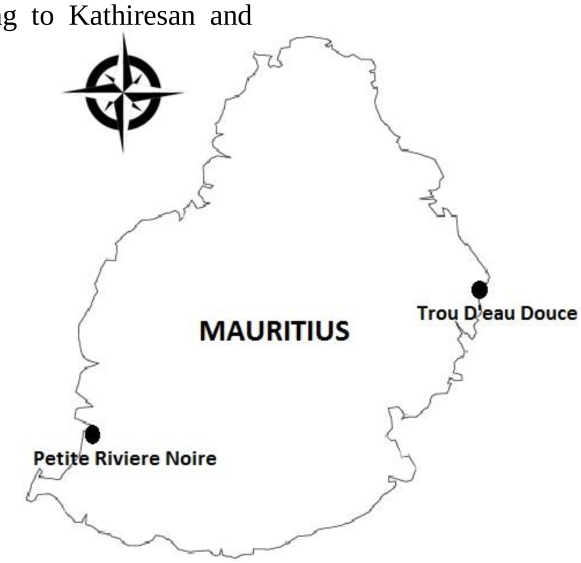


Figure 1: A map of Mauritius showing the two study sites.

Forest structure and plant parameters measurement

In each site quadrats of 5 m x 5 m were set in mangrove areas where trees are well distributed. Mangroves were classified as seedlings (< 1m in height), saplings (a DBH of <2.5 cm) and adult trees (a DBH of >2.5 cm) (Thinh *et al*., 2011). Six regions were sampled at Trou D'eau Douce and seven at Petite Riviere Noire. Samplings were repeated until 200 mature trees were assessed. This was a way to standardize the samplings for both regions. In each quadrat the circumference of each tree was recorded using a flexible measuring tape at a height of 1.3 m (Clough, 1992). Once the measurement of a tree was done, it was tagged with a fluorescent sticker with a sequential number to avoid repetitive sampling. In case where abnormalities such as swelling, forks or prop roots prohibited a measurement being taken at 1.3 m, an appropriate height as highlighted by English *et al.*, (1997) was followed. The number of seedlings was also counted within each quadrat during the sampling.

In order to estimate the height of mangroves at both study sites, the height of five tallest trees and five smallest were taken with the use of a graduated telescopic rod (Cintron and Novelli, 1984) and then the mean of the smallest and tallest height was calculated. The canopy cover of the study areas was also measured using a densiometer.

Leaf litter assessment

Litter traps were constructed taking into consideration the mesh size (Brown, 1984). The litter trap must not retain moisture and remain dry as any presence of moisture will enhance the process of decomposition which may reduce the weight of the litter (Mohit and Appadoo, 2009). The trap was made from nylon fabric a mesh size of 1 mm × 1 mm and a depth of 75 cm. The depth of 75 cm of the trap is suitable enough to prevent any loss of litter materials caused by the constant bouncing out of the litter traps to the mangrove trees as a result of strong winds. The litter traps had a circular frame of one meter in diameter which is made up of raffia rope. Circular frames of raffia ropes were constructed to facilitate the handling of the litter baskets and also for them to be easily fitted among the mangrove trees. This design provided a total interception area of 0.785 m^2.

Seven litter traps were placed at Trou D'eau Douce and nine at Petite Riviere Noire. Particular attention was paid to the inundation zones while placing the traps. The classification of inundation zones was based on scheme used by Kathiresan and Qasim (2005).

At Trou D'eau Douce, the litter traps were placed as follows: two in the Class 1 inundation zone, three in the class three inundation zone and two in the class four inundation zone. At Petite Riviere Noire, three traps were placed in each zone. Each litter trap was attached tightly to the trunk of the mangrove trees above the high-tide mark 0.5 metre (Cunha et *al.,* 2006).

The litter traps were emptied three times- End November 2011, Middle of December 2011 and Middle of January 2012. The litter was collected in plastic bags and were taken to the laboratory.

Litter processing

The litter samples collected were oven dried to constant weight at 70°C (Juman, 2005) and then sorted into leaves, stipules, flowers, fruits woody material and miscellaneous (debris from plants other than mangroves). The weight of each fraction was recorded.

