QUANTIFICATION OF CARBON STOCKS WITH THE COMMON TREE GENUS IN DRYLAND FOREST IN TAITA RANCH, SOUTH EASTERN KENYA

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Abstract

Mapping carbon stock in Kenya is central in establishing the country's potential for carbon emission and emission reduction through forestry. The study aimed to establish the 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 this species in Taita Ranch, South Eastern Kenya. A total of 2060 trees belonging to twenty five tree species from 14 genus were inventoried. Regression model by Wildlife Works predicted total tree biomass to be 262 mg (26.2 Mg/ha). Biomass estimates varied significantly with genus *Commiphora* recording the highest biomass of approximately 193 Mg followed by *Vachellia* and *Acacia* with 30 mg. *Boswellia, Lannea, and Boscia* recorded 22 mg, 18 mg 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 30 and 40 years and based on the average biomass estimates then genus *Commiphora* is able to capture about 5.5 kg of CO_2 per year, *Acacia and Vachellia* is able to capture 5.4 kg while *Boswellia, Lannea* and *Boscia* are able capture 2.6 kg, 2.1 kg and 1.8 kg respectively and other genus pooled together capture 3.2kg on average. Given the above biomass estimates, genus *Commiphora* and *Acacia* and *Vachellia* lead in terms of carbon capture, storage and release of carbon if harvested for charcoal production.

Key words: Biomass, carbon sequestration, carbon stocks, diameter at breast height, regression model, Taita Ranch.

1.0 Introduction

Carbon dioxide (CO_2) is one of the greenhouse gases and a primary agent of global warming. 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 (Kencky and Tans Pieter, 2015; Vaughan, 2015). 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 and Mathews, 2003). However, an increase in the concentration of greenhouse gases in the atmosphere is responsible for increasing global temperatures. 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 and Turnock, 1999). When humans clear and/or burn trees, most of the carbon quickly gets back to the atmosphere as CO_2. The amount of CO_2 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 and Olatiilu, 2011) and having risen risen to 402 ppm as of 2016 (E. Dlugo kencky, 2016). Dramatic rise of CO_2 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). 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). Atmospheric CO_2 concentration can be decreased by reducing fossil fuel burning and also increasing the terrestrial ecosystems that serve as sinks for CO_2.

Plants use CO_2 and sunlight to make their own food and grow. Long-lived plants like trees might keep the carbon sequestered over their lifetime. Once the tree dies, or as limbs, leaves, seeds, or blossoms drop from the tree, the plant material decomposes and the carbon is released to the atmosphere. 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.

Biomass regression equations yield the most accurate estimates (Anneli *et.al.*, 2005; IPCC, 2003), as long as they are derived from a large enough number of trees that are representative of the target population (GTOS, 2009; Husch, Beers TW, and Jr, 2003). 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; Kindermann *et al.,* 2008). Measurements of (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 *et al*., 2005; Brown, 1997). 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). 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)

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.

2.0 Materials and Methods

2.1 The Study Area

The study area is located at eastern edge of Taita Ranch that is 35,612 ha, owned by a collection of indigenous local shareholders under Taita Ranching Company Limited. The study area 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 km west of Mackinnon Road, along Voi-Mombasa highway Fig. 1. The area qualifies as high conservation value based on IUCN guidelines (Donson, 2006a, 2006b). 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 *Vachellia tortilis, Vachellia nilotica, Acacia bussei, Acacia hockii, Commiphora africana, Commiphora campestris and Commiphora confusa*. There are occasional taller hardwood species such as *Terminalia spinosa, Melia volkensii, Boscia coriacea, Cassia abbreviata, and Newtonia hildebrantii*. The average canopy height was between 5-7 m with the maximum height being approximated to 10 m (Korchinsky *et al.,* 2011).

