Quantification of Carbon Stocks With The Common Tree Genus In Dryland Forest In Taita Ranch, South Eastern Kenya

J. E. Eregae, M. W. Gichuhi, and G. Mwangi

Abstract- Mapping of carbon stock in Kenya is central in establishing what potential the country has as far as carbon emission and concentration reduction through forest carbon sequestration effort is concern. This will ultimately define and position the country in carbon "business" if need be and display efforts employed in combating global warming and climate change by protecting and enhancing forest cover. There are some studies that have been conducted outside Africa continent majorly wet climate forest on biomass estimation. However, little has been done to quantify biomass in dry land ecosystem which is about 70% of Kenya land. This study therefore aimed at establishing the level of carbon capture and storage by the common tree genus and their respective species in dry land ecosystem, and estimate the amount of co_2 capture and storage potential of these species in South East Kenya. Twenty five tree species from fourteen genus and a total of 2060 individual trees were sampled. Wildlife Work regression model was used to do biomass estimation and the computation done estimated the total tree biomass in the study area as 262 Mg, approximated to 26.2 Mg/ha. Biomass estimates varied significantly with genus *Commiphora* recording the highest biomass of 241 Mg followed by *Vachenia and Acacia* which recorded 30 Mg. *Boswellia, Lannae, and Boscia* recorded 22Mg, 18Mg and 11 Mg respectively. In terms of dominance genus *Commiphora* dominated at 46% followed by *Lannea* with 19% and *Boswellia* at 13% and *Vachelia* and *Boscia* recorded 9% each while the other pooled genus contributed 2%. *The* age of forest in the study area ranged between 30yrs to 40 years and based on the average biomass estimates then genus *Commiphora* is able to capture about 5.5 Mg of CO_2 per year, *Acacia and Vachenia* is able to capture 5.4 Kgs while *Boswellia, Lannae* and *Boscia* are able capture 2.6kgs, 2.1kgs and 1.8kgs respectively and other genus pooled together capture 3.2kgs on average. Given the above biomass estimates therefore, genus *Commiphora* and *Acacia and Vachenia* lead in terms of carbon capture, storage and release of carbon if harvested for charcoal production.

Keywords—Total Biomass, Carbon Sequestration, Dominant Tree Genus, Regression Model

I. INTRODUCTION

Carbon dioxide (CO2) is one of the greenhouse gases and a primary agent of global warming. It is one of the so-called 'greenhouse gases' which are responsible for absorbing energy from the sun, leading to warming of the earth's atmosphere – the 'greenhouse effect'.Carbon dioxide (CO_2) is an important trace gas in Earth's atmosphere currently constituting about 0.04% (400 parts per million) of the atmosphere(A. Vaughan, 2015; Dlugo kencky & Tans Pieter, 2015)[1], [15]. Many GHGs occur naturally in the atmosphere and their presence is important for ensuring that the global climate is warm enough to support life (Broadmeadow & Mathews, 2003)[8].

Carbon sequestration is the capture and storage of carbon and its products to either mitigate or defer global warming thus avoid dangerous climate change impacts (Kort & Turnock, 1999)[37]. When humans' burn fossil fuels and industrial processes, most of the carbon contributed from the processes, quickly enters the atmosphere as carbon dioxide which constitutes 78% of the total anthropogenic greenhouse gases by 2010 (IPCC, 2014)[32]. The resulting CO_2 causes between 9% - 26% of the greenhouse effect (Kiehl & Trenberth, 1997)[35]. Water vapor is the dominant contributor (~50% of the greenhouse effect), followed by clouds (~25%) and then CO2 with ~20%. All other absorbers play only minor roles (Gavin A. Schmidt, Reto A. Ruedy, Ron L. Miller, & Lacis, 2010)[23].

The amount of carbon dioxide in the atmosphere has increased from 280 ppm in the pre- industrial era (1750) to 379 ppm in 2005, and is increasing by 1.5 ppm per year(Oke & Olatiilu, 2011)[40] and has risen to 402 ppm as of 2016 (E. Dlugo kencky, 2016)[18]. Dramatic rise of CO2 concentration is attributed largely to human activities. Over the last 20 years, 10% - 30% carbon emission is attributed to land use change and deforestation(IPCC, 2001, 2007)[28], [31]. Article 4 of the United Nations Framework Convention on Climate Change (UNFCCC) requires preventing and minimizing climate change by "limiting anthropogenic emissions of greenhouse and protecting and enhancing greenhouse gas sinks and reservoirs".(UNFCC, 2006)[52]. Atmospheric CO2 concentration can be decreased not only by reducing fossil fuel burning but also by increasing the terrestrial ecosystems that serve as sinks for CO_2(Pragasan & Karthick, 2013; P. H. Thangata & P. E. Hildebrand, 2012)[44], [50].

Plants use carbon dioxide and sunlight to make their own food and grow. Long-lived plants like trees might keep the carbon sequestered for a long period of time. Once the tree dies, or as limbs, leaves, seeds, or blossoms drop from the tree, the plant material decomposes and the carbon is released(Benites, Dudal, & Koohafkan, 1999; David & Crane, 2002; P.H. Thangata & P.E. Hildebrand, 2012)[6], [13], [51]. About two-thirds of the globe's terrestrial carbon, exclusive of that sequestered in rocks and sediments, is

J. E. Eregae Author, Department of Energy and Environmental Technology, JKUAT Phone : +254723805913 jeregae@yahoo.com , jeregae@gmail.com
M. W. Gichuhi Co-author Institute of Energy and Environmental Technology, JKUAT phone: +254722311787 email: gichuhimw2@yahoo.com,
G. Mwangi Co-Author wildlife works Kenya-Rukinga ranch Voi email: mwangi@wildlifeworks.com, mwangi_githiru@yahoo.co.uk

sequestered in the standing forests, forest understory plants, leaf and forest debris, and in forest soils"(Roger A. Sedjo, Sohngen, & Jagger, 1998)[45]. Forest programs can effectively provide roughly 30% of the total global effort needed to meet climate mitigation strategies with minimal cost (Arul Pragasan L & A, 2013)[4]. "globally there are about 1.7 Gt/ha of other wooded lands, which include open wooded land, scrub, brush land and forest fallows (resulting from shifting cultivation)" (FAO., 1995)[21]. Even though some of the other wooded lands are unsuitable for forestry, they have considerable potential to mitigate CO_2 emissions if managed appropriately (e.g. through fire prevention in savannahs). In this regard, it is necessary to know the carbon storage capacity in different plant species in their natural habitat and for this case savanna woodland vegetation that is part of the dry land ecosystem.

