Journal of Forestry Research and Management. Vol. 16(3).41-49; 2019, ISSN 0189-8418

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ABOVE-GROUND BOLE CARBON STOCK ESTIMATION USING FOREST INVENTORY OF THE SECONDARY FOREST ECOSYSTEM IN IBADAN, NIGERIA

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ABSTRACT

Secondary forest ecosystem contributes to global climate change mitigation through carbon sequestration. Above-Ground Bole Biomass (AGBB) is the major component for monitoring and estimating Carbon Stocks (CS) and fluxes in tropical forests. However, information on Above-Ground Bole Carbon Stock (AGBCS) for the International Institute of Tropical Agriculture (IITA), which hosts relics of the undisturbed secondary forest ecosystem in south-western Nigeria, has not been documented. Therefore, AGBCS of the secondary forest ecosystem was estimated using forest inventory technique. One hundred and forty plots of 50m x 50m were laid in IITA secondary forest using systematic sampling technique at 10% sampling intensity. Trees in each plot were enumerated and identified to species level. The Total Height (TH) and Diameter at Breast Height (DBH) of trees =10 cm were measured to determine Tree Volume (TV). Sixty wood core samples were randomly collected from dominant trees species at breast height for Wood Density (WD) estimation. The TV and WD were used to determine AGBB, which were converted to CS using standard forest inventory technique. Data were analysed using descriptive statistics, linear regression analysis and correlation matrix. A total of 9,985 individual trees comprising 121 tree species and 30 families were recorded. The highest and least frequency of species recorded were *Funtumia elastica* (61/ha) and *Cordia alliodora* (1/ha), respectively. The TH and DBH ranged from 4.70 to 39.30 m and 10.76 to 74.50 cm, respectively, while TV ranged from 129.57 to 167,186 m^3/ha. The WD of tree species ranged from 0.23 to 0.89 kg/cm^3. The AGBB and CS ranged from 101.06 to 881,834.92 kg/ha and 50.53 to 440,917.46 kg/ha, respectively. Above-ground bole carbon stock estimation based on forest inventory measurements of the secondary ecosystem is the most precise techniques. However, they are hard to conduct over large areas and are time consuming, costly and labour intensive.

Keywords: Carbon stock, inventory, secondary forest ecosystem, species, above-ground

Introduction

Tropical forests form a significant source of biodiversity and carbon storage. They account for about 44.0% of the world's forest (FAO, 2011). They also contain one of the major carbon pools and have a substantial function in the global carbon cycle. Forests store carbon and comprise about 80% of the entire above-ground organic carbon and 40% of the total below-ground organic carbon worldwide (FAO, 2011). Deforestation and forest degradation account for between 15% - 20% of global carbon emissions, and most of which comes from tropical regions of the world. Approximately 60% of the carbon sequestered by forests is released into the atmosphere through deforestation. Deforestation of

tropical forest releases about 1.5 Gt of carbon into the atmosphere every year (Gullison *et al.*, 2007). Deforestation and forest degradation are the main sources of greenhouse gas (GHG) emissions in most tropical regions (Gullison *et al.*, 2007).
Above-Ground Biomass (AGB) is an indicator of carbon sequestration. The amount of carbon sequestered by a forest reserve can be inferred from its AGB accumulation because about 50% of forest biomass is carbon (Brown, 1997). The majority of AGB assessments are achieved for the AGB of trees because it largely signifies the highest fraction of the total living biomass in a forest reserve and does not pose significant logistic glitches during forest inventory measurements (Bolton *et al.*, 2014)**.** Assessments of AGB can also be used to forecast root below-ground biomass, which is generally estimated to be about 20% of the total above-ground biomass (Achard *et al.*, 2014); this figure was based on a prognostic relationship determined from literature review (Mokany *et al.*, 2006). In addition, dead laying trees, standing dead or broken branches and leaves are normally supposed to correspond to range between 10% - 20% of the above-ground carbon stock in advanced forests (Houghton *et al.*, 2009).