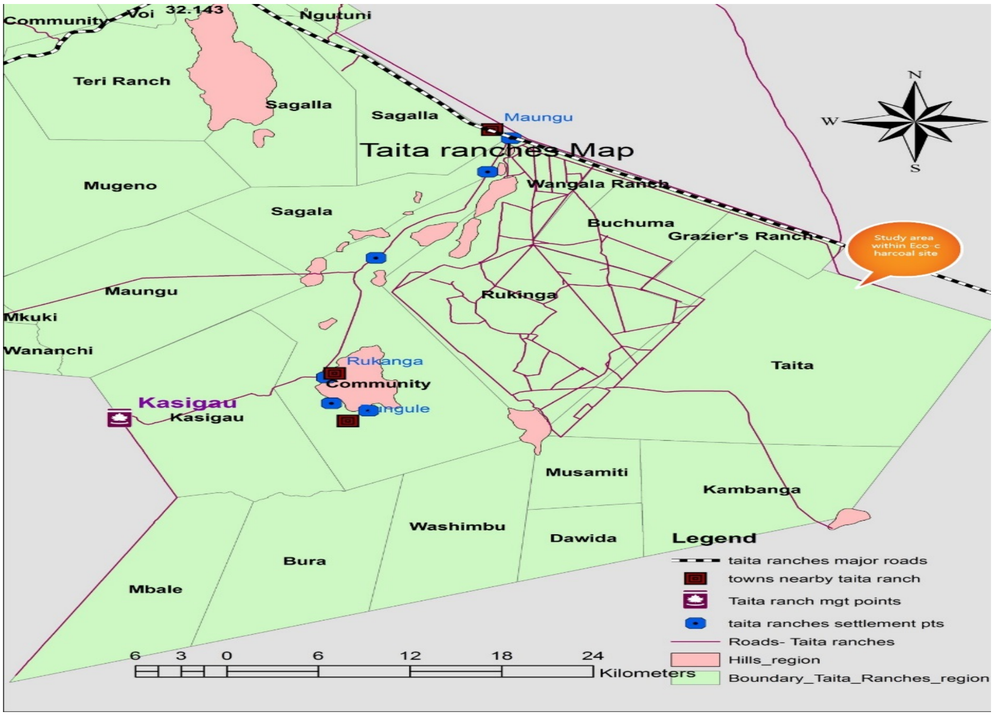


Figure 1: Taita ranches- the eco charcoal site in orange color with grid lines shown as the study area

The climate in this region is semi-arid, with average annual rainfall in the 300-450 mm 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 February being the hottest month. (Korchinsky *et al.*, 2011).

2.2 Sampling

Systematic and random sampling designs are the two broad types of schemes used to estimate forest carbon stocks at the country level (Paciomik and Rypdal, 2003). 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 25 m radius which was named plot 28A and over 20 individual tree 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 25 m 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) in cm ranges. This is also because our method for tree inclusion was independent of DBH, e.g. any tree whose trunk center fell within our 25 m radius was considered in, provided that its DBH was at least 5 cm. Trees less than 5 cm in DBH were excluded from our survey, as they were very light, and this would yield a conservative outcome for tree biomass. From each block therefore, systematic stratification was done to lay 25m x 25m 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 compute species diversity. DBH was measured using diameter tape whereas distance of tree species from different and the same species and diameter of the canopy was measured using a 50 m regular tape.

Upper canopy/height of each tree was measured using theodolite. The angle between the tree top and eye view at breast height angle (α) was taken into consideration for tree height measurement and height of the tree calculated. Considering the angle between tree top and the distance (b) at the point of observer at DBH, the tree height was calculated if α was 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) was height of horizontal plane of Theodolite instrument, then the height of tree (H) is given by $H = h + b \tan \alpha$ (Eneji *et al.,* 2014)

2.3 Biomass Estimation

Biomass was estimated using an existing allometric model since the study applied non-destructive approach. This was done on two major tree carbon pools i.e. stem and root biomass of any tree with DBH≥ 5 cm. The REDD standard approach was used for tree inventory recording of stem DBH and allometric equation to convert diameter readings to wood mass.