Mapping of biomass of dry land ecosystem will further be useful in several habitat management and selecting species for afforestation and reforestation programmes. Improved quantification of carbon pools and fluxes in savanna woodland ecosystems underlies the contribution to the net carbon emissions and their potential for carbon sequestration. The estimation of biomass for various dry land tree species is likely to communicate which tree species are key in carbon sequestration. This could then determine which dry land adapted species could be suitable for afforestation and reforestation programs for enhancing country carbon credit potential. This study was aimed to quantify carbon stock of common tree genus and their respective species in Taita ranch, Kasigau corridor South Eastern Kenya. Which is *Acacia-Commiphora* dominated forest.

II. MATERIALS AND METHOD

A. *The Study Area*

The study area is located at eastern edge of Taita Ranch that is 35,612 ha, owned by Taita Ranching Company Ltd a collection of indigenous local shareholders. It is within Kasigau corridor that connects Tsavo East National Park and Tsavo West National Park in Taita Taveta County and located to the South East of the Taita Hills, approximately 4 kilometers west of Mackinon town which is along Voi - Mombasa highway. The area qualifies as High Conservation Value based on IUCN guideline (Donson, 2006a, 2006b)[16], [17]. The study area is largely comprised of *Acacia-Commiphora* Dryland Forest, where the dominant species are drought tolerant. Tree species in the area have a number of strategies for surviving low moisture and high temperature or for surviving in the arid/semi-arid conditions. The dominant species include *Vachenia tortilis,Vachenia nilotica, Vachenia bussei,Vachenia hockii,Commiphora africana, Commiphora campestris and Commiphora confusa*. There are occasional taller hardwood species such as;*Terminalia spinosa,Melia volkensii,Boscia coriacea,Cassia abbreviata, andNewtonia hildebrantii*. The average canopy height was between 5-7m with the maximum height being approximated to 10m(M. Korchinsky, J. Freund, L. Cowan, & R. Dodson, 2011)[39].

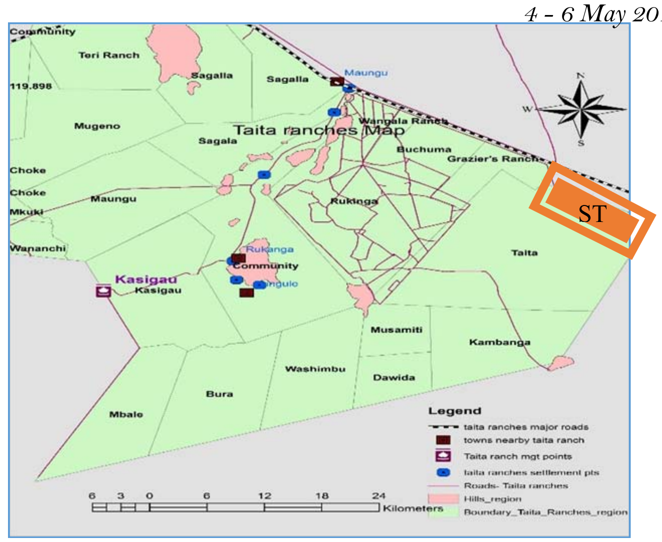

Figure 1 Taita ranches- the Eco Charcoal site in orange color with grid lines shown as the study area
Source: Arc GIS (2014)

The climate in this region is semi-arid, with average annual rainfall in the 300-450mm range. There are no permanent water sources in the study area and rains occurs twice a year, that is December and April however this has changed in the last ten year with irregular rain pattern being recorded. August is the coldest month and the hottest month being February(M. Korchinsky et al., 2011)[39].

B. *Sampling*

Systematic and random sampling designs are the two broad types of schemes used to estimate forest carbon stocks at the country level (Paciomik & Rypdal, 2003)[41]. Based on the almost uniform vegetation structure, the study randomly identified ten study blocks of 100 m x 100 m within the area designated for larger ongoing eco-charcoal study. The blocks were coded as 40, 48, 49, 58, 59, 68, 69, 79, 80 and 91. A Test Plot for tree counting was performed with a 25m radius which was named plot 28A and over 20 individual trees of varied species were recorded in test sub-plot and this was within the anticipated range of individual trees per plot, thus the study determined that the Tree Sample Plots for tree counts would be 25m radius.

As this is a mature forest there is mixed distribution of small and large trees, therefore it was necessary to use the same radius for different trees of different Diameter at Breast Height (DBH) ranges. At the same time, the method used for tree inclusion was independent of dbh, e.g. any tree whose trunk center fell within our 25m radius was considered in, provided that its dbh was at least 5 cm. Trees less than 5cm in dbh were excluded from our survey, as they are very light, and this would yield a conservative outcome for tree biomass. From each block therefore, systematic stratification was done to lay 25 m x 25 m sub-plots and Global Positioning System (GPS) was used to mark four corners and centers of every sub-plot that made 16 sub-plots. Simpson diversity index was used to do species diversity. DBH was measured using DBH meter whereas distance of tree species from different and the same species and diameter of the canopy was measured using a nylon tape.

The height of each tree was measured using theodolite. The angle between the tree top and eye view at breast height angle (α) is taken into consideration for tree height measurement and height of the tree is calculated. Considering the angle ACB between tree top and the distance (b) at the point of observer at DBH, the tree height was calculated if α is the angle between eye view and top of the tree, (a) is the height of the tree in feet, (c) is the slope between tree and eye view, (b) is the distance in meters between tree and observer and (h) is height of horizontal plane of Theodolite instrument, then the height of tree (H) is calculated by the below formula

$$H = h + b \tan\alpha$$ ……………………………………………….***Eqn. 1***(*Ishaq S. Eneji, Ofoegbu Obinna, & Azua, 2014)[33]*)

Where H is the tree height, h is the height of the horizontal plane, b is the distance between the tree and the observer and α is the angle the tree top and the eye view at the breast height.

C. Biomass Estimation

According to the latest FAO report, national forest carbon estimates based on inventory data remain very questionable, with more than half of tropical countries relying on 'best guesses' rather than actual measurements(FAO., 2005; George E. Kindermann, Ian Mc Callum, Steffen Fritz , & Michael Obersteiner, 2008)[22], [24]. Non-destructive biomass estimation does not require harvesting trees; it uses biomass equations to estimate biomass at the tree-level and sampling weights to estimate biomass at the forest level (GTOS, 2009b; Pearson TRH, Brown SL, & RA, 2007; Soares P & M, 2012)[26], [43], [49]. Biomass regression equations yield the most accurate estimates (Anneli, Raisa, Göran, Aleksi, & Hans, 2005; IPCC, 2003)[3], [29] as long as they are derived from a large enough number of trees (GTOS, 2009a; Husch, Beers TW, & Jr, 2003)[25], [27].

