J. Indian Soc. Coastal Agric. Res. 36(1): 1-10 (2018)

# Potential Mitigation Effect of Mangrove Forest on Global Climate Change through its Carbon Storage Capacity

SIRPAUL JAIKISHUN[1], A. A. ANSARI[1]*, PHILIP DASILVA[2] and ALAM HOSEN[3]

[1]University of Guyana, Turkeyen Campus, Georgetown, Guyana
[2]University of Guyana, Berbice Campus, Berbice, Guyana
[3]University of Alberta, T6G 2R3, Canada

Received: 17.07.2017 Accepted: 09.11.2017

**The role of mangrove ecosystem in carbon storage is recognized in many tropical countries across the globe and Guyana is one of the key areas with significant forest coverage. This research was carried out at study sites located in coastal region of Guyana with the objectives; quantification of aboveground biomass and the respective carbon storage of three mangroves species in Guyana, prediction of the future carbon storage capacity in mangrove species in Guyana and justification on the importance of conservation and restoration of mangrove forests towards climate change mitigation in Guyana. The results from all the regions indicated that the two species (*R. mangle* and *A. germinans*) have greater aboveground carbon stock capacity (481 Mg $ha^{-1}$) which can aborb carbon dioxide released from various sources within Guyana. The total forest coverage of Guyana is 18.57 million hectare (mha) containing over 5 giga tonnes (gt) of carbon in aboveground biomass. Total coverage of mangrove forest in Guyana is 22632.4 ha and estimated aboveground carbon locked by this ecosystem is 0.016 gt, which is equivalent to 0.059 gt of $CO_2$. This is significant taking into consideration the coastal locations of robust and dynamic mangrove ecosystem. Recently the phenomenon of global warming has generated interest in understanding the carbon stock capacity of mangrove species. The results of this study support mangrove reforestation and afforestation in the coastal zone of Guyana. The present study led to understanding of the carbon stored in the mangrove forest and its relevance in carbon dioxide trapping in the forest stands. Such relationship establishes the foundation in holistic approach to mangrove restoration and climate change prevention strategy for Guyana.**

***(Key words:** Carbon storage, Climate change mitigation, Conservation, Mangroves)*

Mangroves are coastland forests at the interface between land and sea. They are highly dynamic ecosystems and composed of littoral species of trees, shrubs, and ferns. Some mangrove forests also include the palm *Nypa fruiticans* Wurmb. They tolerate and provide habitat for many species of other organisms and provide significant services to human communities across the world (Albert *et al.,* 2012; Spalding *et al*., 2010; Richards, 1998; Li and Lee, 1997, Fanshaw, 1952). Mangroves play a vital function in preventing and reducing coastal erosion and provides nearby communities with protection against the effects of wind, waves and water currents.

Almost 86% of Guyana's land is covered with tropical rainforest that is still untouched (NLUP, 2013). While more focus is placed on the rainforest, and rightly so because of its coverage, mangroves are also critically important in the Low Carbon Development Strategy (LCDS) because of their high rate of productivity. This means that mangroves occupying only about 0.2% of forest coverage can fix a great deal of carbon in their tissues through photosynthesis (NLUP, 2013). In addition to the high productivity of mangroves there is evidence that there are also high levels of carbon being deposited in soil sediments.

Mangroves support the conservation of biological diversity by providing flourishing habitats, spawning grounds, nurseries and nutrients for a number of animals. Mangroves play a critical role in providing protection of the coastal zone by serving as wind break. In addition, they also provide many other ecological services. However, with the current trend in rising global temperature, mangroves can also be an important sink for carbon by reducing the concentration of carbon dioxide in the atmosphere and thereby lowering of the global temperature (Kridiborworn *et al*., 2012). Mangroves are known to have high productivity (Spalding *et al*., 2010) and can therefore sequester carbon. Global estimates indicated the mangrove forests have the potential of fixing about 17 metric tonnes of carbon $ha^{-1}$ $yr^{-1}$ (NMMAP, 2010).

**Corresponding Author :* E-mail: abdullah.ansari@uog.edu.gy

However, no comprehensive study has been done to ascertain the amount of carbon that is stored in the mangrove forest in Guyana. This research is intended to estimate carbon storage of the three protected species (*Avincennia germinans, Languncularia racemosa,* and *Rizophora mangle*) and hence justify the restoration of mangrove forests along the coast. The study will also help in developing such relationship between carbon and carbon dioxide trapped to establish the foundation in fostering the whole concept of mangrove restoration and protection and their importance to our daily existence.

## MATERIALS AND METHODS

### Study area

Five mangrove species are found along most of the coastlines of Guyana with major stands between the Pomeroon and Waini rivers to the west which represents the largest untouched mangrove forest in the country. Other areas with mangrove stands are located on the northern coast of Wakenaan and Leguan Islands, and in Hogg Island. The dominant mangrove species in the study region are: *Avincennia germinans* (L) Stearn, *Avicennia schaueriana* Stapf and Leechman ex Moldenke, *Canocarpus erectus* L., *Languncularia racemose* (L) Gaertn. and *Rizophora mangle* (Ellison *et al.,* 2010; Hussein, 1990; Fanshaw, 1952). This research focused on the biomass carbon of the two most dominant species *A. germinans* and *R. mangle.*