The study adopted the wildlife works model where above ground biomass was calculated by the tree species specific allometric equation as $\mathbf{AGB} = \boldsymbol{\alpha}(\mathbf{DBH})^{\beta}$ **,** where AGB is above-ground weight of the tree in kilogram (kg), DBH is diameter at breast height in cm and **α** and **β** are the model coefficients (Korchinsky et al., 2011). Below ground biomass is estimated to be between 20-26% of above ground biomass (M. A. Cairns, S. Brown, E. H. Helmer , and Baumgardner., 1997; Santantonio, RK. Hermann RK, and Overton, 1997). The study opted to use 25% of above ground biomass was below ground ***BGB = AGB × (25/100***). Therefore, to determine the total green weight of the tree, then above-ground weight was multiplied by 125%, i.e., ***Total biomass (TB) = AGB x 1.25***

Dry weight of tree was based on publication from the University of Nebraska (Chavan and Rasal, 2010) whereby the dry weight of the tree is calculated by multiplying the total green weight of the tree by 72.5% (Chavan and Rasal, 2010; DeWald, Josiah, and Erdkamp, 2005). The carbon concentration of different tree parts is rarely measured directly, but it is generally approximated to be 47% of dry weight (IPCC, 2006) 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). Tree 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 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 *Vachellia* and *Acacia* will be mentioned in this study interchangeably or together since some the *Acacia* species have been categorized under genus *Vachellia* from 2005 but are still classified under genus *Acacia* in many literature.

3.0 Results

3.1 Distribution of Tree Species and Biomass Across the Study Area

Twenty-five (25) tree species from 14 tree genus were documented in the study area (Table 1). 2060 individual trees were inventoried, where two species encountered for *Vachellia* and four *Acacia,* four species for *Commiphora,* three for *Lannea* and two 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, Vachellia* 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 biomass respectively

Tree Species	***Tree Genus***	***Family Name***	***Dry Biomass Mean (Kg)***	***Dry Biomass SE***	***Number of trees per species)***	***Grand total carbon (Kg ha^{-1})***
Acacia bussei	*Acacia*	Fabaceae	183.6	5.5	47	111
Acacia etbaica	*Acacia*	Fabaceae	140.4	9.2	17	85
Acacia hockii	*Acacia*	Fabaceae	157.9	11.4	11	95
Acacia mellifera	*Acacia*	Fabaceae	171.6	26.7	2	104
Albizia zimmermannii	*Albizia*	Fabaceae	163.6	37.8	1	
Balanites aegyptiaca	*Balanites*	Zygophyllaceae	66.1	37.8	1	

Continued..

Tree Species	***Tree Genus***	***Family Name***	***Dry Biomass Mean (Kg)***	***Dry Biomass SE***	***Number of trees per species)***	***Grand total carbon (Kg ha^{-1})***
Boscia coriacea	*Boscia*	Capparaceae	49.0	2.8	182	30
Boswellia neglecta	*Boswellia*	Burseraceae	69.2	2.4	254	42
Cassia abbreviata	*Cassia*	Fabaceae	153.4	37.8	1	
Commiphora africana	*Commiphora*	Burseraceae	114.7	5.3	50	69
Commiphora campestris	*Commiphora*	Burseraceae	355.2	1.9	405	215
Commiphora confusa	*Commiphora*	Burseraceae	100.4	1.7	491	60
Commiphora edulis	*Commiphora*	Burseraceae	12.6	37.8	1	8
Lannea alata	*Lannea*	Anacardiaceae	35.2	2.0	354	21
Lannea rivae	*Lannea*	Anacardiaceae	45.7	10.1	14	28
Lannea schweinfurthii	*Lannea*	Anacardiaceae	87.2	8.9	18	53
Manilkara mochisia	*Manilkara*	Sapotaceae	71.8	14.3	7	43
Manilkara sulcata	*Manilkara*	Sapotaceae	120.6	21.8	3	73
Ormocarpum kirkii	*Ormocarpum*	Fabaceae	39.5	26.7	2	
Salvadora persica	*Salvadora*	Salvadoraceae	33.5	11.9	10	20
Sterculia africana	*Sterculia*	Malvaceae	96.4	7.9	23	58
Terminalia spinosa	*Terminalia*	Combretaceae	52.1	7.3	27	31
Vachellia nilotica	*Vachellia*	Fabaceae	102.9	5.0	57	62
Vachellia tortilis	*Vachellia*	Fabaceae	103.8	5.0	57	63
Zanthoxylum chalybeum	Zanthoxylum	Rutaceae	46.2	37.78	1	