As the problem of CO_2 emissions continues, part of the mitigation efforts rely on the development and availability of accurate environmentally benign and cost-effective techniques for measuring the quantity and quality of carbon sequestered. Although, conventional techniques for the estimation of biomass may be very precise, their use in carbon sequestration quantification is inadequate. Therefore, the study is aimed at estimating above-ground bole carbon using forest inventory measurements of the secondary forest ecosystem in Ibadan, Nigeria.

Materials and Methods

Study Area

The International Institute of Tropical Agriculture (IITA) Secondary Forest Ecosystem lies at 07^o 30' 00"N and 03^o 53' 30"E and approximately 227m altitude in the city of Ibadan. Ibadan lies in the rainforest zone to the south and savanna zone to the north. To the west lies the Dahomey Gap, where savanna reaches almost to the coast in neighbouring Benin Republic (Aghimien *et al.*, 2015). The secondary forest ecosystem is known for its trees, climbers, shrubs, lianas and grasses. The forest area is classified as dry semi-deciduous rainforest, with a mixture of fast growing pioneer tree species, such as *Anthocleista vogelii* , *Albizia spp.*, *Ceiba pentandra*, *Newbouldia laevis*, , and interspersed with slow growing emergents, including *Antiaris africana*, *Milicia excelsa*, and *Triplochiton scleroxylon*, together with abundant climbers and lianas, especially of the genera *Combretum* and *Dioscorea*, and an understorey of shrubs such as *Mallotus oppositifolius*, *Chassalia kolly* and *Sphenocentrum jollyanum* (Aghimien *et al.*, 2015).

Forest inventory data collection

Systematic sampling technique was used to select temporary sample plots (TSPs) of 50m x 50m (0.25ha) in size. The sample plots were primarily established with 10% sampling intensity. The total area of IITA secondary forest ecosystem was 350ha. One hundred and forty (140) sampling plots were systematically laid in the secondary forest ecosystem, trees in all of the plots with a diameter at breast height (DBH) equal to or greater than 10cm were measured. The trees within a sample plot were measured for diameter at breast height (DBH), diameter at top and bole height (BH). A botanist and local people assisted with the identification of

Journal of Forestry Research and Management. Vol. 16(3).41-49; 2019, ISSN 0189-8418
www.jfrm.org.ng

botanical names and local names of trees, respectively. Plots need to be allocated systematically so as to achieve above-ground biomass (Fayolle *et al.*, 2013). The number of sample plots and the distance between plots were determined by the formula (Goodman *et al.*, 2013);

$$N = \frac{T_A \, x S_i}{P_s \; x \; 100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where N = number of sample plots, P_S = Plot size, T_A = Total area of the forest and S_i = Sampling intensity, while the distance between plots was determined by the formula (Goodman *et al.*, 2013):

$$D = \sqrt{\left(\frac{Af \; X \; 10000}{N}\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots 2$$

Where D = inter plots distance (m), N = number of plots and Af = Area of the forest (ha).

Lu *et al.*, (2012) demonstrated that the precision of forest above-ground biomass estimates due to sampling error can increase by about 10% when the size of sample plots is increased from 0.25 ha to 1 ha.

Volume estimation

Frequently used volume equations include Smalian, Huber and Newton functions. Volume of bole sections are often calculated using Smalian's formula, or alternatively by using the geometric formula for the truncated cone. The above-ground bole biomass models were computed as a product of tree volume. The volume of trees was estimated using geometric formula for truncated cone as shown below;

$$V = \frac{\pi l}{3}(R^2 + Rr + r^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

Where;

V= Volume of the tree (m^3)

l = length of bole sections (m)

R,r = the diameters at the thick and the thin end (cm)

p = 3.143.

