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Structure, Biomass Carbon Stock and Sequestration Rate of Mangroves in the Bakassi Peninsula, S-W Cameroon

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ABSTRACT

The forest plays a major role in stabilizing increasing temperatures due to its climate mitigation capacity. This is not unconnected to the carbon storing and sequestration potentials of forests. The mangrove as one of the global forest types is said to be a major carbon store. This conclusion is characterized by some knowledge gaps on the actual carbon stock and sequestration potentials of some mangroves forest on the Central African Sub-regional landscape. Some of these areas are the Bakassi mangroves in the South West Cameroon. Cross-border conflicts, piracy and over exploitation have rendered the sourcing of appropriate data on its carbon stock and sequestration potentials difficult. In strive to bridge this knowledge gap, this work carried out a baseline assessment of the carbon stock and sequestration rate of the area. To achieve the study objectives, stratified random opportunistic sampling inventory design based on five forest canopy height classes, tree Diameter at Breast Height (DBH) and canopy nature using digital elevation model (DEM) of the shuttle Radar Topographic Mission (SRTM). This combination evaluated the species type and forest structure around the areas. Carbon stocks were estimated with the use of allometric equations using biomass data collected within main plots, sub plots, micro-plots and transects. Results showed that; mean biomass carbon stock density for the height classes for Bakassi ranged from 33.5 Mg/ha to 598.9Mg/ha. Thus on average, for a hectare in Bakassi, the carbon stock is 880.437 (Mg/ha) and a sequestration rate of 3231.204 (tCO_2e/ha).

KEYWORDS: *Biomass, structure, Carbon stock, sequestration rate, mangroves and Bakassi Peninsula*

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INRODUCTION

The forest plays an important role of stocking and sequestrating biomass carbon (Stringer *et al.,* 2016).This role is possible due to their ability to carry out carbon fixation. Carbon fixation occurs in the chloroplasts of green plants or any photosynthetic or chemoautotrophic organism (Rittnera and McCabe, 2004) resulting to large pools of carbon from sinking or cleansed carbon dioxide from the atmosphere (Mbobda *et al.,* 2016).Tropical forests cover a surface area of more than 13 million km^2; corresponding to 33 % of total forest area on earth (FAO, 2011). Mangrove forests are amongst and occupies less than 14 million ha of global forest cover (Giri *et al.,* 2011), just 0.1% of the Earth's continental surface, i.e. 81,485 km^2 (Hamilton and Casey, 2016). Mangroves of West and Central Africa extend over 20,144 km^2, representing 59 % of the African mangroves and 11 % of the total mangroves area in the World (UNEP-WCMC, 2007) and provide a broad array of ecosystem services (Barbier *et al.,* 2011), valued at an average of 4200 US/ ha/yr in Southeast Asia (Brander *et al.,* 2007). Amongst these values are those of carbon stock and sequestration potentials. They are amongst the most carbon (C) rich forests on Earth (Donato *et al.,*2012;Jones *et al.*, 2014) and have highest value per hectare of any blue carbon ecosystem (Nellemann *et al.,* 2016). On the voluntary carbon market, this values could generate revenue to support and incentivize locally-led sustainable mangrove management, improve livelihoods and alleviate anthropogenic pressures on the ecosystem .Developing policy tools to protect and restore mangroves through payment for ecosystem services (Friess *et al.,* 2016, Howard *et al.,* 2017) are important in their role in the terrestrial and oceanic carbon cycling (Alongi, 2012; Donato *et al.,* 2012; Liu *et al.,* 2014). In these regard, they contribute about 10 % of the total net primary production and 25 % of the carbon burial in the global coastal zone, though they colonize only 0.7 % of the global coastal zone (Alongi, 2007; Kathiresan and Bingham, 2001).Besides climate change mitigation, mangroves also render other services like; reducing hazards from winds, serving as breeding and spawning grounds for fishes, fuel wood for the community, construction materials and collection of other non-timber forest products amongst others.

Also, they are estimated to sequester carbon about 10–50 times faster than terrestrial systems (Chmura *et al.,* 2003; Bouillon et *al.,* 2008; Copertino, 2011; McLeod *et al.,* 2011; Siikamäki *et al.,* 2012; Alongi, 2014 and Howard *et al.,* 2017). With the increasing concern over climate change, efforts to evaluate the rate and value of carbon sequestration in forests systems has been increasing

(Bretón *et al.,* 2010; McLeod *et al.,* 2011; Nelleman *et al.,* 2016). At a time when, Africa's mangroves are the most understudied in the world (stringer *et al.,* 2015) especially in the subject of its carbon stock and sequestration services. This knowledge gap in carbon stock and sequestration potentials of most mangroves in Africa and particularly in Cameroon have prompted the assessment of the carbon stock and sequestration potentials of the mangroves of Bakassi Peninsula with hopes to bridge this gap and inform researchers, practitioners and policy makers on the nature of stock and sequestration potentials of the mangroves. This entailed assessing the biomass carbon (standing dead wood, standing live wood, litter herbs and grass, lianas, stumps down dead wood) (Kaufman and Donato, 2012) through a non-destructive method. Their effective assessment will give the government a high bargaining power in the carbon market since policy makers across the tropics propose that carbon finance could provide incentives for forest frontier communities to transition away from swidden agriculture (slash – and – burn or shifting cultivation) to other system that potentially reduce emissions and or increase carbon sequestration (Ziegler *et al.,* 2012).The biomass assessments will also give a reflection of the capacity of that ecosystem to sequester carbon. Many studies have been published on aboveground carbon stocks in tropical forests around the world (Komiyama *et al.,* 2005), but limited studies exist in Bakassi (Ajonina *et al.,* 2014). A gab which this study stand to partly bridge for the Bakassi mangrove areas and to establish baseline data on biomass pools for future studies in these areas since this forests role relies on reliable quantification of current carbon storage in the ecosystem as the baseline Also, concerns over increasing atmospheric carbon emissions are driving the need to improve understanding of carbon sequestration within global ecosystems and investigating solutions to mitigate the effects of resulting climate change (McLeod *et al.,* 2011; Siikamäki *et al.,* 2012; Alongi, 2014 and Howard *et al.,* 2017). Thus, protecting, enhancing and restoring natural carbon sinks have become political priorities (Sanderman *et al.,* 2018). Mangrove forests can play an important role in carbon removals; in addition to being some of the most carbon dense ecosystems in the world (Donato *et al* 2011; Wang *et al.,* 2013), though the role of mangroves in global carbon cycles has been somewhat ignored, due to their relatively small total area and often lower physical build (Spalding *et al.,* 2010).Globally, the total net primary production of the ecosystems has been estimated at 218 × 109 kg C year−1 (Bouillon *et al.,* 2008; Twilley *et al.,* 1992), ranking as one of the most productive biomes on the earth (Tue *et al.,* 2012). Therefore, the role of mangrove forests in the global carbon budget is significant (Bouillon *et al.,* 2008).