The study sites (Fig. 1) were located in Essequibo (Regions 1- Barima – Waini and 2- Pomeroon-Supenaam), Demerara (Regions 3- Essequibo Islands-West Demerara and 4- Demerara-Mahaica) and Berbice (Regions 5- Mahaica-Berbice and 6- East Berbice-Corentyne). These sites include Mora Passage (8°20′24.0″N, 59°46′48.0″W) and Shell Beach (8°23′49.2″N, 59°48′46.5″W) in region 1, Better Hope (7°11′14.0″N, 58°29′16.0″W) in region 2, Ruimzeight (6°50′30.0″N, 58°13′38.0″W) in region 3, Cove and John (6°45′17.0″N, 57°58′05.0″W) in region 4, Bath Settlement (6°22′09.0″N, 57°34′47.0″W) in region 5 and Borlam (6°17′43.0″N, 57°23’05.0″W) in region 6. The sampling sites were identified using the vegetation map prepared by NARIE (NMMAP, 2010). Measurements were also taken from the three main rivers on the coast and includes Berbice (Crab Island-6°18′21.0″N, 57°31′00.0″W), Demerara (Nismes- 6°45′14.0″N, 58°12′03.0″W) and Essequibo (Tiger Island - 7°01′42.0″N, 58°28′12.0″W) rivers that formed part of riverine forests in Guyana.


***Fig. 1.*** *Regions of Guyana and mangrove zones for study (Source: NMMAP, 2010)*

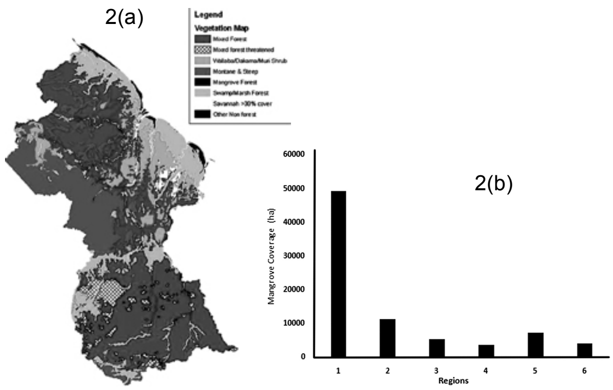



***Fig. 2.*** (a) *Vegetation map of Guyana. (b) Regional distribution of mangroves in Guyana (Source: GFC, 2011).*

### Tree growth parameters

#### *Sampling method*

In this study, belt transects with a length of 140 x 14 m running from the inland boundary of the mangroves and going out into the shore were demarcated. This was further subdivided into smaller squared plots measuring 14 x 14 m each, resulting in ten (10) plots in the entire transects (Fig. 3). From these ten plots, three plots were selected using a random number table for carbon assessment (Brown, 2002; Brown, 1997). This was repeated for the other regions to select the required three plots for the other study areas.

#### *Diameter at breast height (DBH)*

All mangrove trees within the plot were measured and recorded on the basis of species type and categorised into diameter class of ≥5 – 10 cm, >10 – 20 cm, >20 – 30 cm, >30 – 40 cm and >40 cm. In measuring DBH (diameter at 1.3 m aboveground), the procedure as described by Pearson *et al.* (2005) was employed.

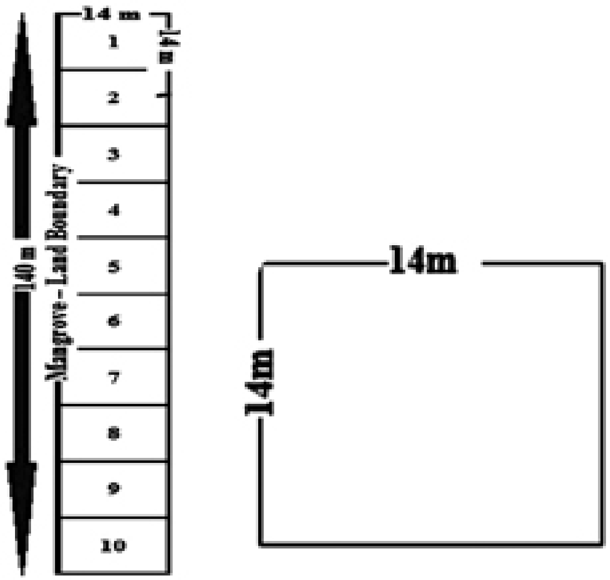



*Fig. 3. Lay out of sampling sites*

## Tree density and dominance

Tree density refers to the number of trees per hectare (ha). This was determined by calculating the mean the number of trees per plot (14 x 14m) for the three randomly selected plots and then multiplying this mean value by the expansion factor (51.02) to determine the tree density. Tree dominance was calculated by using the formula:

$$\text{Tree dominance for specific class DBH} = \frac{\text{Number of trees in specific class interval DBH}}{\text{Total number of trees in all the classes of DBH}}$$

### Tree biomass

The biomass regression equation was used to calculate the biomass of the tree. This equation was developed from data that include all trees of many species harvested from forest of all regions. Regression equations for estimation of aboveground biomass of mangroves were also developed by Chave *et al.* (2005). The equation used in the present study is as follows:

$$(ABG)_{est} = \rho \exp[-1.349 + 1.980 \ln(D) + 0.207 \{\ln(D)\}^2 - 0.0281 \{\ln(D)\}^3] \quad \text{........(1)}$$

Where, ABG is the aboveground biomass, $\rho$ is wood specific gravity, exp is exponential factor, ln is natural logarithm and D is the diameter at breast height in m. The equation was used to calculate the biomass of every tree in the squared plots for each species. This was then extrapolated and multiplied by the expansion factor for each plot which eventually gave the biomass per hectare of the forest. The expansion factors for converting the plot data to a hectare for a 14 x 14 m dimension was estimated as 51.02 using the formula as given by Pearson *et al.* (2005). Although measurements and biomass data were determined from riverine and fringe physiographic and physiognomic forest categories (Lugo and Snedaker, 1974), these were done only to decipher if there is a difference in the carbon storage capacity from the two types. Since there is no distinct forest coverage separately for each category, the estimated carbon quantity reflects the total coverage and is based on the fringe forest carbon quantification.