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

Tree genus	***No. of species***	***Individual trees per genus***	***Biomass Mean***	***Biomass SE***
Albizia	1	1	163.6	
Balanite	1	1	66.1	
Boscia	1	148	49.0	6.17
Boswellia	1	258	69.2	3.43
Cassia	1	1	153.4	
Commiphora	4	957	210.1	7.76
Lannea	3	390	38.0	1.15
Manilkara	2	10	86.4	12.53
Ormocarpum	1	2	39.5	0.49
Salvadora	1	10	33.5	4.96
Sterculia	1	23	96.4	17.28
Terminalia	1	28	52.1	5.07
Vachellia	6	194	130.2	6.55
Zanthoxylum	1	1	46.2	
Grand Total	**25**	**2060**		

3.2 Tree Growth Parameters

Mean DBH across the study area was 13.34 ± 0.30, with standard deviation of 6.8 while the mean height (m) was recorded at 4.56 ± 0.05, with standard deviation of 1.2. The mean distance of species from the same species was 9.13 ±0.37 with standard deviation of while the mean distance of species from different species is 5.25± 0.11 with standard deviation of 2.58 and biomass mean was 131.64 ± 7.97, with standard deviation of 184.5. The CO_2 in kg capture potential mean estimate was at 301.95± 18.28 with standard deviation of 423.3 (Table 3). DBH across species in the study area ranged from 8.7 cm to 44.6 cm with *Commiphora campestris* recording the highest and *Ormocarpum kirkii* registering the lowest. *Boscia coriacea* recorded second largest maximum DBH with 40 cm followed by *Acacia etbaica,* with diameter of 32.1 cm*. Boswellia neglecta* recorded 26.1cm whereas *Sterculia africana* recorded 24.8 cm and *Lannea alata* registering 20.8 cm and other species recorded diameter less than 20 cm (Table 4).

Table 3: Descriptive statistics on tree growth parameters average, P-value, standard deviation and their respective standard error

	Valid	*% Valid obs.*	*Mean*	*p-val.*	*Min*	*Max*	*Range*	*Std. Dev.*	***SE***
Max. DBH(cm)	2045	99.2	13.34	0.0182	5.2	44.60	42.100	6.83	0.15
Tree height (m)	2059	99.9	4.56	0.0000	1.0	20.50	19.500	1.24	0.03
Max. Canopy Diameter (m)	2050	99.5	5.7505	0.0000	1.4	20.00	18.600	2.27	0.05
Distance (NN) Same Sp. (m)	2011	97.6	9.1314	0.0000	0.5	101.00	100.50	8.44	0.19
Distance (NN) Diff. Sp.(m)	2025	98.3	5.2537	0.0013	0.5	18.40	18.40	2.58	0.06
Dry biomass (kgs)	2060	1.0	131.64	0.0000	15.2	1878.5	1863.40	184.53	4.07
CO_2 capture (kgs)	2060	1.0	301.95	0.0000	32.1	4309.0	4276.9	423.28	9.33

Table 4: Genus averages of diameter at breast height (DBH), tree height and distance (NN) of species from the same species and from different species and maximum canopy diameter (Canopy and DBH are important as they are used in biomass estimation; NN (distance) data are important for computation of vegetation structure and composition)

Row Labels	*Average of Max. DBH(cm)*	*Average tree height (m)*	*Average of NN: Same Species(m)*	*Average of NN: Diff. Species.(m)*	*Max. Canopy Diameter(cm)*
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
Vachellia and Acacia	11.8	4.8	14.4	5.2	14.7
Grand Total	**13.3**	**4.6**	**9.1**	**5.3**	**20.0**

3.3 Dry biomass estimates among tree genus across the study area

Total biomass for trees in the study area was approximately 262 mg where by genus *Commiphora* took a whooping proportion of 74% of the total biomass. Genus *Vachellia* together with *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} with the lowest estimate recorded at block 40 and the highest recorded at block 79. 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).**

NB: biomass estimates in table 5 are reported in kg

Table 5: Sum of total biomass of tree genus across the study blocks

Sum of Dry biomass	*Tree genus*						
Study Blocks	*Vachellia and Acacia*	*Boscia*	*Boswellia*	*Commiphora*	*Lannae*	Others	Grand Total
40	1,906	992	2,445	20,621	632	1,048	27,644
48	1,669	1,287	1,049	15,155	1,275	154	20,589
49	5,376	987	1,562	17,807	1,013	454	27,199
58	1,617	697	1,366	15,430	2,192	549	21,852
59	1,548	484	1,503	18,334	2,106	259	24,236
68	2,808	230	1,671	19,957	1,733	387	26,787
69	536	1,322	1,993	19,862	1,601	178	25,492
79	2,213	1,086	1,710	24,950	1,282	429	31,669
80	2,951	643	2,662	18,985	1,942	712	27,894
91	3,421	909	1,380	21,603	483	986	28,782
Grand Total	**24,044**	**8,638**	**17,341**	**192,704**	**14,261**	**5,155**	**262,144**