According to Ajonina *et al.*, 2014, 'Reducing Emissions from Deforestation and forest Degradation' (REDD+) is an emerging international financial mechanism enabling tropical countries to get rewarded for their efforts in reducing CO_2 emissions from deforestation and forest degradation, and a number of Central African countries including Cameroon have embarked on ambitious national reforms and investments to improve forest landscapes management in order to benefit from REDD+, this is good in mangroves since they can store several times more carbon per unit area than productive terrestrial forests (Donato *et al.,* 2011) and in Bakassi area that makes up about 10% of the mangroves of West Africa and half of the mangroves of Cameroon (CECO, Socio-economic studies, 2014)

The main problem that this research seeked to address is the lack or in appropriate nature of mangrove data, both in quality and quantity, especially on carbon stock and sequestration in this area where research is hampered by insecurity, mangroves destroyed by encroaches and the subject neglected by scientists, since this trans-boundary site between Cameroon and Nigeria is a remote and an undeveloped coastline

MATERIALS AND METHODS

Study site

This study was carried around the Bakassi Peninsula particularly in Ndian Divisions South-West Region of Cameroon, a biodiversity hotspot that supports high diversity of animal and plant species (MINEPDED, 2009um). The work touched 7 mangroves subdivisions (Bamuso, Ekondo Titi, Mundemba, Isangele, Kombo Abedimo, Kombo Itindi and Idabato), between latitudes 4°25′E and 5°10′N and longitudes 8°20′E and 9°08′N (GEF, 2016). Here, strong ocean waves work against the incoming river current to precipitate deposits in the form of large inter-tidal mud or sand flats which favours the growths of mangrove tree species. The climate is the equatorial and littoral types with two distinct seasons: a short dry season of 4 months (November to February) and a long rainy season almost 8 months (from March to October). The average rainfall ranges from 5000 mm to 10000 mm with July, August and September been the wettest months. Relative humidity is very high, above 85%. The main annual temperature is from 25, 5 ^{0}C to 27^0 C (GEF, 2016). The average tides waltz between 0.1 m to 2.9 m accompanied very often by scorching heat waves sometimes going up to 45 ° in the shade (Ocholi, 1986).