Estimation of wood density

Wood density is defined as the ratio of the oven-dry mass of a wood sample divided by the mass of water displaced by its green volume (Chave *et al.*, 2005). Seventy percent (70%) of the core samples were used for computation of wood density (Chave *et al.*, 2005). An estimate of wood density requires the collection of cores of wood from randomly selected trees species. The core samples were oven-dried to a constant weight at 105^o C (FAO, 1997); volume of core sample and density of the sample were compiled using equation 5 and 6.

$$V = \frac{\pi}{4} D^2 TL \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

Therefore,

$$\rho = \frac{M}{V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 6$$

Where,

ρ = wood density, M = oven-dry mass of core sample, V = volume of the core sample, TL = total length of the core sample, D = diameter of core sample, p = pi (3.143) (Chave *et al.*, 2005).

Above-ground bole biomass (AGBB) estimation

Above-ground bole biomass of the different trees was carried out using tree volume and wood density. Generally, AGBB was estimated as:

$$AGBB = Tree\ Volume\ X\ WD + \mathcal{E} \ldots\ldots\ldots\ldots 7$$

Where, WD and Ɛ, represent wood density and error (Aghimien *et al.*, 2015, Wang *et al.*, 2011).

Estimation of above-ground bole carbon stock (AGBCS) within a sample plot

The mean plot AGBB for each tree species in the secondary forest ecosystem of International Institute of Tropical Agriculture was computed and then multiplied by 0.25 (the number of 50m x 50m plots in a hectare**)** to acquire the AGBB per hectare. However half of the value gave the AGBCS per hectare for the secondary forest ecosystem (Aghimien *et al.*, 2015).

Results and Discussion

Vegetation Structure and Forest Composition

A total of one hundred and twenty one tree species were found in the temporary sample plots from 9,985 individual species. The dominant tree species included *Funtumia elastica* (2146), *Blighia sapida* (1400), *Newbuldia laevis* (1011), *Antiaris africana* (927), *Ficus exasperata* (823), *Gambeya albidum* (715), *Spondias laevis* (670), *Lecanodiscus cupanioides* (351), *Celtis africana* (237), Albizia *zygia* (236), *Holarrhena floribunda* (146), *Nauclea diderrichii* (107), *Millettia thonningii* (86), *Morus mesozygia* (66), *Milicia excelsa* (36), respectively (Table 1). Some dominant species in this study were similar to the previous studies carried out by Aghimien *et al.*, (2015) which included *Newbouldia leavis* (193), *Blighia sapida* (148), *Funtumia elastic* (139), *Ficus exasperate* (78), respectively.

Table 1: Summary of Species Composition in the IITA Secondary Forest Ecosystem

S/N	Species	Family	frequency	%
1	*Adenanthera pavonina*	Fabaceae –Mim	1	0.01
2	*Afzelia africana*	Fabaceae –Caes	3	0.03
3	*Afzelia bella*	Fabaceae –Caes	4	0.04
4	*Afzelia bipindensis*	Fabaceae –Caes	4	0.04
5	*Afzelia quanzensis*	Fabaceae –Caes	4	0.04
6	*Aganope leucobotrya*	Fabaceae –Pap	2	0.02
7	*Albizia falcataria*	Fabaceae –Mim	6	0.06
8	*Albizia lebbeck*	Fabaceae –Mim	7	0.07
9	*Albizia lebbeck*	Fabaceae –Mim	7	0.07
10	*Albizia niopoides*	Fabaceae –Mim	7	0.07
11	*Albizia zygia*	Fabaceae –Mim	236	2.35
12	*Alchornea cordifolia*	Euphorbiaceae	7	0.07
13	*Anacardium occidentale*	Anacardiaceae	5	0.05
14	*Anthonotha macrophylla*	Fabaceae	4	0.04
15	*Antiaris africana*	Moraceae	927	9.22
16	*Zanthoxylum xanthoxyloids*	Rutaceae	1	0.01