Measurements of diameter at breast height (DBH) alone or in combination with tree height can be converted to estimates of forest carbon stocks using allometric relationships. Allometric equations statistically relate these measured forest attributes to destructive harvest measurements, and exist for most forests (Chave J. et al., 2005; S. Brown, 1997)[12], [47]. Grouping all species together and using generalized allometric relationships, stratified by broad forest types or ecological zones, is highly effective for the tropics because DBH alone explains more than 95% of the variation in aboveground tropical forest carbon stocks, even in highly diverse regions (Brown, 2002)[10]. Generalized allometric equations also have the major advantage of being based on larger numbers of trees that span a wider range of diameters(Chave J. et al., 2005; S. Brown, 1997)[12], [47]. An extensive review of allometric equations concluded that the pan-tropic models were 'the best available' way to estimate forest biomass and recommended them over local allometric models that may be based on less than 100 destructively sampled trees(Chave J et al., 2004)[11]. The major carbon pools of the ecosystem were quantified (tree stem and root biomass; sapling stem and root biomass; and soil carbon from 0 to 50 cm depth).

The standard approach method was used to estimate vegetation (tree) carbon stocks (Chave J et al., 2004)[11] of a tree inventory recording stem diameter (diameter at breast height [dbh]), while an allometric relationship method was used to convert diameter to estimates of woody mass. According to (Williams M et al., 2008)[54] and (Chave J. et al., 2005)[12] the choice of allometric equation can strongly influence the calculation of tree biomass in Miombo woodland and has a widespread problem .Thestudy there adopted the Wildlife Works model where above ground biomass was calculated by the tree species specific allometric equation as $\mathbf{AGB = \alpha(DBH)^{\beta}}$ **,** where AGB is above-ground weight of the tree in kilogram (kg), DBH is diameter at breast height in cm and $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ are the model coefficients(Korchinsky, Freund, Cowan, & Dodson, 2011)[36]. Below ground biomass is estimated to be between 20-26% of above ground biomass (M. A. Cairns, S. Brown, E. H. Helmer , & Baumgardner., 1997; Santantonio, RK. Hermann RK, & Overton, 1997)[38], [48]. The research study opted to use 25% of above ground biomass as below ground. To determine the total green weight of the tree, then above-ground weight is multiplied by 125%.

Below is the summary of equations for biomass estimation using wildlife works model

$$AGB = \alpha DBH^{\beta}$$ ……………………………………...... ***Eqn 2***(*M. Korchinsky et al., 2011)[39]*)

$$BB = AGB \times 0.25$$ ………………………………………………… ***Eqn 3***

$$TB = AGB \times 1.25$$ …………………………………………………..***Eqn 4***

Where from the above three equations AGB is above ground biomass, BB is the below ground biomass and TB is the total biomass.

Dry weight of tree was based on publication from the University of Nebraska(B. L. Chavan & G. B. Rasal, 2010)[5]whereby the dry weight of the tree is calculated by multiplying the total green weight of the tree by 72.5% (B. L. Chavan & G. B. Rasal, 2010; DeWald S., Josiah S, & Erdkamp B., 2005)[5], [14] . The carbon concentration of different tree parts is rarely measured directly, but it is generally approximated to be 47% of dry weight (IPCC, 2006)[30], hence in this study, the aboveground carbon stock was calculated by assuming that the carbon content was 47% of the total biomass. Wood densities range from 0.276 to 0.551 for soft wood category and 0.6 to 1.1 for hard wood category according to wood density data base (Zanne et al., 2009)[56]. Diversity index (SDI) range from 0.85-0.92 along the study area.Correlation analysis was carried out to examine relationships between some paired growth parameters against biomass. Advanced general linear model in Statistica was used to perform multiple regression analysis, T- Test plus. One Way ANOVA test was used to test for significance across tree genus and species within and between study blocks. Mean separation was carried out with Fisher's Least Significant Difference (LSD) where significant differences occur ($P < 0.05$) at 95% CI.

NOTE: Genus *Vachenia* and *Acacia* will be mentioned in this study interchangeably or together since some of the *Acacia* species have been categorized under genus *Vachenia* from 2005 but some are still classified under genus Acacia which is prevalently used in most studies.

III. RESULTS

A. Distribution of tree species and biomass across the study area

Twenty five (25) tree species, from 14 tree genus were encountered in the study area **(Table 1)**. 2060 individual trees were inventoried, where two species encountered for *Vachenia* and four *Acacia,* four species for *Commiphora,* three species for *Lannea* and two species for genus *Manilkara* were encountered. One species each was encountered for the other seven genus encountered. Genus *Commiphora* recorded the highest number of individual trees followed by *Lannea, Boswellia, Vachenia* and *Boscia* respectively **(Table 2).**Between 164 and 228 individual trees were encountered in the respective study blocks which therefore approximated to between 10 and 14 individual trees per sub-plot.

Table 1 Tree genus, species, family and their respective ($\overline{X}$ dry biomass mean, SE standard error)

Tree Species	Tree Genus	Family Name	$\overline{X}$	SE.
Acaciabussei	*Acacia*	Fabaceae	183.6	5.5
A. etbaica	*Acacia*	Fabaceae	140.4	9.2
A. hockii	*Acacia*	Fabaceae	157.9	11.4
A.mellifera	*Acacia*	Fabaceae	171.6	26.7
Al. zimmermannii	*Albizia*	Fabaceae	163.6	37.8
Balanites aegyptiaca	*Balanites*	Zygophyllaceae	66.1	37.8
Boscia coriacea	*Boscia*	Capparaceae	49.0	2.8
Boswellia neglecta	*Boswellia*	Burseraceae	69.2	2.4
Cassia abbreviata	*Cassia*	Fabaceae	153.4	37.8
Commiphora africana	*Commiphora*	Burseraceae	114.7	5.3
Commiphora campestris	*Commiphora*	Burseraceae	355.2	1.9
Commiphora confusa	*Commiphora*	Burseraceae	100.4	1.7
Commiphora edulis	*Commiphora*	Burseraceae	12.6	37.8
Lannea alata	*Lannea*	Anacardiaceae	35.2	2.0
Lannea rivae	*Lannea*	Anacardiaceae	45.7	10.1
Lannea schweinfurthii	*Lannea*	Anacardiaceae	87.2	8.9
Manilkara mochisia	*Manilkara*	Sapotaceae	71.8	14.3
Manilkara sulcata	*Manilkara*	Sapotaceae	120.6	21.8
Ormocarpum kirkii	*Ormocarpum*	Fabaceae	39.5	26.7
Salvadora persica	*Salvadora*	Salvadoraceae	33.5	11.9
Sterculia africana	*Sterculia*	Malvaceae	96.4	7.9
Terminalia spinosa	*Terminalia*	Combretaceae	52.1	7.3
Vachenia nilotica	*Vachenia*	Fabaceae	102.9	5.0
Vachenia tortilis	*Vachenia*	Fabaceae	103.8	5.0
Zanthoxylum chalybeum	Zanthoxylum	Rutaceae	46.2	37.78