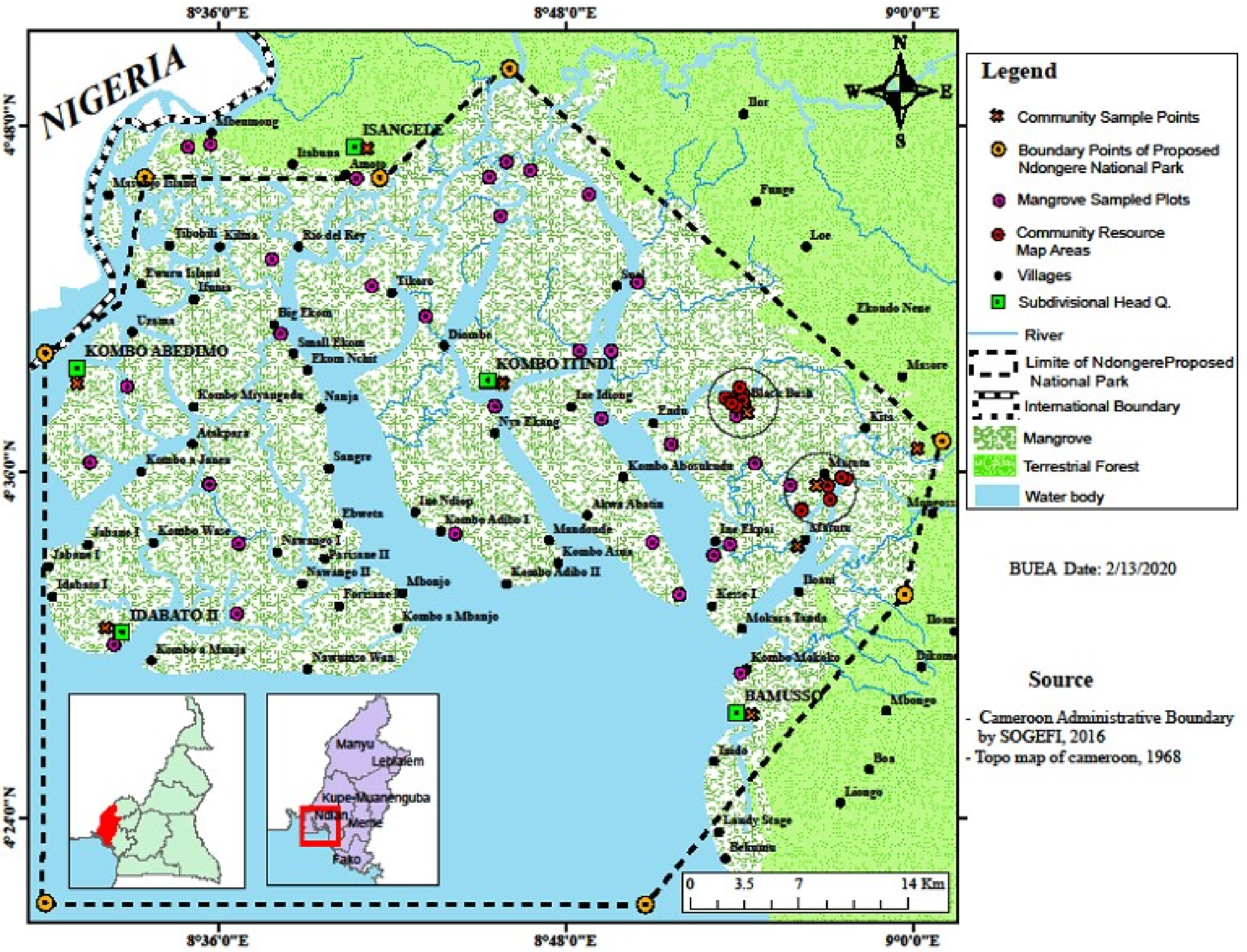

Figure: 1. map of Bakassi Peninsula

With a low elevation of 0 – 2m above sea level (Smoak *et al.,* 1999) the area is predominantly mangroves both indigenous and foreign species (Fig 1) with *Rhizophora racemosa,* dorminating (WWF, 2019). The soils rang from; sandy, ferralitic, to claylike or peat that are generally formed by the deposition of plant particles on watery soils (Smoak *et al.,* 1999).with very old and deeply weathered bedrock, the soils are depleted of nutrients (Bond, 2010) following leaching after heavy rains (Wong & Rowell, 1994).

This area is sparsely populated (about 150,000 and 300,000) by ethnic groups from Nigeria and Cameroon (Ejaghams and the Efiks) where about 70% of the population comes from Nigeria. Their primary economic activity is fishing, farming for subsistence needs as well as timber harvesting which is limited to artisanal tree cutting. Also, the area has rich oil reserves in neighboring areas of Nigeria (GEF, 2016) where off-shore oil exploitation has been going on since 1960, accounting for over 70% of Cameroon's oil production

Methodology

Stratification of the area was done following a Digital Elevation Model of the Shuttle Radar Topographic Mission (SRTM) to differentiate height ranges, since height was the basics of this stratification. Distinguished in to five classes (0-8, 8.1-14, 14.1-21, 21.1-28 and ≥ 28.1 with identities 1, 2, 3, 4 and 5 respectively. This was with the use of geometric intervals which is a compromise method between equal intervals, natural break (Jenks), and quantile (Carl *et al.,* 2015) thus, highlighting changes in the middle values and extreme values, giving a visually appealing and cartographically comprehensive result using ESRI (WWF, 2019). Preliminary stock assessments and test questionnaires for validity was carried out where random and opportunistic sampling was used to identify and establish plots. This took in to account the species, cost, security conditions, accessibility (nature of soil, tides) as recommended in stringer *et al.*, (2014) for better accuracy, precision ,efficiency and ascertain that the study is representative. This was following the heterogeneous nature of the forest and its functional reliability with the necessity to capture relevant variables in the equations coupled to the fact that the area was finite or known as recommended in Kauffman and Donato (2012), Zerim and Yerimu, (2013).

Plot design and establishment

With 50 m transect tape (Tibre)and compass (silver polasis), square plots of 20m x 20m were established, a 10 x 10m subplot was further design and lastly, four 1m x 1m nested plots establish at the extremes of the main quadrant. Four lines transects of 12m each were established at the corners of the plots and the plots centers were marked, i.e. inside the 10m x 10m as recommended in Jones (2014) and Kaufman and Donato (2012). Plots centers were collected with a Garmin GPS (Map 62).This design was preferred due to the diversity of the ecosystem, the need to measure trees of variant sizes, capture all variations within the area and to give better quantification of carbon stock estimates (ICIMOD, 2016)

Data collection for carbon stock assessment

To get species specific gravity, a botanical survey to identify all plant species within the sampled plots was done. Standard plant identification procedures as recorded in Letouzey (1986) from morphological features (leaves, aerial roots, flower, fruits, trunk) was used. When the species were identified, their species specific densities were referred from the World Agroforestry Data base for identified species and used in the allometric equation as recommended in Kaufman and Donato (2012).