Above-Ground Bole Carbon Stocks Estimation from Forest Inventory

The diameter at breast height and bole height of individual species ranged from 10.76 to 74.50 cm and 4.70 to 39.30 m with error value of 0.08 and 0.04 respectively. It implies that the lower the error values the closer to accuracy. The histogram on the distribution of tree bole height and diameter at breast height are presented in Figures 1 and 2. The densities of wood are indirect indicators of carbon storage capacity of trees. Standard wood density varies among the tree species ranging from 0.25kg/cm^3 to 1.00kg/cm^3, with about 90.00% of wood density falling between 0.51kg/cm^3 and 0.75kg/cm^3. It implies that the density of wood >1kg/cm^3 will sink in water while density of wood <1kg/cm^3 will float in water. The histogram on the distribution of wood density is presented in Figure 3. Wood density of core samples taken at breast height were not assumed to represent the wood density of the whole tree but is only used as statistical predictors of the above-ground bole biomass of tree and has been shown to be significantly correlated with the above-ground bole biomass of trees.

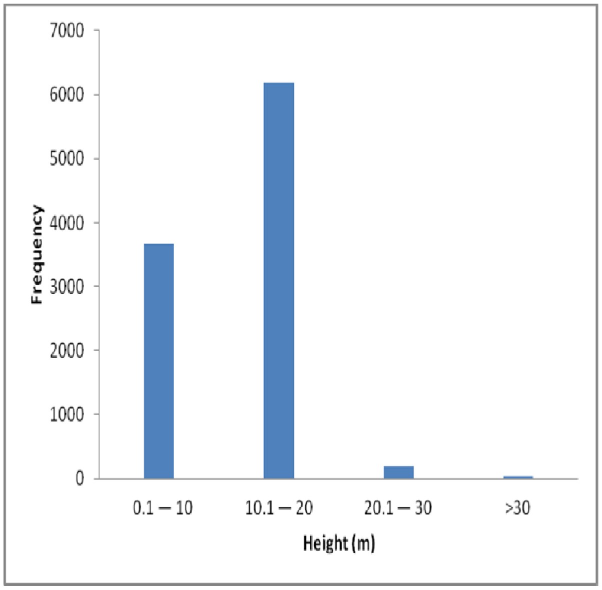

Figure 1: Bole Height and DBH in the Secondary Forest Ecosystem

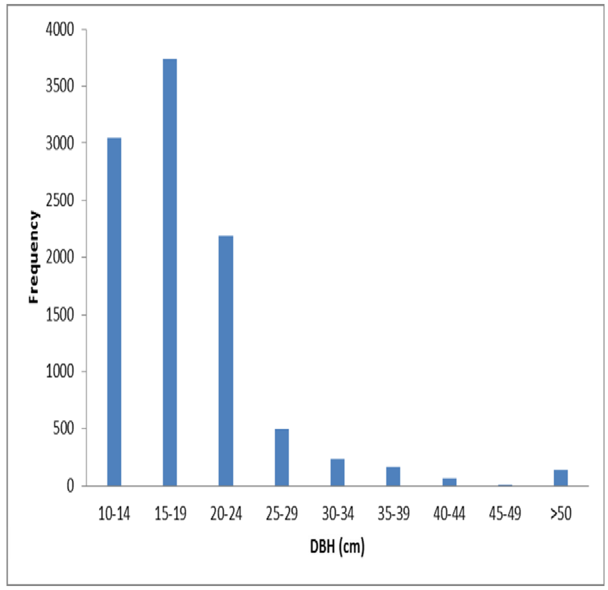

Figure 2: Diameter at Breast Height in the Secondary Forest Ecosystem

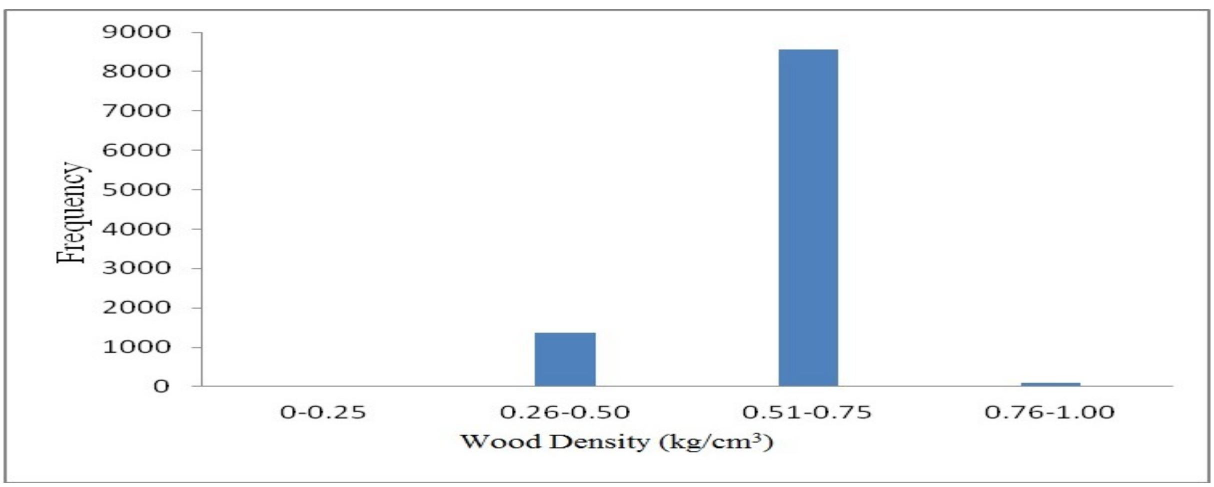

Figure 3: Wood Density of Tree Species in the Secondary Forest Ecosystem

The highest above-ground bole carbon stock (AGBCS) per hectare were found in the family of Moraceae with a value of 440917.46 kg/ha, followed by Apocaceae with a value of 265596.71 kg/ha, while Boraginaceae had the lowest AGBCS per hectare with a value of 50.53 kg/ha. The results also showed that the highest above-ground bole biomass per hectare were found in the family of Moraceae with a value of 881834.92 kg/ha, followed by the family of Apocaceae with a value of 531193.41 kg/ha, while Boraginaceae had the lowest value of above-ground bole biomass per hectare with a