### Aboveground non-tree vegetation

Aboveground non-tree vegetation was measured by harvesting techniques. All vegetation within the frame to ground level was clipped. The frame was viewed as extending vertically and any vegetation falling outside the boundaries of the plot would be excluded. The sample was weighed and well-mixed sub-samples were removed for determining the dry-to-wet weight ratio. The sub-sample was weighed in the field, then oven-dried (~80°C) to a constant weight.

### Forest floor (litter)

The forest floor (or litter) is defined as all dead organic surface material on top of the mineral soil. Some of this material was recognisable (*e.g.*, dead leaves, twigs, dead grasses and small branches) and some were unidentifiable, decomposed fragments of organic material. Dead wood with a diameter of >10 cm was included in the litter layer. Litter was sampled at least once in every month to eliminate seasonal effects. A 30 x 30 cm square sample frame made from PVC pipe was used for sampling. All litter inside the frame was collected and placed on a tarpaulin next to the frame. Sub samples were oven dried to constant weight at ~80°C. If the sample bulk was in excess (above 0.5 kg), the fresh weight of the total sample was recorded in the field and a subsample of manageable size (~80 to 100g) was taken. This was oven-dried (~80°C) to constant weight. This was then used to determine the carbon stored in litter for each of the plots. The mean value was then multiplied by the expansion factor (51.02) to determine the value of carbon stored in litter per hectare for that area and considered in the total carbon quantification.

### Destructive analyses

Two trees each of *A. germinans* and *R. mangle* were destructively analysed from region 3. The trees were felled and then divided into leaves, branches, stem and, where possible, aboveground roots. The total harvested fresh weight of each component was measured in the field, and representative subsamples were taken to the laboratory where they were oven-dried to constant weight at ~$80^0$C. The sub-sample dry-weight of each component was calculated from the ratio of dry-weight to fresh-weight of the corresponding sub-samples. These values were only used to determine the accuracy and assess the validity of the regression equation used in the calculation of aboveground biomass.

**Carbon content in vegetation**

After calculating the biomass of aboveground vegetation, the values of biomass were then converted to carbon. The carbon content of the tree is 50% of the total calculated biomass of the trees in the given area (Houghton *et al*., 2009; Tamooh *et al.,* 2008; Carolina *et al*., 2006; Chave *et al.,* 2005; Pearson *et al.*, 2005; IPCC, 1995). In the present study, the following carbon conversion equation was used:

Carbon (C) = 0.475 x B (oven dried biomass) ...(2)

After arriving at the mean carbon per plot for the three randomly selected plots, was then extrapolated to carbon density by multiplying the expansion factor (51.02). This value represented the aboveground carbon for each hectare of the sampling site. This was then multiplied by the mangrove forest coverage of that region to quantify the carbon for the entire area. The mean carbon was calculated per plot for each class DBH and converted to per hectare to get the carbon density. The biomass was also recorded by destructive analysis of mangroves and then transformed using the equations (that was used by non-destructive method) to get the carbon content in different species of mangroves. The carbon content in different species was compared using destructive and non-destructive methods.

**Soil organic carbon stock**

To obtain soil organic carbon stocks, three variables, namely, depth (D), bulk density (BD, calculated from the oven-dried weight of soil from a known volume of sampled material) and concentration of organic carbon ($OC_{conc}$) within the sample were measured. The soil organic carbon stock was calculated using the following formula:

$$SOC_{stock} = OC_{conc} \times BD \times D \quad ...(3)$$

Soil samples were collected from the sites using a core sampler. The core sampler was inserted to a 30 cm depth and was carefully extracted and the soil samples were placed into a bag and transported to the laboratory. Prepared soil samples were analysed at GuySuCo Laboratory for determination of soil organic carbon using the Walkley-Black method and bulk density.

The carbon stocks from different sources (mangroves from all the regions including riverine mangrove forest and litter) were used to arrive at the total stock for the study area.

**Statistical analysis**

Two way ANOVA and Chi – square test were done (using Microsoft Excel 2010) to determine if there was any significant difference among various parameters of the mangrove species at different diameter classes and to rank the regions based on estimated aboveground biomass carbon stored (Zar, 1996).

## RESULTS AND DISCUSSIONS

Mangroves of all the diameter classes were found in all the study areas. The total distribution of mangroves in Guyana based on the research indicated that for *R. mangle* the maximum distribution existed in the diameter class >10 – 20 cm while the minimum distribution existed at > 40 for fringe forest. The maximum distribution for *A. germinans* existed in the diameter class >10 – 20 while the minimum distribution in the diameter class >30 – 40. The entire study area was monospecific with *A. germinans* in region 1, 2, 4 and 5 whereas *R. mangle* and *A. germinans* were recorded in regions 3 and 6, thus indicating the existence and dominance of two major species *R. mangle* and *A. germinans* in tropics of South America (Comeaux *et al.* 2012; Giarrizzo *et al.,* 2011).