Standing live tree DBH was gotten at 1.3m from the ground using the diameter tape and to the nearest 0.1cm. Climbing was done and measurements at 0.3m-0.5m for hight stilt roots. Trees diameters were measured as; > 5cm within the 20 m x 20 m, between 2.5cm - 5cm within the 10m x10m subplots and regenerating trees (< 2.5cm) within the 1m x1m plots. With a bold maker trees with at least 50% of their trunks inside the plots were marked and counted while those with 50 % outside the plot were not counted as recommended in Kaufman and Dnato (2012). Large lianas were considered as trees, and their DBH were measured DBH as recommended in Donato and Kauffman (2012). Standing dead trees were measured same but their status noted where, they were categorized in to 3 statuses; status I (having branches and twigs still present or recent dead trees), status 2 (having secondary branches only or no twigs) and status 3 (only the main branches or standing stems). For status 3 both the DBH and basal diameter were measured and this was used to calculate the top diameter of the trees as recommended in Kaufman and Donato (2012). Stumps were measured like standing dead trees (where DBH was > 1.3m), but where it was < 1.3m the diameter was measured as close as possible to the top. The height and dead state of the stumps were noted and classified as classes; 1 (a machete/knife did not sink into stump at a single strike), 2 (intermediate, a machete sank partly into at a single strike), and 3 (Rotten /crumble wood, machete cut through at a single strike) as recommended in Donato and Kauffman (2012). For biomass of the palms, all palm leaves (fronts) that occurred within each sample plot were counted for all the palms with height greater than 1.3m and at least 15-25 palm fronts from different individuals collected from ground level outside these sample plots. Their initial weights were taken on the field and samples taken to the laboratory to determine the dry weight. Trees heights were measured using a Suunto clinometer for a number of trees and the process continued through estimation using expert judgment. For Herbs and Grasses, all vegetation <1.3m in height were clipped off in the two 50cm by 50 cm micro quadrats at the 10m point on the 12m transect using a scissors down to the mineral soil surface as described in Striger *et al.,* (2015) while all Litter in the other two micro plots of 50cm x 50 cm were established at both the 6m and 12m points along the same 12m transect line on which herbs and grass were collected. The total weights of the samples in each plot were measured using a portable electronic (Wriheng) scale balance and readings documented to the nearest gram. Well mixed samples were composed from each subplot, weighed on the field and 50g at most collected for drying in the laboratory as recommended in Kaufman and Donato (2012). For Downed Dead Wood Debris, their diameter (in cm) were measured along the 12m line transects. Those that intersected these transects were counted and measured using aluminum caliper (go-no-go gauge) based on the classification: Fine (0-0.6), small (0.6-2.5), medium (2.5-7.6) and large(> 7.6) with a measurement approach (tallied from); 10m -12m, 7- 10m, 2-7m, and entire length respectively(Brown, 1971). Where each of the 3 smaller size classes where encountered, the number of debris intersections were tallied along the corresponding designated length of these transects. The numbers of intersections were counted, not the number of debris pieces. Individual diameters of large wood (> 7.6 cm) were measured and recorded along the entire transect length and its decay status recorded as solid or rotten as recorded in Kaufman and Donato (2012)

To get the specific gravity of wood debris, at least 20-25 pieces were randomly collected throughout the entire area from each class size where a representative range of size and species present in the sample plots was insured. Each piece collected had a mass of about 0.5 –50g, and were collected outside the sample plots to avoid disturbance and taken to the laboratory as recommended in Donato and Kauffman (2012)

Laboratory and Data analysis

Mean Specific Gravity for wood debris was determined dividing each wood mass (g) by its volume (cm^{-3}). To get the masses, wood debris pieces were oven dried using a memmert Oven at 105°C for 24 hours and their masses gotten through measurements on an electronic balance. Debris volumes were obtained by submerging wood in to a container placed on a digital balance and displaced water measured in a burrete at 0.2mL with error margine of 0.1mL. Since specific gravity of the water was known ($1gcm^{-3}$), the resultant displaced water in the burette was the volume of the particle. Their mean specific gravity was gotten by summing their individual specific gravities and dividing by the number of the wood counts.

To get the Dry mass for Litter Herbs and Grass (LHG), their samples taken to the laboratory where dried at 105°C for 24 hours using a memmert Oven and the dry masses measured on an electronic balance. These masses were inputted in to the formula to get the biomass of leaf, litter herbs and grass using; weight of fresh samples of leaf, litter, herbs and grass in metre square, weight of oven dry sample of leaf, litter and grass in grams, weight of fresh subsample of leaf, litter and grass in grams. These masses were converted to carbon concentration by multiplying it with the recommended representative conversion factor of 0.45 as mean carbon concentration for tropical forest litter, herbs and grass(Kauffman and Donato, 2012). Dry mass measurement for Nypa as gotten just as those for LHG

Data and statistical Analysis

For live trees, general allometric equations by Komiyama et *al*., (2005) were used for estimating the biomass of live standing trees for with DBH > 5cm (Above ground biomass) as recommended in Kauffman and Donato (2012). Also, Species specific densities of the identified species used were gotten from World Agroforestry Centre data base (G.W.W MEY) .To get biomass for Nypa, the number of leaves (leave density) was multiplied by average of the different leave masses.

Biomass were then converted to carbon using the carbon concentration of 0.5 above-ground carbpn (Kauffman and Donato, 2012).The sequestration rate of carbondioxied was gotten by multiplying the C by 3.67 for all the biomass (Pearson *et al.,* 2007).

With Lianas, the equation in Schnitzer *et al*., (2006) inputing diameter as a variable was used to get the biomass of lianas.The biomass was converted to carbon mass by multiplying with a default value for carbon concentration of 0.46 (Jaramillo *et al*., 2003b).

For Standing Dead Trees, corresponding to the decay status of each wood category, statuses 1 and 2 used the same allometric equation as in live trees and the densities used were those of the identified species.Where more than one species was identified, the density was their average. Thus, status 1 (those with almost all branches) were estimated using the live tree equation minus a constant of 2.5% from the tree biomass, while status 2(those that had lost its leaves and a portion of its main branches) was estimated by subtracting a constant of 20 % biomass accounting for both leaves and some branches. Status 3, were those that lost a significant part of their branches, and were difficult to subtract. In this case, the tree volume was estimated using an equation for a truncated cone where the top diameter was estimated with a taper equation, using the tree basal diameter and height as recommended in Kaufman and Donato (2012). The volume was then determined by assuming that the tree is a truncated cone. Once the volume was gotten, biomass of the dead trees in grams was then determined by multiplying the volume with the wood density. Biomass density estimated was converted to carbon mass by using the carbon conversion factor of 50% or 0.5.

With the Dead Downed Wood; small, fine and medium wood classes of the debris, the diameter of each wood particle was derived from the measurement of about 50-100 randomly selected particles of each class on the field.bTo get the quadratic mean diameter of the different classes, the diameter of each sampled piece of wood in the size class and the total number of pieces sampled were inputed in to the equation for this variable as mentioned in Kaufman Donato and (2012). For large down wood, their diameters were measured at the points of intersection of the transect using a diameter tape or caliper (go-no-go) and these diameters were used to get the volumes of the different downed woods.