3.4 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 99.1 kg to 181.5 kg. Block 91 registered high average biomass while block 58 recorded the lowest and the other blocks fell 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). It is worth noting that the variance below was pegged on the biomass of a block in relation to individual trees encountered.

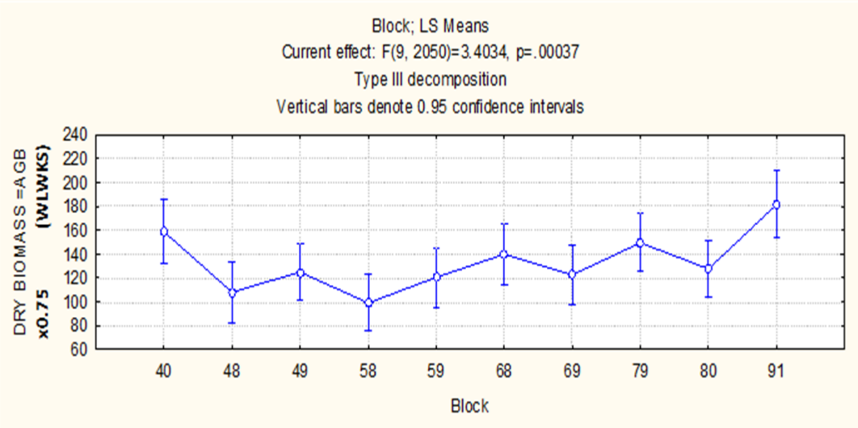
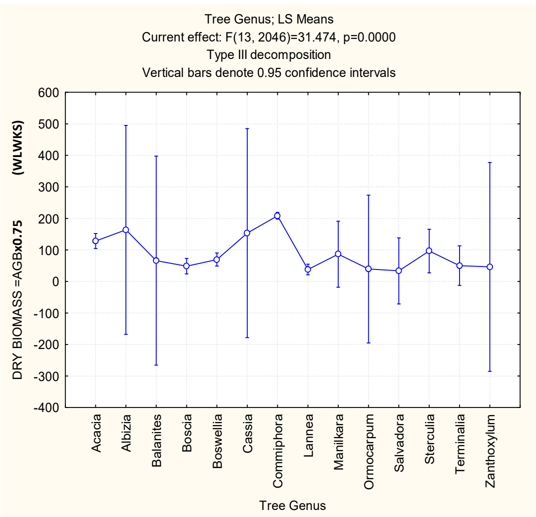


Figure 2: Graph of dry biomass across the study block



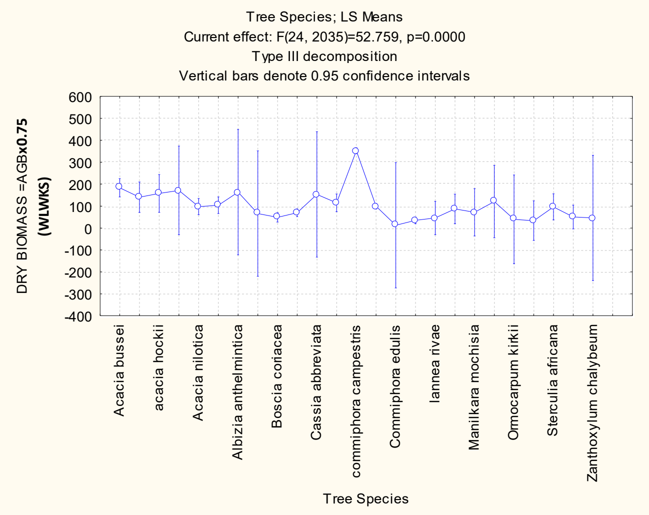


Figure 3: Graphs of variance across tree genus (a) and their respective species (b)