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value of 101.06 kg/ha. The highest tree volume per hectare was recorded in the family of Moraceae with a value of 1671858 m^3/ha, followed by Apocaceae with a value of 965763.80 m^3/ha, while Boraginaceae recorded the least tree volume per hectare of 129.57 m^3/ha. The total above-ground bole biomass and bole carbon stock per hectare for all the trees species were calculated to be 3381754.16 kg/ha and 1690877.08 kg/ha as presented in Table 2.

Table 2: Tree Volume and Above-Ground Bole Carbon Stocks per Hectare

Family	**TV m^3 per ha**	**AGBB kg per ha**	**AGBCS kg per ha**
Anacardiaceae	435502.50	235052.11	117526.06
Apocaceae	965763.80	531193.41	265596.71
Bombacaceae	1434.96	330.04	165.02
Bignoniaceae	338345.70	189461.29	94730.65
Boraginaceae	129.57	101.06	50.53
Chrysobalanaceae	1302.51	1159.23	579.62
Combreteceae	587.43	322.86	161.43
Caesalpinaceae	1909.76	1268.32	634.16
Ebenaceae	24033.14	16823.20	8411.60
Euphorbiaceae	1355.12	528.50	264.25
Fabaceae	45570.81	27928.83	13964.42
Helicteraceae	107186.70	34299.74	17149.87
Irvingiaceae	7493.70	4562.14	2281.07
Leg-Caes	15261.25	11718.97	5859.49
Leg-Mim	238228.50	141756.64	70878.32
Leg-Pap	431822.40	250141.16	125070.58
Leycithidaceae	6223.47	2551.62	1275.81
Malvaceae-Tiliaceae	3056.72	1719.84	859.92
Moraceae	167186	881834.92	440917.46
Myristicaceae	159071	95442.61	47721.31
Meliaceae	87430.18	52458.11	26229.05
Moringaceae	361.62	216.97	108.49
Proteaceae	7739.12	4488.69	2244.34
Rutaceae	811.87	267.92	133.96
Rubiaceae	26465.86	16673.49	8336.75
Sapindaceae	716009.80	418476.63	209238.32
Sapotaceae	496678.40	347414.65	173707.32
Sterculiaceae	3838.53	3336.64	1668.32
Ulmaceae	140491.20	105487.43	52743.72