Volumes calculation for fine, small and medium size woods, was through the equation developed for volume in Kaufman and Donato (2012) using the number of count of intersecting woody debris pieces in a size class, the quadratic mean diameter of each size class (c and the transect length (m) while for the large wood, the equation for volume using diameters of each intersecting pieces of the large wood (cm), and Length of transect was used as recommended in Kaufman and Donato (2012)

The biomasses of the downed wood debris (fine, small and medium) were then gotten by multiplying their volumes by the calculated mean specific gravity of their respective classes while those of large downed dead wood where equally calculated by multiplying its volume by the specific gravity of the plot's live wood species specific gravity or average of the different species. Thus, wood biomass was gotten by, multiplying the volume by the specific gravit. Finally the downed wood biomass was converted to carbon mass by multiplying the biomass by the carbon concentration of the wood using 0.5 or 50% which is the acceptable default value of carbon concentration for dead wood in the tropics (Kauffman and Donato, 2012).

Total carbon stock or the total ecosystem carbon pool

Total carbon stock in Mg per hectar for each height class were estimated by adding C of; standing live tree, standing dead tree, stump, lianas, palm, LHG and downed dead wood. These different height class carbon stock values were summed across the different height classes and divided by the total sampled area to get the average or baseline carbon stock in the entire project zone.

The data was inputted in to the excell spread following the stratification then charts and tables where produced in a simple and understandable way for all potential redears as commended in Djomo (2015).

Variables like the standard error of the mean in the carbon stock gotten was the standard deviation to the true mean of all the different means from the population (Tesfaye & Astrat (2013) while the standard deviations was taken as the square root of the variance, variations were the average of the squared deviations between each data thus, the mean was sum of all the values of the variable divided by the total as recommended in Yeomans (1968), Ullman (1978).

RESULTS

Plot flora diversity

The species variations amongst the different height classes were heterogeneous(Table 1). Plots had homogenous species in most cases and heterogenous in some. Within the sampled plots twelve plant (both true and associate mangrove) species were identifies belonging to 11 families.

Table1: True and associate mangrove species in sampled plots

SN	Species in Bakassi	Family	Habit
1	**Rhizophora racemosa*	Rhizophoraceae	Tree
2	**Laguncularia racemosa*	Combretaceae	Tree
3	**Nypa fructican* (Thumb) Wurmb	Arecaceae	Palm
4	**Acrostichum aureum* (Linner)	Pteridaceae	Herb
5	*#Ceasalpinia bonduc*	Ceasalpinoideae	Shrub
6	*#Cynometra ramiflora* L.	Leguminosea	Shrub
7	*#Dalbergia menoeides* (Prain)	Leguminosea	Liana
8	*#Dolichanrone spathacea*	Bignoniaceae	
9	*#Excoecaria agallocha*	Euphorbiaceae	Shrub
10	*#Hibiscus tiliaceus*	Malvaceae	Tree
11	*#Pandanus odoratissimus* (Boa Ikasbikeyo)	Pandanaceae	Shrub
12	*#Tristellateria australasiae* (A. Rich)	Malpighiaceae	

* = true mangroves species; # = associate mangrove species

The dominant family was Rhizophoraceae followed by Combretaceae with the two dominant species being *Rhizophora racemose* and *Laguncularia racemosa* for Rhizophoraceae and Combretaceae families respectively. The true mangrove species identified were; *Rhizophora racemosa, Laguncularia racemose, Acrostichum aureum,*and *Nypa fructican* (Thumb) Wurmb*.* The associate species recorded were; *Ceasalpinia bonduc, Cynometra ramiflora L., Dalbergia menoeides, Dolichanrone spathacea, Excoecaria agallocha, Hibiscus tiliaceus, Pandanus odoratissimus* (Boa Ikasbikeyo), *Tristellateria australasiae* (A. Rich)*. Nypa fructican* (nipa palm) identified is an invasive species to this area. The 8 associate mangrove species habits are normally; herbs, shrubs, lianas and epiphytes but those noticed were less than one meter thus considered as herbs or grass except for the Lianas and epiphytes. Also, *Acrostichum aureum* or mangrove fern occurred as underground vegetation in most degraded plots as well as plots with high elevation and those inland towards terrestrial forest.

Forest Structure

The mean heights ranged from 4.40 m to 25.81 m from height classes 1 to 5, respectively. This variation showed a steady increase from one class to the other (Table 2)

Table2: Structure for different height classes of over story

Height classes	1		2		3		4		5	
Elements	mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Height(M)	4.36	1.18	9.92	0.26	12.89	0.33	17.77	0.16	25.81	5.39
Diameter(CM)	8.17	1.49	12.46	5.48	24.93	1.52	34.24	1.68	47.43	13.77
Basal Area(M2/ha)	2.31	0.63	8.06	1.66	20.13	3.71	30.20	3.06	59.64	28.87
Density((Stem/ha)	525.00	212.38	1225.00	1024.83	390.63	53.55	279.17	15.97	300.00	86.60