Estimation of above ground biomass

There are three main methods, which can be used to calculate mangrove biomass: the harvest method, mean tree method and by using allometric equations (Komiyama et *al.,* 2008). The harvest method involves the cutting down of trees, which are then separated into components (branch, leaves, trunk, and bark), dried and then weighted. This method is difficult to use as it requires intensive labour and also not all the trees within a set of area can be felled. The mean tree method is mostly used in plantation where most of the trees are of similar size. This method involves the weighing of one tree, which is considered as the average one and then extrapolating the biomass for the entire stand.

Therefore, since the mean tree and harvest method is extremely time-consuming and involved the destructive method (Ketterings, 2001), the theory of allometric relationships is applied. In Mauritius, it is not possible to do estimation by sacrificing the plant as this is protected by law (Fisheries and Marine Resources Act of 2007). Allometric equations are the most common and widely used method for measuring biomass. The equations are derived from selective sampling of trees that are representative of the size-classes in the forest, and it is used to estimate partial weight of trees relative to tree metrics, such as diameter breast height (DBH) and tree height (Fatoyinbo and Amstrong, 2010).

Data Analysis

1. Estimation of above ground biomass

From the circumference of trees recorded, the DBH (diameter at breast height) was calculated by using the formula:

DBH = ($2\pi r$) / π

Where ($2\pi r$) is the circumference of trees.

The DBH is then used in the following allometric equation to estimate the above ground biomass of mangroves in the present study. This equation is obtained from a study in Madagascar (Rakotomavo, 2010). The choice of the allometric equation was based on the DBH range, the species of mangrove and the climatic conditions.

<u>The equation used was as follows:</u>

Log y = a Log DBH + b,

Where: *y* is the above ground biomass of mangroves,

DBH is the diameter of stems at the breast height,

a and *b* are regression coefficients

a=2.383, b= -0.799

2. Estimation of Productivity

Litterfall was calculated as the rate of fall in g DW m^{-2} day^{-1}. The calculations were as follows:

1. The dry weight of litter (g DW) for each litter trap (surface area of 0.785 m2) is calculated in a surface area of 1 m^2.

$$\frac{Dry\ Weight\ of\ litter\ (g\ DW)}{0.785\ m^2} = g\ DW\ m^{-2}$$

2. The rate of litterfall is then calculated by dividing the dry weight of litter (g DW m^{-2}) by the number of days between each collection date.

$$\frac{Dry\ Weight\ of\ litter\ (g\ DW\ m^{-2})}{Number\ of\ Days\ Between\ Each\ Collection\ Date} = g\ DW\ m^{-2}\ day^{-1}$$

RESULTS AND DISCUSSION

Forest structure

Structural measurements for mangroves at both study sites, Trou D'eau Douce and Petite Riviere Noire are presented in Table 1. Petite Riviere Noire mangrove forest was the densest site with 30000 trees/hectares. At both sites, high density values were obtained for seedlings followed by adult mangroves and saplings. Stem diameters of mangroves at Trou D'eau Douce ranged from 1.3 cm to 13.6 cm which is much higher than that of Petite Riviere Noire (1.2 cm – 5.1 cm). This was also the case for height (3.6 m – 8.4 m) and also basal area (245.7 m^2/hectares). The canopy cover for Trou D'eau Douce and Petite Riviere Noire mangrove forest are 72% and 88% respectively. Overall, the results clearly reflect that Trou D'eau Douce mangrove forest is at higher maturity stage as compared to that of Petite Riviere Noire.

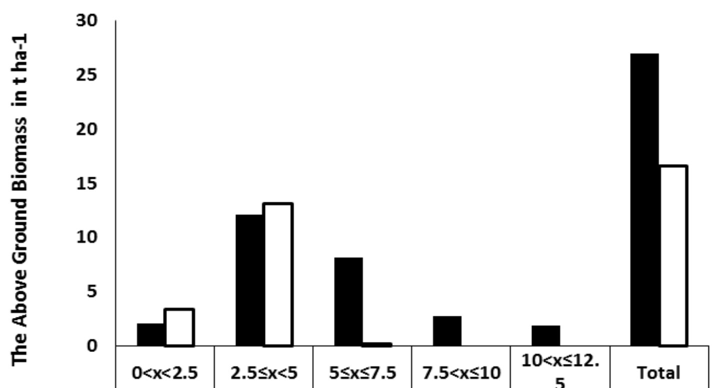
Table 1: Structural parameters of the mangrove forest at Trou D'eau Douce and Petite Riviere Noire.