Table 2 Scientific names for tree genus within the study area, number of species and individual trees per the respective genus and Total biomass of each genus that was sampled ($\overline{X}$ is mean of biomass SE is the standard error)

s/no	*Tree genus*	*No. of species*	*No. of trees*	$\overline{X}$	*SE.*
1	*Albizia*	1	1	163.6	
2	*Balanite*	1	1	66.1	
3	*Boscia*	1	148	49.0	6.17
4	*Boswellia*	1	258	69.2	3.43
5	*Cassia*	1	1	153.4	
6	*Commiphora*	4	957	210.1	7.76
7	*Lannea*	3	390	38.0	1.15
8	*Manilkara*	2	10	86.4	12.53
9	*Ormocarpum*	1	2	39.5	0.49
10	*Salvadora*	1	10	33.5	4.96
11	*Sterculia*	1	23	96.4	17.28
12	*Terminalia*	1	28	52.1	5.07
13	*Vachenia& Acacia*	6	194	130.2	6.55
14	*Zanthoxylum*	1	1	46.2	
	Grand Total	**25**	**2060**		

B. *Tree growth parameters*

Mean diameter at breast height (DBH) in cm across the study area was 13.34 ± 6.8 with standard (STD) error of 0.151 while the mean height (m) was recorded at 4.56 ± 1.2 with STD error of 0.027. The mean distance of species from the same species was 9.134 ±8.4 with STD error of 0.188 while the mean distance of species from different species is 5.25 ±2.58 with STD error of 0.057 and biomass mean was 131.64± 184.5 with STD error of 4.066. CO_2 capture potential mean estimated at 301.95±423.3 with STD error of 9.326 (Table 4). Maximum DBH (cm) across species range from 8.7cm to 44.6cm with *Commiphora campestris* recording the highest and *Ormocarpumkirkii* registering the lowest. *Bosciacoriacea* recorded second highest maximum diameter at breast height with 40cm followed by *Vachenia etbaica* with diameter of 32.1cm. *Boswellia neglecta* recorded 26.1cm whereas *Sterculia africana* recorded 24.8cm and *Lannea alata* registering 20.8cm and other species recorded diameter less than 20cm.

Table 3 Descriptive statistic on tree growth parameters average, P-value standard deviation and their respective standard error*(DBH-Diameter at breast height, H- Tree height, CD- Canopy diameter, DSS- Distance of species from the same species, DDS- Distance of species from different species, TB- Total biomass)*

	$\overline{X}$	*p*	*min*	*max*	*SD*	*SE*
DBH	13	0.0182	5	44	6.83	0.15
H	5	0.0000	1	21	1.24	0.03
CD	6	0.0000	1	20	2.27	0.05
DSS	9	0.0000	1	101	8.44	0.19
DDS	5	0.0013	1	18	2.58	0.06
TB	132	0.0000	15	1879	184.53	4.07
CO_2	302	0.0000	32	4309	423.28	9.33

Table 4 Genus averages of diameter at breast height (DBH), T-tree height and Average distance of species from the same species and from different species (ADSS & ADDS respectively) and maximum canopy diameter (MCD)

Tree genus	*ADBH*	*AH*	*ADSS*	*ADDS*	*MCD*
Boscia	9.9	4.1	12.4	4.9	16.3
Boswellia	11.9	4.5	9.0	5.0	14.4
Commiphora	17.0	4.9	7.4	5.2	20.0
Lannea	8.3	3.9	7.1	5.7	9.5

Others	12.0	4.3	27.5	5.0	7.3
Salvadora	7.8	4.5	19.9	4.7	8.5
Sterculia	12.3	4.1	20.4	5.2	9.5
Terminalia	9.5	4.5	17.8	5.2	9.8
Vachenia	11.8	4.8	14.4	5.2	14.7
Grand Total	**13.3**	**4.6**	**9.1**	**5.3**	**20.0**

C. Dry biomass estimation among tree genus across Taita ranch in Mg (kgs/1000)

Total biomass for trees in the study area was approximately 262 Mgwhere by genus Commiphora took a whooping proportion of 74% of the total biomass. *Vachenia/Acacia* despite low number of trees recorded 9% of total dry biomass while genus *Boswellia* and Lannea registered 7% and 5% respectively. *Boscia* registered 3% of the total biomass whereas the other genus pooled together, registered 2%. Biomass across the study area varied between 20.6 $Mg\ ha^{-1}$ to 31.7 $Mg\ ha^{-1}$ while the genus biomass varied from 0.5 $Mg\ ha^{-1}$ to 19.3 $Mg\ ha^{-1}$ whereby *Commiphora* recorded the highest average biomass estimates followed by other species **(Table 5).**

Table 5 Sum of total biomass (Mg) of tree genus across the study blocks (*V&A- Vachenia and Acacia, Bos- Boscia, Bsw- Boswellia, Com- Commiphora, Lan-Lannea*, GT- Grand total)

STB	*Tree genus*						
	V & A	*Bos*	*Bsw*	*Com*	*Lan*	Others	GT
40	1.9	0.9	2.4	20.6	0.6	1.0	27.6
48	1.7	1.3	1.0	15.2	1.3	0.2	20.6
49	5.4	1.0	1.6	17.8	1.0	0.5	27.2
58	1.6	0.7	1.4	15.4	2.2	0.5	21.9
59	1.5	0.5	1.5	18.3	2.1	0.3	24.2
68	2.8	0.2	1.7	20.0	1.7	0.4	26.8
69	0.5	1.3	2.0	19.9	1.6	0.2	25.5
79	2.2	1.1	1.7	25.0	1.3	0.4	31.7
80	3.0	0.6	2.7	19.0	1.9	0.7	27.9
91	3.4	0.9	1.4	21.6	0.5	1.0	28.8
GT	**24.0**	**8.6**	**17.3**	**192.7**	**14.3**	**5.2**	**262.1**

D. Biomass estimate variance in the study area, tree species and respective genus

Within the study area there was varied mean biomass estimates among the blocks that range from the mean of 99.147kgs to 181.548kgs. Block 91 registered high average biomass while block 58 recorded the lowest and the other blocks fall in between the highest and the lowest average. The analysis exhibited high significance with $F_{(9,2050)}$=2.3, P=0.00037 at 95% confidence level (Figure 2).