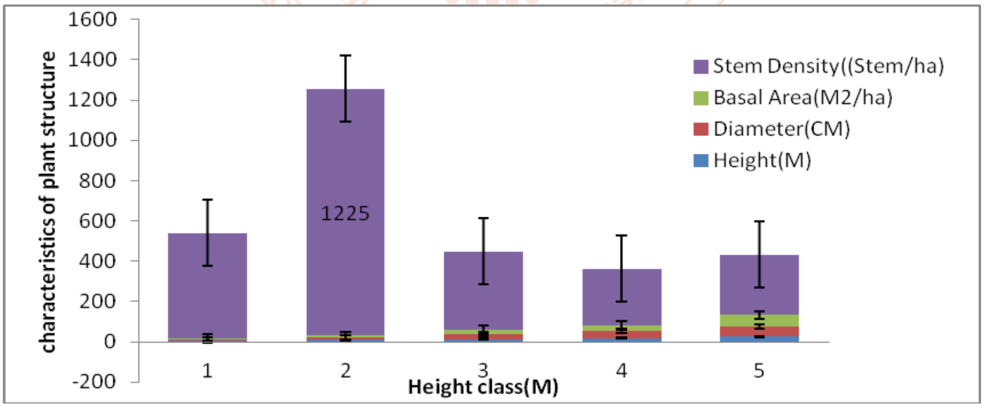

Figure2: Structure of mangrove stands in Bakassi

The mean tree diameter equally increased as their height classes changed. This ranged from 8.17 cm to 47.43 cm from height classes 1 to 5, respectively (Fig.2). The increasing diameter with height class was steady from the lower to the higher height class. The mean Basal areas ranged from 2.31 m² ha^{-1} to 59.64 m² ha^{-1}, exhibiting an increasing steady trend with height from height class 1 to height class 5(Fig.2). The mean stem density ranged from the minimum value of 279.17(height class 4) stem/ha to a maximum value of 1225 (height class 2) stem/ha. These values were however irregular amongst the classes. Averagely, it showed a decreasing trend with height (Fig.2).

Biomass Carbon stocks

The Biomass carbon stock involved all the vegetative components of these ecosystems or study areas; standing live wood, standing dead wood, stumps, down woody debris, LHG (Tab. 3). Standing live wood's carbon density ranged from 8.83(Mg/ha) for height class 1, to 594.16 (Mg/ha) for height class 5, increasing with class height and in a steady manner and had highest % of biomass C

Table3: Biomass mangrove density per height class

Biomass Carbon density per height class in Mg/ha										
Element	1		2		3		4		5	
Over story	mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Standing live trees	8.83	2.48	37.32	23.08	166.44	25.17	238.51	25.02	594.16	416.57
Standing dead trees	0.25	0.15	0.19	0.22	5.87	2.86	0.30	0.15	0.00	0.00
Stumps	0.30	0.30	4.31	4.97	26.10	18.46	16.70	7.46	0.00	0.00
Lianas	0.13	0.13	0.27	0.31	0.00	0.00	0.00	0.00	0.00	0.00
Down wood debris	0.00	0.00	69.10	75.65	10.71	6.10	28.15	6.70	0.00	0.00
Litter and Understory	24.01	14.42	2.12	1.42	6.98	2.81	2.50	0.54	4.79	2.26
Total	33.53	17.48	113.32	105.64	216.10	55.40	286.16	39.87	598.95	418.83

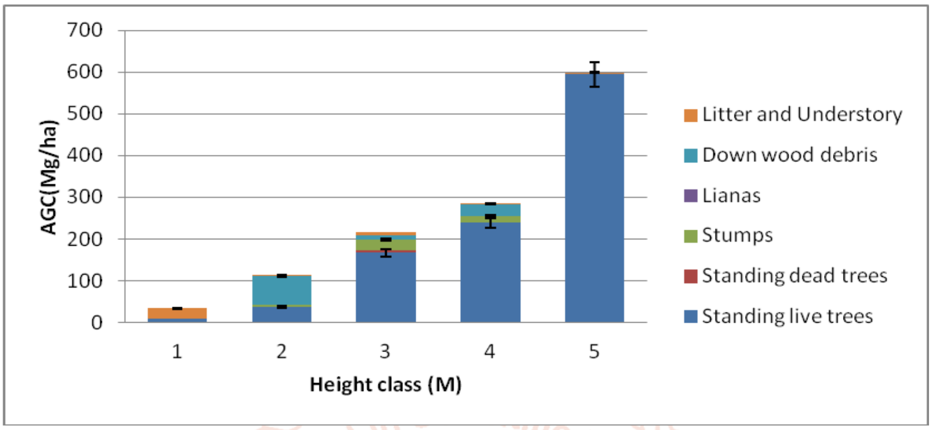

Figure3: Varaiations of components of AGC in Bakassi

Standing dead wood mean carbon density ranged from 0.00 (Mg/ha) in height class 5 to 5.87(Mg/ha) in height class 3.The variations where irregular and an irregular trend was witnessed as well (Fig.3). Stumps mean carbon density values per height class ranged from 0.00(Mg/ha) in height class 5 to 26.10 (Mg/ha) in class 3. Its variation across the different height classes were not steady and no steady trend could be witnessed. There was however an increasing trend with height. Lianas mean carbon densities ranging from 0.00 (Mg/ha) in height classes 3, 4 and 5 to 0.27 (Mg/ha) in height class 2.This variation across the sample plots were irregular and up to 3 height classes had no lianas. Where they were recorded, there was an increase in C stock values with height class (Fig.3). LHG mean carbon densities per height class ranged from 2.12 (Mg/ha) in height class 2 to 24.01 (Mg/ha) in height class 1. About 67.96% of the plots had litter and underground vegetation though the presence was not significant while 32.04% did not have any LHG. Even with this, their contribution to the total ecosystem carbon was low since the litter is constantly washed away by the backwash of the tidal waters. The trends of variations in this area were irregular from one height class to the other but generally decreasing (Fig.3). Down wood debris had mean carbon density values that ranged from 0.00 (Mg/ha) for height class 1 and 5, to 69.10 (Mg/ha) for height class 2. The wood debris was observed in about 42.86% of the sampled plots with very little samples within these plots.

However, during this research , trees considered as understory with DBH < 5cm where found only in height class 1 and made up about 2.5 % of the total trees sampled in that class. They had an average diameter of 8.17cm for all the trees recorded in that height class 1 so, they could not be sampled as understory since their average diameters were greater than 5 cm, since in this study understory was classified as trees with diameter < 5 cm.