**Tree density**

Table 1 below shows tree density in all the study areas (regions 1-6) in Guyana with reference to *A. germinans*. Tree density was highest in region 1 compared to other region (Table 1). Based on two way ANOVA ($p=0.05$) there is significant differences in the DBH ranges with reference to tree density in all the regions of Guyana ($F=0.027$). Variations in *A. germinans* population density follow environmental changes like human population expansion and infrastructural development. The present study correlates with the studies by Comeaux *et al*. (2012) and Giarrizzo *et al.* (2011). Lesser tree density in regions 1-6 could be due to human influence where more mature trees are cut and used for cooking and as poles for fishing nets. The area is also covered with lots of garbage which can prevent the roots from breathing freely. Pollution appeared to have an impact on the growth and development of the mangrove species. Most of the garbage appeared to have floated and deposited there from other places (FAO,

***Table 1.*** *Tree density and dominance of A. germinus in regions 1-6 of Guyana*

| DBH (cm) | Tree Density (no of trees $ha^{-1}$) (*A. germinans*) | | | | | |
|---|---|---|---|---|---|---|
| | Region 1 | Region 2 | Region 3 | Region 4 | Region 5 | Region 6 |
| ≥ 5-10 | 459.18 | 272.00 | 238.00 | 323.00 | 544.00 | 153.00 |
| >10-20 | 4030.80 | 901.00 | 680.00 | 799.00 | 663.00 | 153.00 |
| >20-30 | 1275.50 | 306.00 | 425.00 | 119.00 | 119.00 | 221.00 |
| >30-40 | 102.04 | 17.00 | 187.00 | 0.00 | 17.00 | 255.00 |
| >40 | 0.00 | 0.00 | 85.00 | 0.00 | 34.00 | 136.00 |
| DBH (cm) | Dominance (%) (*A. germinans*) | | | | | |
| | Region 1 | Region 2 | Region 3 | Region 4 | Region 5 | Region 6 |
| ≥5-10 | 7.69 | 18.18 | 14.74 | 26.03 | 39.51 | 16.67 |
| >10-20 | 67.52 | 60.23 | 42.11 | 64.38 | 48.15 | 16.67 |
| >20-30 | 21.36 | 20.45 | 26.32 | 9.59 | 8.64 | 24.07 |
| >30-40 | 171.00 | 1.14 | 11.58 | 0.00 | 1.23 | 27.78 |
| >40 | 0.00 | 0.00 | 5.26 | 0.00 | 2.47 | 14.81 |

2007; Sherman *et al.*, 2001). These areas are also influenced by population pressure leading to deforestation, land use change together with global climate change (Langner *et al.*, 2007; Valiela *et al.*, 2001).

*R. mangle* species was recorded in regions 3 and 6. Tree density was higher in region 3 with respect to DBH range of >5-10 cm and >20-30 whereas, it was greater in DBH range of >20-30 for region 6 (Table 2). Regions 3 and 6 are unaffected by anthropogenic influence, a major factor in the depletion of the mangroves in the some areas. However, there was evidence of fresh water intrusion through a drainage canal that comes from the rice field area. Large section of the area is deforested which resulted from high tide and movement of the mud flat. These are natural phenomena that play key role on the survival and existence of mangroves within the ecosystem (Adame *et al.*, 2013; Cahoon and Hensel, 2006; Sherman *et al.,* 2001; Woodroffe, 1987).

**Tree dominance**

Diameter at Breast Height (DBH) range between >10-20 cm was dominant in all the regions, an indication that the mangrove forests are relatively young (Table 1). Region 3, 5 and 6 showed the presence of trees of DBH > 40 cm. Tree dominance was higher in region 3 with respect to DBH range of ≥5-10 cm and >20-30 where as it was greater in DBH range of >30-40 for region 6 (Table 1). Based on two way ANOVA (p=0.05) there is significant differences in the DBH ranges with reference to tree dominance in all the regions of Guyana (F=0.027). Similar findings have been reported by Comeaux *et al.* (2012) and Giarrizzo *et al.* (2011).

## Carbon density

Carbon density was highest in in DBH range of >10-20 cm in region 2 followed by 4 and 3, whereas carbon density was zero for region 1, 2 and 4 in DBH range > 40 cm (Fig. 4). Carbon density was maximum in region 3 with respect to DBH range of ≥5-10 cm and >20-30 whereas it was higher in DBH range of >20-30 for region

***Table 2.*** *Tree growth parameters and carbon density of R. mangle in regions 3 and 6 of Guyana*

| DBH (cm) | Carbon density (*R. mangle*) | | | | | |
|---|---|---|---|---|---|---|
| | Region 3 | | | Region 6 | | |
| | Tree Density (no. $ha^{-1}$) | Dominance (%) | Carbon density (Mg $ha^{-1}$) | Tree Density (no. $ha^{-1}$) | Dominance (%) | Carbon density (Mg $ha^{-1}$) |
| ≥5-10 | 34.00 | 28.57 | 0.41±0.19 | 17.00 | 20.00 | 0.21±0.8 |
| >10-20 | 17.00 | 14.29 | 1.71±1.00 | 17.00 | 20.00 | 1.01±0.42 |
| >20-30 | 34.00 | 28.57 | 8.35±2.12 | 34.00 | 40.00 | 9.05±2.79 |
| >30-40 | 17.00 | 14.29 | 9.38±1.25 | 17.00 | 20.00 | 17.95±5.39 |
| >40 | 17.00 | 14.29 | 33.79±3.15 | 0.00 | 0.00 | 0.00±0.00 |

6 (Table 2). Based on two way ANOVA (p=0.05) there is significant differences within all the regions of Guyana with reference to carbon density (F=0.028).

The growth parameters and carbon density of the two species within region 1-6 correlates with the earlier studies of Comeaux *et al.* (2012) and Giarrizzo *et al.* (2011). The carbon density (in terms of accumulated biomass) is affected by salt tolerance by mangroves in relation to climatic variables like hyper-saline conditions due to drought, heat, evaporation rate and low river discharge (Krauss *et al.,* 2008; Sherrod and McMillan, 1985).