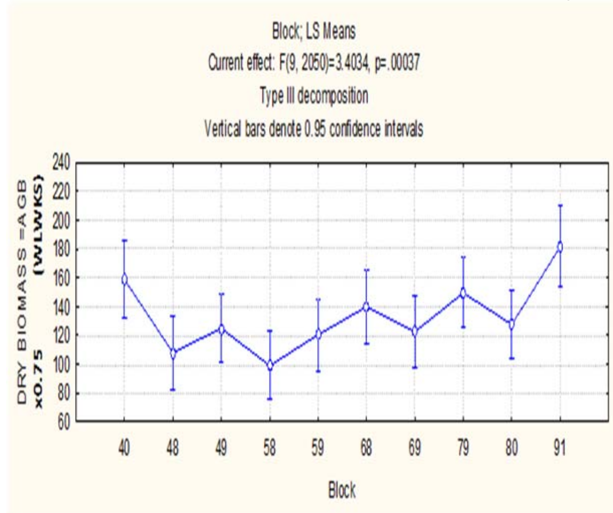

Fig.2. Graph of dry biomass across the study block

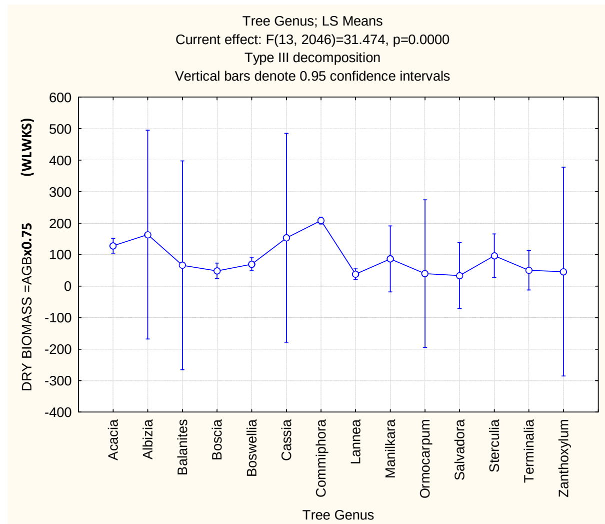

Fig.3 Graphs of dry biomass variance across tree genus

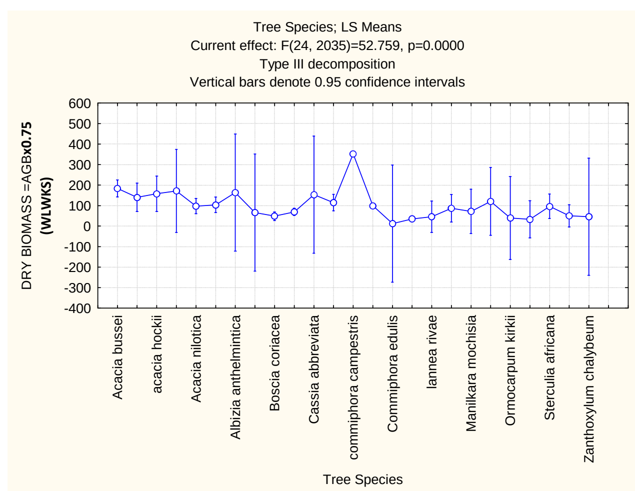

Fig.4 graph of mean biomass variance among tree species

Mean biomass among tree genus range from 33.49kgs to 208.306kgs with Commiphora recording the highest mean of 208.306kgs and salvadora recording the lowest. *Albizia* recorded the second highest with a mean of 168.60kgs followed closely by cassia with a mean of 153.36kgs while genus acacia recorded a mean of 128.212kgs.the other genus registered mean less than 100kgs but it worth noting that, genus *Albizia, Balanite, Cassia* and *Zanthoxylum* recorded only one species each therefore that represent the biomass estimates and not mean records (Figure 3). The variance registered high significance with $F_{(13,2046)=}28.600$, P< 0.0001. Mean biomass among trees species range from 12.58kgs by *Commiphora edulis* to 352.68kgs as the highest mean recorded by *Commiphora campestris*. The second highest mean biomass was recorded by *Acacia bussei* at 183.61kgs followed by *A. mellifera* recording a mean biomass of 171.60kgs and *Albizia anthelmintica* at a mean of 163.60kgs. The other species other than *C. Africana, A. nilotica and Manilkara mochisia* recorded mean biomass less than 100kgs. The analysis from the species mean biomass exhibited high significance with $F_{(24,2035)}$ =52.759, P<0.0001 (Figure 4).

IV. DISCUSSION

Numerically genus Commiphora dominated the study with more than 900 individual trees encountered, whereas genus *vachenia* and *Boscia* had each less than 200 individual trees encountered. *Lannea* and *Boswellia* had each trees above 200 individual trees while the other genus had less than fifty trees. The study area diversity structure indicates an imbalanced ecosystem that is likely to have been caused by natural and human-induced disturbances. Notably also the area is frequently subjected to prolonged drought which is a limiting factor on biomass production and crop yields. Moreover, human induced factors such as over cultivation, overgrazing, selective harvesting of hardwood species and other forms of inappropriate land use have resulted to a significant degradation of vegetation, soil leaching and in many cases resulting low diversity index thus imbalanced tree community structure (Abdi, Glover, & Luukkanen, 2013)[2].

Clearing tropical forests also destroy globally important carbon sinks that are currently sequestering CO2 from the atmosphere which are critical to future climate stabilization (Britton B. Stephens et al., 2007; Ishaq S. Eneji et al., 2014)[7], [33]. It is evident in the study area that there are human induced disturbances including selective harvesting of hardwood trees where more preference has been directed to genus *Acacia*/*Vachenia* as indicated by acacia tree stumps remnant found in the study area. The area is overstocked with large numbers of livestock that results to over-grazing. Huge numbers of livestock in dry area destroys tree seedlings, causes soil erosion and introduces invasive alien species.