Attribute	Site	
	Trou D'eau Douce	Petite Riviere Noire
Height (m)	3.6 – 8.4	2.0 – 5.2
Canopy Cover (%)	72	88
Basal Area (m^2 per hectare)	245.7	89.3
Stand Density (trees per hectare)	2.8×10^4	3.0×10^4
Seedlings Density (seedlings per hectare)	1.50×10^4	1.8×10^4
Saplings Density (saplings per hectare)	2.3×10^3	3.3×10^3
Adult Trees Density (adult trees per hectare)	1.1×10^4	8.1×10^3
DBH range (cm)	1.3 – 13.6	1.2 – 5.1

Above ground biomass

Mangroves were classified into diameter at breast height (DBH) classes of width 2.5 cm in order to make the distinction between the saplings and the adult trees. This was also a means to determine the different maturity stage of the mangroves at the two study sites. Figure 2 shows the estimated standing biomass of the above ground biomass for each DBH class. In both study sites, high standing biomass were obtained for the DBH class 2.5≤x<5. For Trou D'eau Douce this was followed by DBH class 5≤x≤7.5 and for Petite Riviere Noire DBH class 0<x<2.5. The data also shows that the higher classes (5≤x≤7.5, 7.5<x≤10 and 10<x≤12.5) have an important contribution to the total biomass for Trou D'eau Douce study site. At Petite Riviere Noire, the same DBH classes are almost non-existing. Therefore, Trou D'eau Douce mangrove stand has the highest biomass estimated at 26.96 t ha^{-1} as compared to Petite Riviere Noire estimated at 16.63 t ha^{-1}.

In general, the DBH classes at Trou D'eau Douce ranged from 0 cm to 12.5 cm as compared to that of Petite Riviere Noire which ranged only from 0 to 7.5 cm. Also, from Figure 2 it can be deduced that at both study sites the DBH class 2.5≤x<5 accounted for most of the standing biomass.



	0<x<2.5	2.5≤x<5	5≤x≤7.5	7.5<x≤10	10<x≤12.5	Total
■ Trou D'eau Douce	2.03	12.13	8.14	2.76	1.91	26.96
□ Petite Riviere Noire	3.36	13.12	0.14	0	0	16.63

Figure 2: The above ground biomass of mangrove in the different DBH classes at Trou D'eau Douce and Petite Riviere Noire.

a. Litter Production

The mean rate of the total litterfall for Trou d'eau Douce and Petite Rivière Noire were 3.2 ± 0.44 g DW m^{-2} day^{-1} and 4.07 ± 0.95 g DW m^{-2} day^{-1}, respectively. At Trou D'eau Douce, little variation with almost two constant litterfall rate for samplings "End-November 2011" (2.94 g DW m^{-2} day^{-1}) and "Mid-December 2011" (2.95 g DW m^{-2} day^{-1}) were observed. The highest litter fall rate was recorded for "Mid-January 2012" which was 3.71 g DW m^{-2} day^{-1} (figure 3).

At Petite Rivière Noire, the rate of litterfall showed an increasing trend with the lowest rate for "End- November 2011" (3.20 g DW m^{-2} day^{-1}) followed by Mid-December 2011" (3.93 g DW m^{-2} day^{-1}) and peaked for "Mid-January 2012" (5.09 g DW m^{-2} day^{-1}).

Litterfall rate between the two study sites was not significantly different at 95% confidence level (Z=-1.000, P=0.317).