Mean biomass among tree genus range from 30 kg, to 208 kg with Commiphora recording the highest mean of 208 kg and salvadora recording the lowest. *Albizia* recorded the second highest with a mean of 169 kg, followed closely by cassia with a mean of 153 kg while genus acacia recorded a mean of 128 kg. The other genus registered mean less than 100 kg 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 3a). The variance registered high significance with $F_{(13,2046)}$=28.600, P<0.0001. Mean biomass among trees species range from 13 kg by *Commiphora edulis* to 353 kg as the highest mean recorded by *Commiphora campestris*. The second highest mean biomass was recorded by *Acacia bussei* at 184 kg followed by *A. mellifera* recording a mean biomass of 172 kg and *Albizia anthelmintica* at a mean of 164 kg. The other species other than *C. Africana, A. nilotica and Manilkara mochisia* recorded mean biomass less than 100 kg. The analysis from the species mean biomass exhibited high significance with $F_{(24,2035)}$ =52.759, P<0.0001 (Figure 3b).

4.0 Discussion

Commiphora dominated the study area with more than 900 individual trees encountered, whereas genus *Vachellia* and *Boscia* each had less than 200 individual trees encountered. *Lannea* and *Boswellia* had each trees above 200 individual trees while the other genus had less than 50 trees. Looking at study area diversity structure, this can then be termed as imbalanced ecosystem that is likely to have been caused by natural and human-induced disturbances. The study is frequently subjected to prolonged drought which is the main limiting factor on biomass production and crop yields. Human induced factors such as over cultivation, overgrazing, selective harvesting of hardwood species and other forms of inappropriate land use may result in significant degradation of vegetation, soil leaching and in many cases resulting low diversity index thus imbalanced tree community structure (Abdi, *et al.,* 2013). Clearing tropical forests also destroy globally important carbon sinks that are currently sequestering CO_2 from the atmosphere which are critical to future climate stabilization (Britton B. Stephens *et al.,* 2007; Eneji *et al.*, 2014). 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*/*Vachellia* 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 as well caused imbalance in the study area especially elephants (*Loxodanta africana)* which has a preference of some tree species over others; For example, *Manilkara mochisia* hardly grows to big trees in the area dominated with elephants. Elephants destroy huge trees not necessarily for food, but also when they are upset, or even to test its strength. The highest number of *Commiphora* may among other factors have been contributed by a non-commercial value such as fuelwood and charcoal production and timber just to mention a few attached to the genus unlike genus *Acacia/Vachellia* that is likely threatened due to high demand for charcoal production among other uses.

The average forest biomass across the study area was 26.2mg ha^{-1}, this notwithstanding the fact that study area is dryland forest, falls far below global average forest biomass of 109mg ha^{-1} (FAO, 2001). Forest biomass within the study area, ranged from 21mg ha^{-1} to 32mg ha^{-1}. The average carbon sink is therefore range from 0.3-0.5mg C ha^{-1} yr^{-1} since the average forest age in the study area is approximately 30 years old. The above falls below the average carbon sink of 0.5-0.8mg C $ha^{-1}yr^{-1}$ (FAO, 2001).

On average tree genus biomass ranged between 0.5mg ha^{-1} to 19.3mg ha^{-1} where genus *Commiphora* had the highest average biomass estimates ha^{-1}. *Vachellia/Acacia* despite the low number of species per hectare recorded an average of 2.4mg ha^{-1} whereas *Boswellia* and *Lannea* recorded an average of 1.9 and 1.4mg 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 (Brown, 1997) that reduce biomass: primarily clearance for agriculture (William *et al.,* 2011), charcoal production (Brouwer, 2004; FALCA˜O, 2008) and fire (Williams, *et al.,* 2012). Elephant activity can also reduce tree populations significantly (Guy 1989, Ribeiro et al. 2008b). The other factor brought the variation is variation in mean biomass genus interaction with DBH which partial square $(\eta^2)_{=}$ 0.118. This explains that about 12%

of variance is been caused by genus in relation to diameter at breast height. 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 and NC- Non Centrality)