Additionally wildlife disturbance also caused imbalance in the study area especially elephants (*Loxodanta Africana)* whichhas a prevalence of some tree species over others, for example *Manilkara mochisia* hardly grows to big trees due to elephant destruction. Elephants destroy huge trees not necessarily for food but also when they are upset or even to test its strength. However, the highest number recorded by the Commiphora species may among other factors have been contributed by a non-commercial value such as char production, timber just to mention a few.Genus *Acacia/Vachenia* recorded low number in the study area and this likely to be the case due high demand of the genus for char production, fuel wood and building material by the local community.

Average forest biomass across the study area was 26.2 Mg ha^{-1}, this notwithstanding the fact that study area is dryland forest, falls far below the range of published values in amazon region forest of 372 Mg ha^{-1}(Keller, Palace, & Hurtt, 2001)[34] and far below global average forest biomass of 109 Mg ha^{-1} (FAO, 2001)[20]. The forest biomass within the study area, ranged from 21 Mg ha^{-1} to 32 Mg ha^{-1} which is half of it carbon. The average carbon sink is therefore range from 0.3-0.5 Mg C ha^{-1} yr^{-1} since the average age forest in the study area is approximately 30years old. The above falls below the average carbon sink of 0.5-0.8 Mg C $ha^{-1}yr^{-1}$(FAO, 2001)[20].

On average tree genus biomass ranged between 0.5 Mg ha^{-1} to 19.3 Mg ha^{-1} where genus *Commiphora* recorded the highest average biomass estimates ha^{-1}. *Vachenia/Acacia* despite the low number of species per hectare recorded an average of 2.4 Mg ha^{-1}whereas Boswellia and Lannea recorded an average of 1.9 and 1.4 Mg ha^{-1}. The other genus recorded less than one Mg ha^{-1}.There was high significance of carbon stock across tree genus in the study area with $F_{(13,2046)=}28.600$, P< 0.0001. With (95% CI).

The spatial pattern of woody biomass described above is subject to frequent and widespread disturbances (S. Brown, 1997)[46] that reduce biomass: primarily clearance for agriculture (William et al., 2011)[53] charcoal production (Brouwer R. & P., 2004; FALCA˜O, 2008)[9], [19] and fire(Williams, Hill, Ryan, & A, 2012)[55]. Elephant activity can also reduce tree populations significantly. The other factor brought the variation is the difference tree genus whereby genus interaction with DBH had partial eta square (η_{eta}^2) = 0.118. This therefore explains that 12% of variance is been caused by genus difference in relation to diameter at breast. Consequently DBH interaction with tree height and perpendicular canopy diameter explains for approximately 6% of the mean biomass variation (Table 6).

Table 6 Univariate tests of significance, Effect sizes and powers for variation biomass in tree genus (OP- Observed Power, P_{eta}^2- Partial eta squared, NC- Non centrality, DBH- diameter at breast height, H- tree height, CD= canopy diameter, PCD- Perpendicular Canopy Diameter)

	F	*p*	P_{eta}^2	*NC*	*OP* (alpha=0.05)
Tree Genus	3.1	0.0017	0.012	24.9	0.97
DBH	22.4	0.0000	0.011	22.4	1.00
H	9.0	0.0027	0.004	9.0	0.85
MCD	0.2	0.6423	0.000	0.2	0.08
PCD	0.24	0.6243	0.000	0.2	0.08
Tree Genus*DBH	33.28	0.0000	0.119	266.3	1.00
Tree Genus*H	7.88	0.0000	0.031	63.0	1.00
DBH*H	127.69	0.0000	0.061	127.7	1.00
Tree Genus*CD	1.23	0.2775	0.005	9.8	0.58
DBH*CD	19.40	0.00001	0.01	19.4	1.00
H*CD	0.62	0.4328	0.000	0.6	0.12
Tree Genus*PCD	2.0	0.043	0.008	16.0	0.83
DBH*PCD	120.76	0.0000	0.058	120.8	1.00
H*PCD	13.66	0.0002	0.007	13.7	0.96
CD*PCD	108.34	0.0000	0.052	108.3	1.00
Error					

Variation in tree species biomass is also contributed by difference in species structure/morphology, wood density and adaptability to varied nutrients systems and climatic conditions. This has been supported by the interaction of tree species and DBH that has $\eta^2_{p=}$ 0.307. This therefore indicate that approximately 31% of variation has been contributed by interaction of difference in species in the study area in relation DBH. Additionally DBH and interaction with tree height and DBH explains roughly 5% and 6% of variation of biomass among tree species (Table 7).

Table 7 Univariate tests of significance, Effect sizes and powers for variation biomass in tree speciesP_{eta}^2- Partial eta squared, OP- Observed power, T. spps- Tree species, DBH-DBH, H- Tree height CD- canopy diameter, PCD- Perpendicular canopy diameter

	F	*p*	P_{eta}^2	*OP (alpha=0.05)*
T. spps	3.62	0.0000	0.029	1.00
DBH	5.30	0.0215	0.003	0.63
H	19.03	0.0000	0.010	0.99
CD	0.10	0.7464	0.000	0.06
PCD	5.79	0.0162	0.003	0.67
T. spps*DBH	53.63	0.0000	0.307	1.00
T. spps*H	2.20	0.0040	0.018	0.98
DBH*H	94.80	0.00000	0.047	1.00
T. spps*CD	0.16	0.9999	0.001	0.12
DBH*CD	0.45	0.5014	0.000	0.10
H*CD	0.82	0.3657	0.000	0.15
T. spps*PCD	3.58	0.0000	0.029	1.00
DBH*PCD	132.32	0.0000	0.064	1.00
H*PCD	3.52	0.0606	0.002	0.47
MCD*PCD	36.75	0.0000	0.019	1.00
Error				

Diameter at Breast Height and tree height are key predictor parameters in biomass estimation whereby DBH had a fairly positive correlation with tree height, canopy diameter and perpendicular canopy diameter with r values recording 0.51716, 0.5985 and 0.6155 respectively. There was a strong relationship between diameter and biomass estimated by wildlife works with r =0.9167. The association of upper canopy/tree height with biomass estimated, despite wildlife works model r values recording 0.458, is important predictor variable in biomass estimation. In this regards therefore high diameter value is likely to influence the overall biomass estimates and CO_2 capture and storage. This strongly agrees with the fact that DBH is key parameter in biomass estimation as indicated by high r values compared with other parameters.

V. CONCLUSIONS

Commiphora species have shown high mean biomass values than any species followed by acacia thus it is likely that Commiphora species have high carbon sequestration potential than any other genus. Commiphora species have also shown significant growth parameters such as bigger diameter at breast height and higher tree height better than other species thus has better traits that could have contributed higher values compared to other species in extreme dry weather and in this regard therefore the study Commiphora species are highly recommended for combating global warming and climate change as whole and of course not in isolation but rather in mixed forest of other major key species that include among others acacia. Despite low biomass index compared to the global biomass per hectares dry forest as well contribute to the global carbon sequestration spectrum.