Verbenaceae	11553.96	4737.12	2368.56

Aghimien *et al.,* (2015) reported that the above-ground tree biomass at whole stand level accounted for 838036.15 g/ha through allometric equations, while above-ground tree biomass and carbon per hectare accounted for 736560.83 g/ha and 368280.40 g/ha through standard technique. The difference in the current and previous studies could be due to the variation in distribution characteristics across the temporary sample plots covering a wider area in IITA secondary forest ecosystem. The percentage carbon content in wood biomass of the tree species ranged from 48.5% to 54.4%, with an average carbon content of 52.3%. Intergovernmental panel on climate change (2006) recommended carbon content of 49% (in wood and tree = 10 cm) for tropical forests. The generic assumption that tree above-ground biomass consist of 50% carbon remain common place in forest carbon estimates and have been widely used by researcher (Soto-Pinto *et al.*, 2010); (Beets *et al.*, 2011). However the use of this value or the wood carbon content value of 49% would result in an underestimation of carbon content.

Earlier studies have also shown that the use of these values may result to either an underestimation or overestimation in carbon content by between 2% - 8% (Jones and Hara, 2012). A review of carbon content reported in previous studies in the tropics found the carbon content ranges of 41% to 59%. Martin and Thomas, (2011) found that carbon content varied from 41% to 51.6% with a mean of 47.4% for 59 rain forest tree species in tropical forest in Panama. The mean carbon content of 46.53% was found in tropical forest of Cameroon (Djomo *et al.*, 2011). The average carbon content of 50.8% and 48.2% for some conifers and broadleaf species respectively were found in a tropical forest in Costa Rica (Arias *et al*., 2011). Based on the values obtained from the previous studies, the generic 50% average carbon content was used for the estimation of above-ground bole carbon stock in this study.

A very strong linear relationship was observed between above-ground bole biomass per hectare and tree volume with correlation value of 0.99, followed by total height and diameter at breast height with a value of 0.99. However, the lowest linear relationship between above-ground bole biomass per hectare and wood density had a value of 0.89 as presented in Table 3. This implies that all the indicators were suitable predictors for estimating above-ground bole biomass.

Table 3: Pearson correlation Matrix for Forest Inventory Variables

	BH (m)	DBH (cm)	WD (kg/m^3)	TV (m^3)	AGBB per ha
BH (m)	1				
DBH (cm)	0.99* 0.0000	1			
WD (kg/m^3)	0.99* 0.0000	0.99* 0.0000	1		
TV (m^3)	0.92* 0.0000	0.92* 0.0000	0.87* 0.0000	1	
AGBB per ha	0.93* 0.0000	0.93* 0.0000	0.89* 0.0000	0.99* 0.0000	1

- = Significant level at 0.05

Conclusion

Forests are the largest carbon pool on earth. It acts as a major source and carbon sinks in nature. Thus, it has a potential to form a chief component in the mitigation of global warming and adaptation to change in climate. The principal element for the estimation of forest's carbon stocks is the estimation of forest above-ground bole biomass. It is possible to improve global measurements of forest area, biomass, structure and carbon using remote sensing techniques that are currently available. The use of high-resolution forest imagery will improve the quality of information generated, but above-ground bole carbon stock estimation based on forest inventory measurements of the secondary ecosystem is the most precise techniques. However, they are hard to conduct over large areas and are time consuming, costly and labour intensive.

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