**Riverine forest**

Research sites in Demerara river included both *R. mangle* and *A. germinans* while *L. racemose* was absent, whereas, Berbice and Essequibo rivers included both *R. mangle* and *A. germinans* while *L. racemose* was absent. Fig. 5 shows the tree density in riverine zones in Guyana for species *A. germinans* and *R. mangle*. The tree density was maximum in the DBH range of >10-20 cm for *R. mangle* species (in Essequibo river) followed by >20-30 cm range (*R. mangle*) and ≥5-10 cm range (*R. mangle* in Berbice river). Based on two way ANOVA (p=0.05) there is significant differences within the three riverine zones of Guyana with reference to tree density (F=0.007).

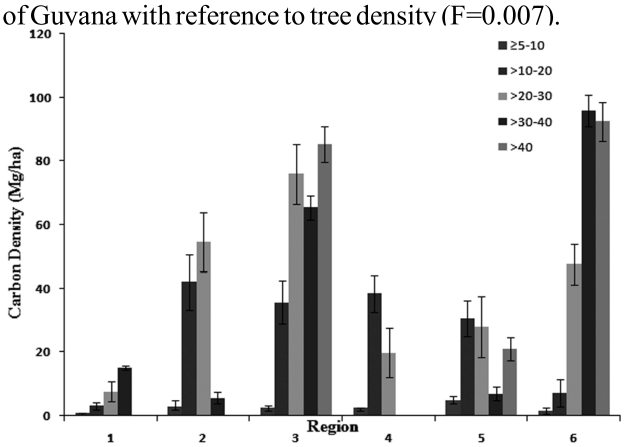



***Fig. 4.*** *Carbon density in regions 1-6 of Guyana*

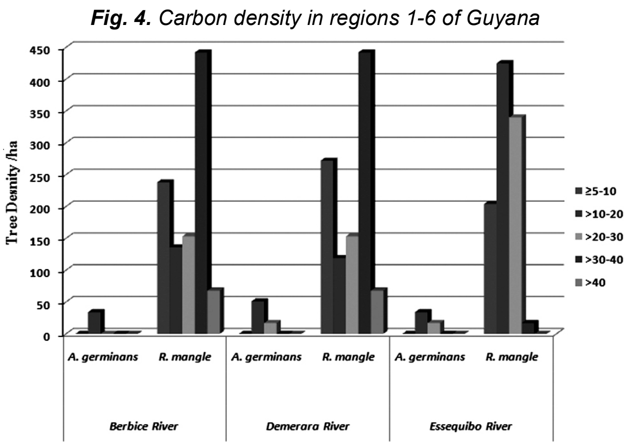



***Fig. 5.*** *Tree density in riverine zones*

The tree dominance (Fig. 6) was maximum in the DBH range of >10-20 cm for *A. germinans* species (Berbice river) followed by *A. germinans* in Demerara river and *A. germinans* in Essequibo river.

Carbon density (Table 3) was maximum in the DBH range of >30-40 cm for *R. mangle* species (in Berbice river) followed by *R. mangle* in Essequibo river in DBH range of >20-30 cm and *R. mangle* in Demerara river in DBH range >30-40 cm. The mangrove density, dominance and carbon density of mangroves in all the riverine zones are dominated by *R. mangle* in comparison to *A. germinans*. This is in agreement with the works of Comeaux *et al.* (2012) and Giarrizzo *et al.* (2011). These zones are less affected by turbulent factors such as tidal waves and hyper-salinity. The study locations in riverine zones are not within close proximity to residential area and therefore less contact with the inhabitants for usage for domestic purposes. There was also no evidence of pollution and farming, two principal means of destruction and degradation (Spalding *et al.*, 2010; FAO, 2007).

**Destructive analysis**

The estimated aboveground carbon for the *R. mangle* and *A. germinans* using the biomass values obtained from two methods *viz.,* one that was estimated from DBH (non destructive) and the other obtained by destructive analysis was quantitatively similar (Fig. 7). The equation already includes the correction factor of 19.5 % if height (H) is not available when estimating the biomass of the tree (Chave *et al.*, 2005). The calculated $X^2$ (0.85, 0.81, 0.45 and 0.74) values (respectively for each tree species) are less than the tabulated value $X^2$ (3.84). This indicated that there is no significant difference between the two methods used to determine the biomass of *R. mangle* and *A. germinans.*

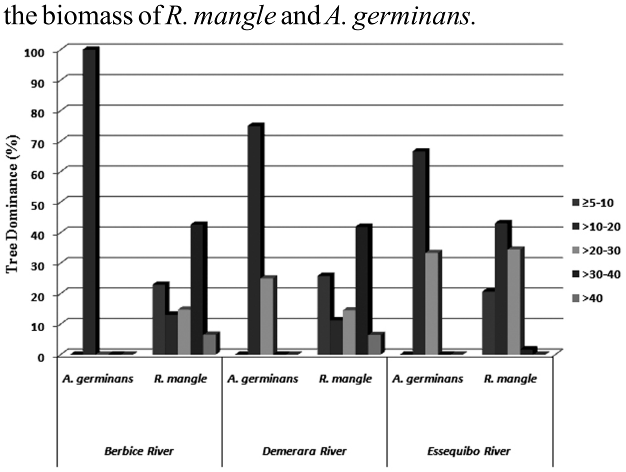



***Fig. 6.*** *Tree dominance in riverine zones*

***Table 3.*** *Carbon density in riverine zones*

| DBH (cm) | Carbon density (Mg ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | Berbice River | | Demerara River | | Essequibo River | |
| | *A. germinans* | *R. mangle* | *A. germinans* | *R. mangle* | *A. germinans* | *R. mangle* |
| ≥5-10 | 0.00±0.00 | 2.97±1.00 | 0.00±0.00 | 2.67±2.63 | 0.00±0.00 | 2.40±0.24 |
| >10-20 | 2.14±0.86 | 14.64±4.23 | 2.80±0.62 | 6.77±2.99 | 4.07±1.46 | 35.58±7.91 |
| >20-30 | 0.00±0.00 | 33.88±8.48 | 1.68±0.922 | 15.91±9.18 | 3.42±1.93 | 80.32±21.56 |
| >30-40 | 0.00±0.00 | 227.29±9.72 | 0.00±0.00 | 71.28±24.36 | 0.00±0.00 | 7.15±2.39 |
| >40 | 0.00±0.00 | 61.62±5.01 | 0.00±0.00 | 15.08±3.10 | 0.00±0.00 | 0.00±0.00 |