*Univariate Tests of Significance, Effect Sizes, and Powers for DRY BIOMASS =AGB**x0.75 (WLWKS)** (final tree analysis) Sigma-restricted parameterization Type III decomposition*								
	SS	**DF**	**MS**	**F**	**p**	**P eta ^{2}**	**NC**	**OP (α=0.05)**
Intercept		0						
Tree Genus	48832	8	6104.0	3.1	0.0017	0.012	24.9	0.97
Max. DBH	44020	1	44019.6	22.4	0.0000	0.011	22.4	1.00
Upper Canopy	17683	1	17683.4	9.0	0.0027	0.004	9.0	0.85
Max. Canopy Diameter	423	1	423.3	0.2	0.6423	0.000	0.2	0.08
Perp. Canopy Diameter	470	1	470.4	0.24	0.6243	0.000	0.2	0.08
Tree Genus*Max. DBH	522273	8	65284.1	33.28	0.0000	0.119	266.3	1.00
Tree Genus*Upper Canopy	123638	8	15454.7	7.88	0.0000	0.031	63.0	1.00
Max. DBH*Upper Canopy	250470	1	250469.9	127.69	0.0000	0.061	127.7	1.00
Tree Genus*Max. Canopy Diameter	19292	8	2411.5	1.23	0.2775	0.005	9.8	0.58
Max. DBH*Max. Canopy Diameter	38047	1	38046.6	19.40	0.00001	0.01	19.4	1.00
Upper Canopy*Max. Canopy Diameter	1207	1	1207.2	0.62	0.4328	0.000	0.6	0.12
Tree Genus*Perp. Canopy Diameter	31381	8	3922.6	2.0	0.043	0.008	16.0	0.83
Max. DBH*Perp. Canopy Diameter	236882	1	236882.5	120.76	0.0000	0.058	120.8	1.00
Upper Canopy*Perp. Canopy Diameter	26805	1	26804.6	13.66	0.0002	0.007	13.7	0.96
Max. Canopy Diameter*Perp. Canopy Diameter	212512	1	212511.6	108.34	0.0000	0.052	108.3	1.00
Error	3881959	1979	1961.6					

Table 7: Univariate tests of significance, Effect sizes and powers for variation biomass in tree species

	SS	**DF**	*MS*	**F**	**p**	**Partial eta-squared**	**Observed power (alpha =0.05)**
intercept		0					
Tree species	82520	16	5157.5	3.62	0.0000	0.029	1.00
Max. dbh	7555	1	7555.4	5.30	0.0215	0.003	0.63
tree height	27148	1	27148.4	19.03	0.0000	0.010	0.99
Max. canopy diameter	149	1	149.3	0.10	0.7464	0.000	0.06
perp. canopy diameter	8260	1	8260.3	5.79	0.0162	0.003	0.67
Tree species*max. dbh	1224248	16	76515.5	53.63	0.0000	0.307	1.00
Tree species*upper canopy	50161	16	3135.0	2.20	0.0040	0.018	0.98
Max. dbh*upper canopy	135238	1	135238.0	94.80	0.00000	0.047	1.00
Tree species*max. canopy diameter	3760	16	235.0	0.16	0.9999	0.001	0.12
Max. DBH*max. canopy diameter	645	1	645.0	0.45	0.5014	0.000	0.10
Upper canopy*max. canopy diameter	1168	1	1167.9	0.82	0.3657	0.000	0.15
Tree species*perp. canopy diameter	81734	16	5108.4	3.58	0.0000	0.029	1.00
Max. dbh*perp. canopy diameter	188775	1	188775.2	132.32	0.0000	0.064	1.00
Upper canopy*perp. canopy diameter	5027	1	5027.4	3.52	0.0606	0.002	0.47
Max. canopy diameter*perp. canopy diameter	52430	1	52430.0	36.75	0.0000	0.019	1.00
Error	2757623	1933	1426.6				

Variation in tree species mean 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 interaction with tree height and DBH in itself explains roughly 5% and 6% respectively of variation of mean biomass among tree species (Table 7).

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.

5.0 Conclusions

Commiphora species has shown high mean biomass values than any other 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 upper canopy/ 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; Brown, 1997). The study estimates are bound to be subject to such biases but this can be addressed. Finally, we did not measure the more transient carbon pools such as fine root, tree leaves and grass biomass, which contribute to the total ecosystem carbon stocks. The current biomass estimates disregarded smaller and younger trees (DBH <5 cm), which may have led to underestimation, as those trees may have a significant contribution to forest biomass stock.

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