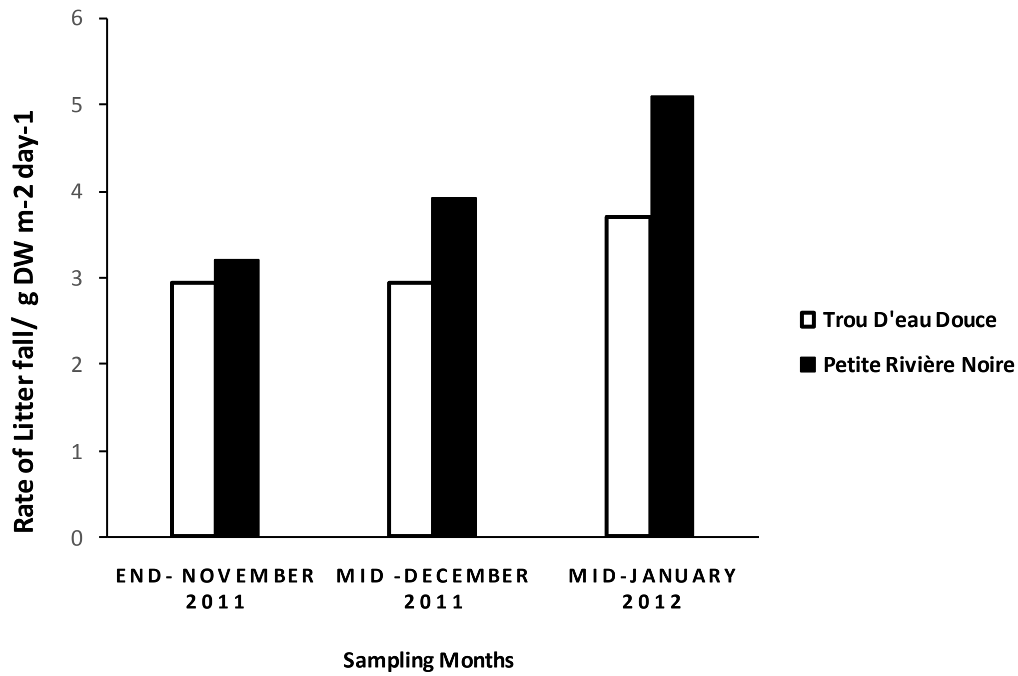


Figure 3: The rate of litterfall for each sampling month at Trou D'eau Douce and Petite Riviere Noire.

b. Litterfall Components

The results show that leaf has the highest litterfall rate as compared to any other litterfall components (Table 2) and also the leaf fall rate for Petite Riviere Noire (3.24 ± 0.48 g DW m^{-2} day^{-1}) was much higher than that of Trou D'eau Douce (2.73 ± 0.45 g DW m^{-2} day^{-1}) . This was followed by wood for Trou D'eau Douce (0.47 ± 0.26 g DW m^{-2} day^{-1}) and fruits for Petite Riviere Noire (1.24 ± 1.30 g DW m^{-2} day^{-1}). Stipule was the third highest litterfall rate. The stipule fall rate was approximately the same for the two study sites with 0.28 ± 0.03 g DW m^{-2} day^{-1} for Trou D'eau Douce and 0.30 ± 0.31 g DW m^{-2} day^{-1} for Petite Riviere Noire. High wood fall rate was reported for Trou D'eau Douce (0.47 ± 0.26 g DW m^{-2} day^{-1}) as compared to Petite Riviere Noire (0.04 ± 0.06 g DW m^{-2} day^{-1}). Conversely, high flower fall rate was reported for Petite Riviere Noire (0.20 ± 0.12 g DW m^{-2} day^{-1}) as compared to Trou D'eau Douce (0.13 ± 0.10 g DW m^{-2} day^{-1}).

Wood fall rate between the two study sites was not significantly different at 95% confidence level (P=0.046, Z=-1.993).

Table 2: The rate of fall for each litter components at different sampling time for the two study sites.

Litterfall Components	Rate of fall (g DW m^{-2} day^{-1})							
	Trou D'eau Douce				Petite Riviere Noire			
	End-November 2011	Mid-December 2011	Mid-January 2012	Mean	End-November 2011	Mid-December 2011	Mid-January 2012	Mean
Leaf	2.49	2.44	3.25	2.73	2.74	3.69	3.29	3.24
Stipule	0.31	0.29	0.23	0.28	0.09	0.15	0.66	0.30
Wood	0.19	0.51	0.70	0.47	0.11	0.00	0.00	0.04
Flower	0.24	0.07	0.07	0.13	0.12	0.13	0.34	0.20
Fruit	0.00	0.00	0.26	0.10	2.59	0.00	1.14	1.24

Discussion

Mangrove Forest Structure

The density of seedlings and saplings gives an indication of the natural regeneration occurring (Kasawani *et al.*, 2007). From Table 1, the high density of seedlings and saplings gives a clear indication that Petite Riviere Noire is a newly planted forest. Conversely, Trou D'eau Douce which is a natural forest has a high abundance of adult mangroves. In 1992, a study (Luo et *al.*, 2010) found high abundance of smaller mangroves in an 11 year old *Rhizophora mangle* plantation as compared to a natural mangrove stand. Similar finding was obtained by another study carried out by Luo et *al.* (2010).

Mangrove plantations have a fast growth rate (Luo et *al.*, 2010) this is why the density of seedlings and saplings (Table 1) is higher at Petite Riviere Noire. Other reasons could be the intense intra-specific competition through a combination of space exploitation, resource exploitation and light competition between seedlings and adult trees which result in an increase in the mortality rate among the seedlings at Trou D'eau Douce.