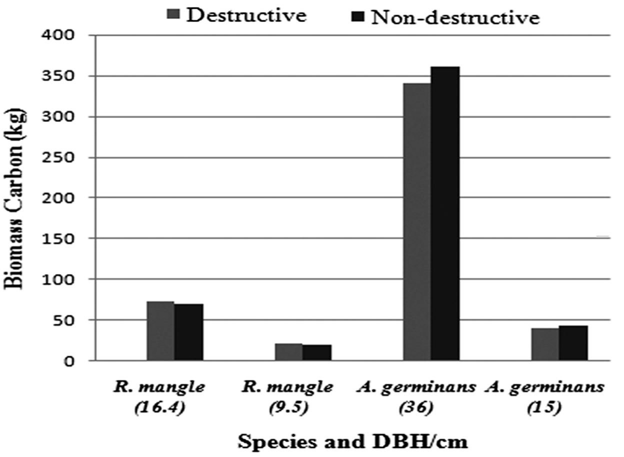



***Fig. 7.*** *Biomass carbon estimated from DBH and destructive analysis*

**Aboveground non –tree carbon**

Regions 3 and 5 have undergrowth of non-tree vegetation (Table 4). Mangrove distribution is clustered resulting in a very close canopy, thus preventing the penetration of light to allow the growth of forest floor vegetation. Region 6 shows a higher amount of carbon stored in non-tree vegetation. This is because there is more canopy opening and less trespassing of individuals in the area.

**Aboveground litter**

Litter collected from the forest floor shows interesting amounts of carbon captured and stored within the organic matter. Region 1 has the highest amount of carbon stored in litter while region 2 shows the least amount (Table 5). The regions with the highest significant amount of litter and consequently carbon are being less frequently flooded thereby leaving most of the litter on the floor. Also noticeable was the regions with higher amounts of litter which experienced less anthropogenic activities and trespassing. So less anthropogenic activities in these areas promoted better and sustainable growth resulting in greater number of matured trees with larger diameter size. Thus, higher amount of biomass carbon is being stored in their tissues.

***Table 4.*** *Non-tree carbon in different regions of Guyana*

| Region | Mangrove Coverage (ha) | Carbon (Mg ha$^{-1}$) | Carbon per region (MG) |
|---|---|---|---|
| 1 | 10161.8 | ND | ND |
| 2 | 4097.1 | ND | ND |
| 3 | 1513.5 | 3.06±0.53 | 4646.41±1.65 |
| 4 | 91.9 | ND | ND |
| 5 | 2082.8 | ND | ND |
| 6 | 4685.3 | 3.32±0.42 | 15555.07±1.42 |

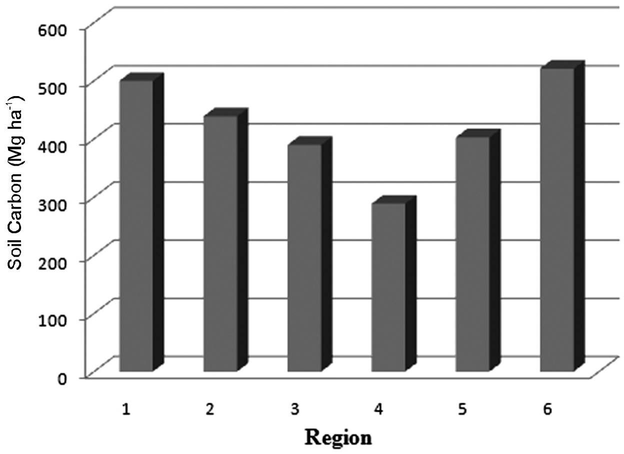
ND: Not detected

***Table 5.*** *Carbon in aboveground litter*

| Region | Mangrove Coverage (ha) | Carbon (Mg ha$^{-1}$) | Carbon per region (Mg) |
|---|---|---|---|
| 1 | 10161.80 | 3.23±0.82 | 32822.35±2.64 |
| 2 | 4097.10 | 3.13±0.45 | 12823.82±1.41 |
| 3 | 1513.50 | 2.66±0.99 | 4025.88±2.62 |
| 4 | 91.90 | 2.38±0.53 | 218.72±1,25 |
| 5 | 2082.80 | 2.57±1.17 | 5352.75±3.00 |
| 6 | 4685.30 | 1.61±0.64 | 7543.27±1.03 |

**Soil carbon**

Soil also serves as an important reservoir of carbon. The carbon stored in the mangrove shows wide variation based on the soil activity and environmental conditions. The carbon stored in soil is highest (500 Mg ha$^{-1}$) in Region 1 while the lowest is in Region 4 (298 Mg ha$^{-1}$) (Fig. 8). Soil contained significant amount of carbon that is trapped in mangrove forest, the estimated global average is 396 Mg C ha$^{-1}$. It is estimated that the amount of carbon per hectare in the world's most carbon-rich mangroves is 703 ± 38 Mg C ha$^{-1}$ and reduces in carbon poor soil to 272 ± 49 Mg C ha$^{-1}$. There is also substantial within-country variation in mangrove soil carbon. Mangove forest captured and stored significant amount of carbon dioxide from the atmosphere through carbon sequestration. While most of the carbon is stored as biomass in trees, a significant quantity is also found in the




florest floor and non-tree vegetation including dead wood. However, none of the study sites and more specifically the sampling plots did not have dead woody materials. The average estimated aboveground (live tree) carbon stored in mangrove species, in litter collection and non-tree in different regions of Guyana was 497.05 Mg ha$^{-1}$. This represented a higher estimate than that reported by Donato *et al*. (2011) who concluded that the aboveground carbon in mangrove forest varied with the minimum being 159 Mg C ha$^{-1}$ and the maximum 435 Mg C ha$^{-1}$.