The use of allometric models, even site specific ones, can introduce significant biases depending on their form, and how the heteroscedasticity of the destructive data is dealt with(Parresol, 1999; S. Brown, 1997)[42], [46]. The study estimates are bound to be subject to such biases, a subject that will addressed in a further studies. Finally, the studydid not measure biomass estimates of smaller and younger trees with DBH <5 cm, which may have led to underestimation, as those trees may have a significant contribution to forest biomass stock.

ACKNOWLEDGEMENT

I would sincerely want thank Wildlife Works-Kenya as an institution for their support both technical and professional. Last but not least I would like to thank wildlife works sampling team lead by Mwololo Muasa and eco-char team for their support in data collection, species identification and acting as guides in several wildlife encounters while in the Bush. "G. Mwangi & M. W. Gichuhi Co-authors, thank you for your support and contribution"

REFERENCES

[1] A. Vaughan. (2015, 6th May 2015). Global carbon dioxide levels break 400ppm milestone, *The Guardian.*

[2] Abdi, O. A., Glover, E. K., & Luukkanen, O. (2013). Causes and Impacts of Land Degradation and Desertification: Case Study of the Sudan. *International Journal of Agriculture and Forestry, 3*(2), 40-51. doi: 10.5923/j.ijaf.20130302.03

[3] Anneli, J., Raisa, M., Göran, S., Aleksi, L., & Hans, P. (2005). Estimation of the biomass stock of trees in Sweden: comparison of biomass equations and age-dependent biomass expansion factors. *62*(8), 845-851. Retrieved from doi:10.1051/forest:2005075

[4] Arul Pragasan L, & A, K. (2013). Carbon Stock Sequestered by tree plantations in University campus at Coimbatore, India. *International Journal of Environmental Science, 3*(5).

[5] B. L. Chavan, & G. B. Rasal. (2010). sequestered standing carbon stock in selective tree species grown in university campus at Aurangabad, Maharashtra, India. *International Journal of Engineering Science and Technology*(2), 3003-3007.

[6] Benites, J., Dudal, R., & Koohafkan, P. (1999). Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land use change and sustainable management with a focus on Latin America and the Caribbean. *Proceedings of the IFAD/FAO expert consultation, IFAD, Rome, Italy*, 37-42.

[7] Britton B. Stephens, Kevin R. Gurney, Pieter P. Tans, Colm Sweeney, Wouter Peters, Lori Bruhwiler, . . . Denning, A. S.

(2007). Weak Northern and Strong Tropical Land Carbon Uptake from Vertical Profiles of Atmospheric CO_2. In A.-A. f. t. A. o. Science (Ed.), *Science* (Vol. 316, pp. 1732-1735.). New york City: AAAS- New York City.

[8] Broadmeadow, M., & Mathews, R. (2003). *Forests, Carbon and Climate Change: the UK Contribution*. 231 Corstorphine; Road Edinburgh; EH12 7AT: Forestry commission Retrieved from http://www.forestry.gov.uk/.

[9] Brouwer R., & P., F. M. (2004). Wood fuel consumption in Maputo, Mozambique. *Biomass Bioener, 27*(3), 233-245.

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

[11] Chave J, Condit R, Aguilar S, Hernandez A, Lao S, ., P. R., & (2004). Error propagation and scaling for tropical forest biomass estimates. *Philosophical Transactions of the Royal Society of London Series B*(359), 409-420.

[12] Chave J., Andalo C., Brown S., Cairns M.A., Chambers J.Q., Eamus D., . . . T., Y. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *oecologia, 145*(1), 87-89.

[13] David, N., & Crane, D. E. (2002). Carbon storage and sequestration by urban trees in the USA, Environmental Pollution,. (116), pp 381-389.

[14] DeWald S., Josiah S, & Erdkamp B. (2005). Heating With Wood: Producing, Harvesting and Processing Firewood. Retrieved from www.ianrpubs.unl.edu/ website: www.ianrpubs.unl.edu/

[15] Dlugo kencky, & Tans Pieter. (2015). global greenhouse Gas Reference Network *ESRL (Earth System Research Laboratory)- Global Monitoring Division.* US: National Oceanic & Atmospheric Administration. .

[16] Donson, R. (2006a). *Mt. Kasigau Area Biodiversity Survey Report*, 2006, details on this HCV area. *High Conservation Value Survey*. Rukinga Ranch Wildlife Works Kenya.

[17] Donson, R. (2006b). *Mt. Kasigau Biodiversity Report* by Kim Medley of Miami University of Ohio, . Rukinga Ranch-Kenya: Wildlife Works Kenya.

[18] E. Dlugo kencky. (2016). Annual Mean Carbon Dioxide Data *ESRL (Earth System Research Laboratory) National Oceanic & Atmospheric Administration.*

[19] FALCA˜O, M. P. (2008). *Charcoal production and use in Mozambique, Malawi, Tanzania, and Zambia:*. Maputo, Mozambique.

[20] FAO. (2001). Global Forest Resources Assessment 2000 *Main Report*. Rome: FAO.

[21] FAO. (1995). Forest Resources Assessment. 1990 Global Synthesis. *FAO Forestry* Retrieved 12th February 2016, 2016, from http://www.fao.org/

[22] FAO. (2005). Global Forest Resources Assessment 2005,Progress towards sustainable forest management. In S. Fennica (Ed.), (Vol. 147). Rome.

[23] Gavin A. Schmidt, Reto A. Ruedy, Ron L. Miller, & Lacis, A. A. (2010). Attribution of the present day total greenhouse effect. *Journal of Geophysical Research, , 115*.

[24] George E. Kindermann, Ian Mc Callum, Steffen Fritz , & Michael Obersteiner. (2008). A Global Forest Growing Stock, Biomass and Carbon Map Based on FAO Statistics. *Silva Fennica 4, 42*(3), 387–396.

[25] GTOS. (2009a). Assessment of the status of the development of the standards for the terrestrial essential climate variables. . *NRL, FAO-Rome*, 18.

[26] GTOS. (2009b). Assessment of the status of the development of the standards for the terrestrial essential climate variables. NRL, FAO, Rome, p 18 *NRL* (pp. 18). Rome: FAO.

[27] Husch, B., Beers TW, & Jr, K. J. (2003). Forest measurement, 4th edition. *Wiley, Hoboken*, p443.