Above Ground Biomass

The amount of standing biomass stored in mangrove forest is a function of the system's productivity, age and organic matter allocation and exportation strategies (Kasawani et al., 2007). In the present study, the total above ground biomass was 26.96 t ha^{-1} and 16.63 t ha^{-1} at Trou D'eau Douce and Petite Riviere Noire respectively. This is close to the above ground biomass of 25.6 t ha^{-1} for Ile D'Ambre and 13.7 t ha^{-1} for Maconde that was reported by (Runghen, 2011). Comparative study has been carried out in Kenya where high above ground biomass of 244 t ha^{-1} was reported by Slim et al. (1996). Similarly, in Japan Suzuki and Tagawa (1983) reported an above ground biomass of 108.1 t ha^{-1} in a mangrove stand dominated by *Rhizophora mucronata*. Other studies in Thailand (Komiyama et al., 1987) , India (Mall et al., 1991) and Sri Lanka (Komiyama et al., 2008) reported an above ground biomass of 298.5 t ha^{-1}, 214 t ha^{-1} and 71 t ha^{-1} respectively (Komiyama et al., 2008). These results indicate great variability in the above ground biomass of mangrove across the world.

A comparison of mangroves at each site revealed that standing biomass at Trou D'eau Douce is much higher 26.96 t ha^{-1} as compared to that of Petite Riviere Noire which is 16.63 t ha-1. Komiyama et al. (2008), reviewed past 50 years of data on biomass of mangrove forests and the highest above ground biomass, 460 t ha^{-1} was found in a *Rhizophora apiculata* forest in Malaysia. However, in Indonesia above ground biomass of more than 300 t ha^{-1} was also reported. This shows that the Mauritian mangrove forests are among the smallest stands in the Indian Ocean.

Primary Productivity

The mangroves stand at Petite Riviere Noire has a higher productivity as shown in figure 3 as compared to that of Trou D'eau Douce. The mean litterfall rate for Petite Riviere Noire and

Trou D'eau Douce was 4.07 ± 0.95 g DW m^{-2} day^{-1} and 3.20 ± 0.44 g DW m^{-2} day^{-1}, respectively. Comparative study on mangrove productivity in Mauritius carried out by Mohit and Appadoo (2009) showed that litterfall rates were 4.63 g DW m^{-2} day^{-1} and 4.74 g DW m^{-2} day^{-1} at Maconde and Bambous Virieux, respectively. This suggests that the mangrove forests at the two study sites are less productive as compared to that of Macondé and Bambous Virieux. Comparing the rate of litterfall obtained in the present study with that of other countries [2.4 g DW m^{-2} day^{-1} in South Africa (Rajkaran and Adams, 2010), 2.2-2.5 g DW m^{-2} day^{-1} in Brazil (Saint-Paul and Schneider, 2010) and 0.28 g DW m^{-2} day^{-1} in Mexico (Navarette and Rivera, 2002)], it can be concluded that the Mauritian mangrove forest has the highest litterfall rate. The main reason is that at lower latitudes, litterfall rates are high and decrease linearly with increasing latitudes (Saenger and Snedaker, 1993).

Litter production is subjected to continuous temporal and spatial variations. In fact, biomass and rates of litterfall decrease with increasing latitude (Saenger and Snedaker, 1993). The litterfall rate at the two sites was approximately the same. Despite the fact that Trou D'eau Douce is situated on the east side of Mauritius and Petite Riviere Noire on the west side of Mauritius, a Mann-Whitney test (Z=-1.000, P=0.317) shows no significant difference in mean litterfall rate. Therefore, there may be random fluctuations in productivity at the two sites but overall there was no major difference in productivity.

CONCLUSIONS

The estimated standing biomass of mangroves, give an overview of the actual amount of carbon which is trapped into living mangrove plants in Mauritius. From the results of it can be concluded that the studied Mauritian mangrove forests have small above ground biomass as compared to other countries, albeit they have the highest litterfall rate. Information presented in the study on forest structure and biomass will be useful for demonstrating the importance of the ecosystem, proper management and conservation decision can be initiated to protect these fragile ecosystems in the new era of global climate change. This study also provides productivity data on mangroves in Mauritius and gives an overview of how fast the mangroves are producing new biomass. These data contribute to a better understanding of the mangrove ecosystem of the island.

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