**Aboveground carbon**

The results from all the regions of Guyana indicate that the two species (*R. mangle* and *A. germinans*) have greater aboveground carbon stock capacity (481 Mg ha$^{-1}$) which can absorb carbon dioxide released from various sources within Guyana. The total forest coverage of Guyana is 18.57 mha containing over 5 gt of $CO_2$ in aboveground biomass (NMMAP, 2012). Mangrove total coverage in Guyana is 22632.43 ha and estimated aboveground carbon locked is 0.016 gt which is equivalent to 0.059 gt of $CO_2$. This has taken into consideration the mangroves from the riverine and fringe physiographic and physiognomic forest categories and includes litter and non–tree data (Table 6). This is significant taking into consideration the low stature, coverage and density of mangroves (Spalding, 2010). Significant variations in DBH values and height were observed in the sampling areas among the regions. This resulted from less anthropogenic influence and thus more sustainable growth of the mangrove trees. In addition to the human influence on the continued depletion of mangroves, increase in tidal waves and drifting of the mudflats are also creating more disturbance of the natural environment for the sustainability of the mangroves.

The results indicated that there is no significant difference in the diameter class intervals with reference to carbon storage capacity of the mangrove species *R. mangle* and *A. germinans* in regions 1 - 6 in Guyana. There is significant difference in carbon storage in all the regions (1 - 6) of Guyana. The maximum storage capacity was observed in region 1 (Barima–Waini) which is statistically significant. This is due to the high mangrove coverage in that region which is 49.9% of the other 5 regions (Table 6). The present study conclusively indicate with all statistical subjugation that mangrove ecosystem contributes significantly towards absorbing carbon dioxide, thereby reducing the effects of global warming.

The findings of this study indicate that although mangroves are the most carbon-rich ecosystems in Guyana, this ecosystem accounts for less than 1% of total carbon storage potential for the country. This level of carbon storage potential is far below the global average of 3%. The relatively low level of carbon storage potential in Guyana's mangrove ecosystems reflects a comparatively low (0.12%) level of mangrove forest coverage in relation to other forest ecosystems. In light of Guyana's commitment to a low carbon development (LCD) strategy, the carbon storage potential of mangrove relative to its small areal extent, underscores the need for strategies, not only to preserve existing mangrove

***Table 6.*** *Estimated aboveground carbon in Guyana*

| Region | Mangrove Coverage (ha) | Total Aboveground Carbon (Mg) | | | |
|---|---|---|---|---|---|
| | | Non- Tree | Litter | Mangrove Tree | Total C |
| 1 | 10161.80 | ND | 32822.35 | 13498427.03 | 13531249.00 |
| 2 | 4097.10 | ND | 12823.82 | 431219.77 | 444043.60 |
| 3 | 1513.53 | 4646.41 | 4025.88 | 503965.20 | 512637.50 |
| 4 | 91.90 | ND | 218.72 | 5551.67 | 5770.39 |
| 5 | 2082.80 | ND | 5352.75 | 191367.66 | 196720.40 |
| 6 | 4685.30 | 15555.07 | 7543.27 | 1280258.00 | 1303356.00 |
| Total | 22632.43 | 20201.47 | 62786.89 | 15910789.33 | 15993778.00 |

forests, but also to restore and indeed expand the areal coverage of mangrove. These measures will serve to enhance the carbon storage potential of mangrove ecosystems in Guyana and better synchronized the LCD policy with measurable implementation actions.

Specific actions which are recommended based on the output of this research include mapping of appropriate sea-edge locations, the expansion of mangrove conservation areas, development of a mangrove expansion/conservation strategy/policy, indicating specific time frames and benchmarks, institute a program for monitoring trends in carbon stock, ecological modelling for carbon storage prediction in relation to climate change, integration of mangrove conservation/protection considerations into public and private sector development programs, promote mangrove conservation at all levels of the education system, but especially in primary and high schools, conduct a review of mangrove conservation-related policies, programs, and regulations in Guyana.

## REFERENCES

Adame, M. F., Kauffman, J. B., Medina, I., Gamboa, J. N., Torres, O., Caamal, J. P., Reza, R. and Herrera-Silveira, J. A. (2013). Carbon stocks of tropical coastal wetlands within the Harstic landscape of the Mexican Caribbean. *PLoS ONE* **8**(2): 1-13.

Albert, J. A, Warren-Rhodes, K, Schwarz, A. J and Duke, N. D. (2012). *Mangrove Ecosystem Services and Payments for Blue Carbon in Solomon Islands*, The World Fish Centre, Solomon Islands.

Brown, S. (1997). *Estimating Biomass and Biomass Change of Tropical Forests.* A primer. FAO. 134 p.

Brown, S. (2002). Measuring carbon in forests: current status and future challenges. *Environmental Pollution* **116**(3): 363-372.