[28] IPCC. (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability *Contribution of Working Group II to the 3rd Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York.

[29] IPCC. (2003). Intergovernmental Panel on Climate Change. Good Practice Guidance for Land Use, Land-Use Change and Forestry.

[30] IPCC. (2006). Default biomass conversion and expansion factors. . In I. G. f. N. G. G. Inventories (Ed.), *Agriculture, Forestry and Other Land Use, Intergovernmental Panel on Climate Change.* (Vol. 4). Japan: IPCC.

[31] IPCC. (2007). Climate Change 2007: The Physical Science Basis, Summary for Policymakers *The IPCC 4th Assessment Report (IPCC AR4)* (2007 ed.).

[32] IPCC. (2014). Climate Change 2014. In E. Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)] (Ed.), *Mitigation of climate change*. New York, NY 10013-2473, USA: Cambridge.

[33] Ishaq S. Eneji, Ofoegbu Obinna, & Azua, E. T. (2014). Sequestration and Carbon Storage Potential of Tropical Forest Reserve and Tree Species Located within Benue State of Nigeria *Journal of Geoscience and Environment Protection,, 2*, 157-166.

[34] Keller, M., Palace, M., & Hurtt, G. (2001). Biomass estimation in the Tapajos National Forest, Brazil Examination of Sampling and allometric uncertainities. *Forest Ecology and Management, 154*, 371-382.

[35] Kiehl, J. T., & Trenberth, K. E. (1997). Earth's Annual Global Mean Energy Budget. *Bulletin of the American Meteorological Society, 78*(2), 197-208.

[36] Korchinsky, M., Freund, J., Cowan, L., & Dodson, R. (2011). Kasigau Corridor REDD Project Phase II- Community Ranches. Rukinga Ranch HQS- Maungu, Voi-KENYA: Wildlife Works- Kenya.

[37] Kort, J., & Turnock, R. (1999). Carbon reservoir and biomass in Canadian prairie shelterbelts, Agroforestry Systems. (44), 175-186.

[38] M. A. Cairns, S. Brown, E. H. Helmer , & Baumgardner., G. A. (1997). Root biomass allocation in the world's upland forests. *Oecologia 111:1-11., 111*, 1-11.

[39] M. Korchinsky, J. Freund, L. Cowan, & R. Dodson. (2011). Kasigau Corridor REDD Project Phase II- Community Ranches *Kasigau Corridor REDD Project* (Vol. II). Rukinga-Maungu, Voi- Kenya: Rukinga Wildlife Works Kenya.

[40] Oke, D., & Olatiilu, A. (2011). Carbon Storage in Agroecosystems: A Case Study of the Cocoa Based Agroforestry in Ogbese Forest Reserve, Ekiti State, Nigeria*Journal of Environmental Protection*(2), 1069-1075.

[41] Paciomik, N., & Rypdal, K. (2003). Good practice guidance for land use, land-use change and forestry, intergovernmental panel on climate change national greenhouse gas inventories programme. In: Penman, J., Gytartsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K., Wagner, F. (Eds.), Cross cutting issues. ,. *Institute for Global Environmental Strategies (IGES)*, pp 5.21-25.28 (Chapter section 25.23 sampling).

[42] Parresol, B. R. (1999). Assessing tree and stand biomass: A review with examples and critical comparisons. . *Forest Ecology and Management, 45*(4), 573-593.

[43] Pearson TRH, Brown SL, & RA, B. (2007). Measurement guidelines for the sequestration of forest carbon. United States Department of Agriculture, *Forest Science, General Technical Report* (Vol. 18).

[44] Pragasan, L. A., & Karthick, A. (2013). Carbon Stock Sequestered by tree plantations in University campus at Coimbatore, India. *International Journal of Environmental Sciences 3*(5), pp. 1700-1710.

[45] Roger A. Sedjo, Sohngen, B., & Jagger, P. (1998). Carbon Sinks in the Post-Kyoto World-I N T E R N E T E D I T I O N. *RFF Climate Issue Brief #12*.

[46] S. Brown. (1997). Estimating Biomass and Biomass Changes of Tropical forest. *A Primer, FAO Forestry Paper, 134*.

[47] S. Brown. (1997). Estimating biomass and biomass change of tropical forests *A primer. FAO Forest Resources Assessment Publication 134*, 55.

[48] Santantonio, D., RK. Hermann RK, & Overton, W. (1997). Root biomass studies in forest ecosystems. *Pedobiologia 17*, 1-31.

[49] Soares P, & M, T. (2012). (2012) Biomass expansion factores for Eucalyptus globulus stands in Portugal. *Forest system, 21*(1), 141-152.

[50] Thangata, P. H., & Hildebrand, P. E. (2012). Carbon stock and sequestration potential of agroforestry systems in smallholder agroecosystems of sub-Saharan Africa: 'Mechanisms for reducing emissions from deforestation and forest degradation' (REDD+). *Agriculture, Ecosystems and Environment.*(158), pp 172-183.

[51] Thangata, P. H., & Hildebrand, P. E. (2012). Carbon stock and sequestration potential of agroforestry systems in smallholder agroecosystems of sub-Saharan Africa: Mechanisms for „reducing emissions from deforestation and forest degradation" (REDD+), Agriculture, Ecosystems and Environment. (158), pp 172-183.

[52] UNFCC. (2006). United Nations Framework Convention on Climate Change (UNFCC), 2015, from http://unfcc.int/resource/docs/convkp/conveng.pdf

[53] William, M., Ryan, C. M., Hill, T., Woolen, E., Ghee, C., Mitchard, E., . . . Woodhouse, I. H. (2011). Quantifying small-scale deforestation and forest degradation in African woodlands using radar imagery. *Global Change Biology (2011), doi: 10.1111/j.1365-2486.2011.02551, 1111/ J*, 1365-2486. doi: 10.1111/j.1365-2486.2011.02551

[54] Williams M, CM Ryan, RM Rees, E Sambane, Fernando, J., & ., J. G. (2008). Carbon sequestration and biodiversity of re-growing miombo woodlands in Mozambique. *Forest Ecology and Management*(254), 145-155.

[55] Williams, M., Hill, T. C., Ryan, C. M., & A, K. (2012). Using biomass distributions to determine probability and intensity of tropical forest disturbance. *Plant Ecology & Diversity*(6:1), 87-99.

[56] Zanne, A. E., Lopez- Gonzales, G., Coomes, D. A., Llic, J., Jansen, S., Lewis, S. L., . . . Chave, J. (2009). Global Wood Density Database. Dryad. identifier, from Dryad. Identifier http://hdl.handle.net/