Ecosystem Biomass Carbon Stocks

A sum of the different mean biomass carbon stock for the different pools ranged from 33.53(Mg/ha) in height class 1 to 598.95 (Mg/ha) in height class 5 and the results showed an increasing trend with increasing height class. Values were highest for height class 5 and lowest for height class 1(Fig.4)

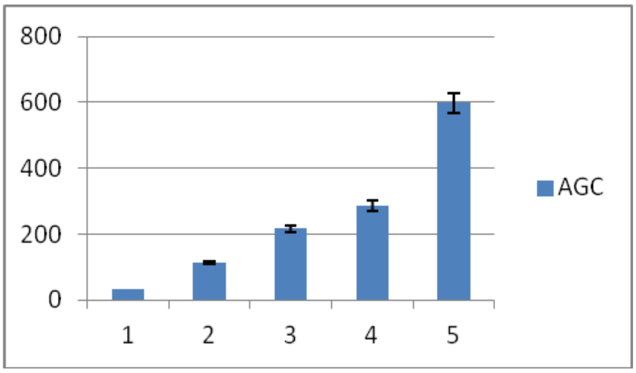

Figure4: Total Biomass Carbon density in Bakassi

Average carbon stock per height class

Average carbon stock per height class ranged from 739.298 (Mg/ha) in height class 1 to 1145.201(Mg/ha) in height class 5.The values increased in a regular manner from height class 1 to 5.

Per hectare average carbon for area

Table4: Average carbon per hectare

Height class	Total C stock(Mg C/ha)	Area(ha)	Total carbon/class height(Mg/ha)
1	739.30	0.16	118.29
2	740.29	0.12	88.83
3	989.88	0.32	316.76
4	823.37	0.48	395.22
5	1145.20	0.12	137.42
Total		1.20	1056.52
Av. Mg/ha			880.44

Thus on average, for a hectare in Bakassi, the carbon stock is 880.437 in Mg/ha (Tab. 4) and a sequestration rate of 3231.204 (tCO_2e/ha).

DISCUSION

Inventory Design

For a better quantification, accuracy and precision of the desired results a rectangular sampling design adapted from kaufman and Donato (2012), Jones (2014), WWF(2019), was used. Thus; trampling was reduced, accessibility was enhanced and sampling was consistent in all plots irrespective of the species composition. This approach was different from the circular plots recommended by Murdiyarso *et al.,* (2009), Kauffman and Donato (2012) in the Indo-pacific mangroves. The application of canopy height classes as the basis for stratification proved effective, since canopy height classes reflected variations in stand density and height that reflected the corresponding difference in biomass and carbon estimates. Thus the design gave the study an inclusion of the range in composition and structure of the entire forest area since; adults, mature, juvenile, seedlings, standing death, lianas, stumps, litter, herbs and grass as well as down dead trees were all studied.

Flora diversity

Mangrove type and distribution pattern follow topographical dynamics to tidal movements and tolerance to salinity. Climbers are often absent and few epiphytes are associated with mangroves due to their wide vessels and subjection to extreme water tension as they grow very high up the canopy or on inland mangrove fringes Tomlinson (1986). Four true and eight associate mangrove species were record making a total of 12 species identified (Tab.1).This is not up to the six true mangrove species in Cameroon as reported by UNEP (2007). Worthy of note are the facts that the species identifies were just those found within the sampled plots, and the sampling was random opportunistic thus may not cover species for the entire mangrove block (Djomo, 2015). Adekanmbi and Ogundipe (2009) reported more than 11 plant species in the mangroves of the neighbouring west African city of Lagos in Nigeria amongst were, *Laguncularia racemosa, Acrosticum aureum, , Hibiscus tiliaceus,* supporting the conclusion of their presence in the area. Like the rest of the mangroves in Cameroon, the area is dominated by Rhizophora sprecies. This is in line with other studies which have revealed that along the coast line of West and Central Africa, 8 species are unique with Rhizophora species and *Avicennia germinan* as the dominant species (Ajonina, 2008; Ajonina *et al.,* 2016 and Orock *et al.,* 2019). Amongst these species was the Nypa palm which is identified as an invasive species, out competing the indigenous mangroves in this area.

Forest Structure

The stand, structure and canopy height are influenced by; climate, topography and human disturbance. Mature undisturbed stands may have high dense canopy with little stratification. Competition for light promots linear growth and fewer stems grow per hectare than those on the edge of the forest (Tomlinson, 1986). This could be attributed to the nature of the terrain, rates of sedimentation in and varying soil type. The diameter range (8.17 to 47.43cm) in the area were less than those in the Douala Edea national park where plant species could reach a diameter of up to 131.7cm in well stocked stands (Ajonina, 2008). For the stem density (Fig. 2), where all necessary conditions are equal, the more dense a forest is, the taller the trees. This is because they do compete for sunlight in order to produce their required food in the process of photosynthesis. The variation in the number of stems per plot (279.17 to 1225 stem/ha).The decrease of stem density with height class is due to the intact nature of most plots showing less regeneration in the area.Where regeneration is ongoing stem density might be high than in than in established stands that tend to take up more space due to wide nature of their canopy.