Cahoon, D. R., Hensel, P. F., Spencer, T., Reed, D. J., McKee, K. L., Saintilan, N. (2006). Coastal wetland vulnerability to relative sea-level rise: wetland elevation trends and process controls. In: *Wetlands and Natural Resource Management, Ecological Studies,* Verhoeven, J. T. A., Beltman, B., Bobbink, R., Whigham, D. (eds.) **190**: 272 - 292.

Carolina, V., de Castilho, C., Magnusson, W., R. Nazare O. de Araujo, R., Luizao, R. C. C., Luizao, F. J., Lima, A. P. and Higuchi, N. (2006). Variation in aboveground tree live biomass in a central amazonian forest: effects of soil and topography. *Forest Ecology and Management* **234**: 85-96.

Chave, J., Andalo, C., Brown, C., Cairns, M. A., Chambers, J. Q., Eamus, D., H. Folster, H., Fromard, F.,Higuchi, N., T. Kira, T., Lescure, J. P., Nelson, B. W.,Ogawa, H., Puig, H., Rie´ra, B. and Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocksand balance in tropical forests. *Oecologia* **145**: 87-99.

Comeaux, R. S., Allison, M. A., Bianchi, T. S. (2012). Mangrove expansion in the Gulf of Mexico with climate change: Implications for wetland health and resistance to rising sea levels. *Estuarine Coastal and Shelf Science* **96**: 81-95.

Donato, P. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M. and Kanninen, M. (2001). Mangroves among the most carbon-rich forests in the topics. *Nature Geoscience* **4**(5): 293-297.

Ellison, A., Farnsworth, E. and Moore, G. (2010). *Avicennia schaueriana*. *The IUCN Red List of Threatened Species*. Version 2014.2. <www. iucnredlist.org>. Retrieved on 24 October 2014.

Food and Agriculture Organisation (FAO) of United Nations. (2007). *World's Mangrove 1980-2005. Forestry Paper 153.* FAO, Rome.

Fanshaw, D. B. (1952). *The Vegetation of British Guyana. A Preliminary Review.* Institute Paper No. 29. Oxford, I.F.I.

Giarrizzo, T., Schwamborn, R., Paul, U. S. (2011). Utilization of carbon sources in a northern Brazilian mangrove ecosystem. *Estuarine Coastal and Shelf Science* **95**: 447-457.

Guyana Forestry Commission (GFC) (2011). *Guyana National Forestry Policy Statement.* Guyana Forestry Commission, Georgetown, Gayana.

Houghton, R. A., Hall, F. and Goetz, S. J. (2009). Importance of biomass in the global carbon cycle. *Journal of Geophysical Research* **114**. G00E03, doi:10.1029/2009JG000935.

Hussein, M. (1990). *The Mangrove Belt in Guyana.* Technical Paper No. 1TCP/Guy 18953. FAO. Rome.

Intergovernmental Panel on Climate Change (IPCC). (1995). Cambridge University Press. 63 p.

Krauss, K. W., Lovelock, C. E., McKee, K. L., López-Hoffman, L., Ewe, S. M. L., Sousa, W. P., (2008). Environmental drivers in mangrove establishment and early development: a review. *Aquatic Botany* **89**: 105-127.

Kridiborworn, P., Chidthaisong, A., Yuttitham, M. and Tripetchkul, S. (2012). Carbon sequestration by mangrove forest planted specifically for charcoal production in Yeesarn, Samut Songkram. *Journal of Sustainable Energy and Environment* **3**: 87-92.

Langner, A., Miettinen, J., Siegert, F. (2007). Land cover change 2002–2005 in Borneo and the role of fire derived from MODIS imagery. *Global Change Biology* **13**: 2329-2340.

Li, M. S. and Lee, S. Y. (1997). Mangroves of China: a brief review. *Forest Ecology and Management* **96**: 241-259.

Lugo, A. E. and Snedaker, S. C. (1974). Ecology of mangroves. *Annual Review of Ecology and Systematics* **5**: 39-64.

National Land Use Plan (NLUP) Guyana. (2013). Guyana Lands and Surveys Commission, Goergetown, Guyana. 174 p.

National Mangrove Management Action Plan (NMMAP) 2010 – 2012. (2010). Guyana Forestry Commission, Georgetown, Guyana. 91 p.

Pearson, T. R. H., Brown, S. and Ravindranath. (2005). *United Nations Development Programme Global Environment Facility: Integrating Carbon Benefits Estimates into GEF Projects*. Winrock International. 64 p.

Richards, P. W. (1998). *The Tropical Rain Forest an Ecological Study*. (2nd ed.) United Kingdom: Cambridge University Press. 600 p.

Sherman, R.E., Fahey, T.J., Martinez, P. (2001). Hurricane impacts on a mangrove forest in the Dominican Republic, damage patterns and early recovery. *Biotropica* **33**: 393-408.

Sherrod, C.L., McMillan, C.,(1981). Black mangrove, *Avicennia germinans*, in Texas: past and present distribution. *Contributions in Marine Science* **24**: 115-131.

Spalding, M. D., Kaimuma, M. and Collins, L**.** (2010). *World Mangrove Atlas*. London: Earth Scan.

Tamooh, F., Huxhamd, M., Karachi, M., M. Mencuccini, M. and Kairo, B. (2008). Below-ground root yield and distribution in natural and replanted mangroveforests at Gazi Bay, Kenya. *Forest Ecology and Management* **256**: 1290–1297.

Valiela, I., Bowen, J. L., York, J. K. (2001). Mangrove forests: one of the world's threatened major tropical environments. *Bioscience* **51**: 807-815.

Woodroffe, C. D. (1987). Pacific island mangroves: distributions and environmental settings. *Pacific Science* **41**: 166–185.

Zar, J. H. (1996). *Bio Statistical Analysis* (3rd ed.) London: Prentice-Hall. 620 p.