Biomass carbon

The forest type, age and size class of trees influence the potential of forest to sequester carbon (Terakunpisut *et al*., 2007) while basal area and height of the dominant mangrove species in each vegetation types are the key indicator determining the nature of biomass ecosystem carbon stock (Mizanur *et al.,* 2014)

Standing Live wood range (8.83 to 594.16 Mg/ha) may have been influenced by human activities like; harvesting, slash and burnt agriculture, human induced fire and war that lead to their reduction in the stands (Tab. 3). The Carbon value was similar to (505 Mg/ha) those reported by Ajonina *et al.,* (2014) in Cameroon, around intact plots in Bamusso. This range differed slightly from the live tree values ranging from 75.4 Mg/ ha to 268.5 Mg /ha recorded by Stringer *et al.,* 2016 in Eastern Zambezi. Ocuurence of dead standing trees might be due to the age of the forest, pollution, deliberate killing or common mangrove diseases, which might not occure and the forest will be void of dead stands. Standing dead wood were realised with an average carbon stock density (5.87 Mg/ha) recorded (Fig. 3).This value falls within the range (5.37-10.97 Mg/ha) recorded by Stringer *et al.,* (2016) in the mangroves of the Zambezi. Stump stands could be justification of tree harvest.Though stumps stands are left in the soil after a greater portion of the wood have been harvested, they also make up a relevant proportion of carbon. Stumps will point if the forest is intact or degraded and rate of harvesting in the case of an agroforestry or silvicultural system. The range (0.00Mg/ha to 26.10(Mg/ha) of their average carbon density for the different class heights varied across the different plots following different species of interest to the community. Most plots with stumps were dominated by *Rhizophora racemosa* giving their need for drying of fish, construction of furniture and buildings. A few *laguncularia racemosa* species stump stands did exist but the community rarely used this species so they were least harvested. In the case of Lianas, though they do not regularly occur in mangroves, their value range (0.00Mg/ha to o.27Mg/ha) were low but recorded for the purpose of accuracy and efficiency of the study. They were recorded in plots with higher elevation and closer to the terrestrial habitat or associated forests. LHG are always few in the mangrove, since tidal waters often carry them away. They occur in areas of high natural or artificial degradation. In this area, litter occurred in areas of; higher elevation where they could not be washed off or decomposed easily from tidal or logging took place. Herbs and grass were witnessed in areas of open canopy, degraded plots or those closer to terrestrial environment. In this area, the mangrove fern was amongst the highest recorded. The assessment of LHG had values (2.12 to 24.01 Mg/ha) varied from one height class to the other. Most of the higher values occurred in the lower height class where litter fall or productivity was higher. This values were higher than those (0.17-0.66 Mg/ha) recorded by Stringer *et al.,* (2014) in the Mangroves of the Zambezi River Delta. Down wooden debris occurs in the mangroves in instances of degradation like; harvesting agriculture, or wind disaster, pollution, disease infestation or old age. Also, in plots that are constantly inundated, the down wood debris easily decomposes due to the presence of water and the elevated temperature in mangrove areas. They are equally reduced at times when humans pick them up to use as fuel wood or for other related uses. In Bakassi, DDW C values (0.00Mg/ha to 69.10 Mg/ha).This was higher than the values (6.72 -12.51 Mg/ha) reported by Stringer *et al.,* (2014) in the Zambezi River Delta.

Total Biomass Carbon density

The variation in biomass carbon is often influenced by; canopy cover and basal area, the biotic, edaphic, topographic and disturbance factors and age (Forrester *et al*., 2013; Gebeyehu and Soromessa, 2019; Bekele. *et al.* 2019). Plots with factors like larger tree; heights, diameter, stem densities and diameter had more biomass and carbon stock than those with lower value of the factors. The values increased with class height (33.53 to 599.0 Mg/ha) close to the values (32.47 Mg/ ha to 261.64 Mg/ha) reported by Hall and Uhling (1991), Ravindranath *et al*. (1997) and Haripriya (2000) and the (40 – 400 Mg/ha) range reported by Ziegler *et al.,* (2012) in S-E Asia. The values are partly within the ranges reported by *Ajonina et al.,* (2014) in the degraded plots (394Mg/ha)) in the Republic of Congo and the intact plots (825 Mg/ha) in Bamusso, Cameroon and larger than that reported (75.4-268.5 Mg/ha) by stringer *et al.,* (2014) in the Zambezi mangroves.

Total Ecosystem Carbon density (TEC)

The total ecosystem carbon is often the summation of the different biomass components of carbon stocks. During this study, the TEC for the Bakassi mangroves ranged from 739.30Mg/ha to 1145.2Mg/ha (Fig. 38). The ranges of these values were slightly lower than that reported for undisturbed plots (1520 Mg/ha) in Cameroon by Ajonina *et al.,* (2014) and higher than the range (119-737 Mg/ha) reported by Ziegler *et al.,* (2012) while calculating the REDD+ uncertainties in S-E Asia. The values recorded in this study are far above the ecosystem carbon density among the five height classes (373.78 Mg/ ha to 620.98Mg/ ha) recorded by Stringer *et al., (*2014) in the Zambezi mangroves.Thus, Looking at the per hectare carbon and sequestration rate; Per hecta, the Bakassi mangroves carbon stock stands at 880.437(Mg/ha) and has a sequestration rate of 3231.204 (tCO_2e /ha). This values are below the 1520Mg/ha reported for the undisturbed plots in Cameroon but larger than the values (454.92Mg C/ha and 340.87MgC/ha) reported by Benson *et al., (*2017) for the assessment of open and closed canopy mangrove respectively in S-W Madagascar. Also, the values are higher than the mean value (799MgC/ha) reported by kaufman and Bhomia (2017) for the mangroves of West-Central Africa and closer to the global values (885MgC/ha) for mangroves.

Conclusion

Increase with diameter, stem density and height, the mean biomass carbon density for the Bakassi peninsular ranged from 33.53 Mg C/ha to 598.95 Mg C/ha for the five different height classes witnessed and the sequestration rate of mangroves in this Peninsular ranged from 123.06tCO_2e/ha to 2198.15tCO_2e/ha for this same height classes.

Recommendation

Sustainable management of the mangrove should be promoted through afforestation and setting up of Forest Village Management Units to ensure good management practices, laws and community participate the process.

Perspectives

From this baseline assessment, a block to block assessment should bedone and the results used to set up a REDD+ pilot project for the area. Also, site specific allometric equations should be developed to realize accurate results.

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