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Research Article

Above-ground biomass and carbon stocks of different land cover types in Mt. Elgon, Eastern Uganda

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ABSTRACT

This research applied selected allometric models to estimate the total above ground biomass (TAGB) and carbon stocks in the different land-use/ land cover (LULC) types in Mt. Elgon National Park, in Eastern Uganda. The LULC types identified for the study were – tropical high forest (THF) - normal, THF- degraded and grasslands. The vegetation in each land cover type was assessed at four levels i.e. the mature trees, poles, saplings and undergrowth. Tree diameter and height of each sampled tree were also measured. In each plot, one sapling was randomly selected, uprooted and sub-samples of the foliage, bole and root components were collected, and their fresh weight was determined in the field. Calculation of the Mean Squared Error (MSE), Prediction Sum of Squares (PRESS) statistic and Predicted R^2 values of the selected equations was done to establish the most appropriate equation for biomass and carbon estimation. The TAGB was 652.15t/ha, 55.16t/ha and 41.7t/ha in the THF-Normal, THF-Degraded and Grasslands respectively. The carbon stocks in the THF-normal were 293.65tC ha^{-1}, 25 tC ha^{-1} in the THF-degraded and 18.76 tC ha^{-1} in the grasslands. Over 90% of sequestered carbon was lost due to land cover change from THF-Normal to THF-Degraded. This calls for policy makers to urgently come up with interventions to address forest degradation.

Key words: biomass, carbon sink, land cover change, Mt. Elgon, Uganda

Introduction

Removing carbon from the atmosphere and storing it in the terrestrial biosphere is one of the methods proposed to reduce greenhouse gas emissions (Albrecht and Kandji 2003). Forests contain about 80% of global terrestrial above-ground biomass and are important carbon sinks (Houghton 2005). Carbon stored in the aboveground biomass constitutes the largest pool of all the carbon pools in tropical forest ecosystems (Baccini et al. 2008). As trees grow, they sequester carbon in their tissues, and as the amount of tree biomass increases the rise in atmospheric carbon dioxide is mitigated (Losi et al. 2003). The existing schemes for carbon credit allocation based on carbon stocks performance require accurate estimates of carbon (Gurney and Raymond 2008). Schemes such as Reducing Emissions from Degradation and forest Deforestation (REDD+), Clean Development Mechanism (CDM) and voluntary schemes can only be harnessed if estimation of carbon stock is accurate.

Highlights

- Above-ground biomass is a useful measure for assessing changes in forest structure;
- In terrestrial ecosystems appropriate model selection is important for estimating forest biomass;
- Over 90% of sequestered Carbon is lost due to land cover change in Mt. Elgon forests.

Above-ground biomass (AGB) is a useful measure for assessing changes in forest structure (Brown et al. 1999) and an essential aspect of studies of carbon cycle (Cairns et al. 2003). Biomass estimates have always been a source of uncertainty in the carbon balance from the tropical regions, partly due to a scarcity of reliable estimates of live aboveground biomass (Nakakaawa et al. 2011; Baker et al. 2004) and variation across landscapes and forest types (Houghton et al. 2009). Therefore, improved estimates will provide essential data that would enable the extrapolation of biomass stocks to ecosystems and allow reliable emission estimates from land use and land cover change scenarios (Houghton and Goodale 2004). The study applied different methodologies of estimating aboveground carbon and recommended the appropriate method of accounting for the amount of C stored in terrestrial accounting for the amount of C stored in terrestrial ecosystems. The study also provides estimates of the above ground biomass and carbon stocks of the different land cover types in Mt. Elgon landscape in eastern Uganda. The information may be useful in identifying land use systems that can contribute to carbon sequestration and provide insight into changes in the forest structure.

Materials and methods

Study area

The study was conducted in Mt. Elgon protected area and the Benet settlement areas on the slope of the mountain located in Kapchorwa district, eastern Uganda. This area was purposively selected because of the unique trend of events that have taken place in the area involving forest encroachment by the Benet communities and gazettement by the government dating way back in 1936, when Mt. Elgon forest was gazetted as a crown forest (Luzinda 2008). It has discernible landscapes of natural forest that is "undisturbed", degraded and grasslands. Three land cover types exist as a result of land use change including the Tropical High Forest (THF) - Normal (natural forest), THF-Degraded (encroached area) and Grasslands/ agriculture fields. The natural forest is at the highest altitude, followed by the encroached forest and grasslands as one moves from the top to the bottom of the mountain.

Data collection

The study area was established from a 2009 Land Satellite image of the area, which depicted the three land cover types, obtained from the National Forestry Authority (NFA). A 200m x 400m grid was superimposed on the image, running north-south and east-west on the map (Figure 1). Random numbers were generated and used to randomly select 30 grid intersections in each land cover type on the map.

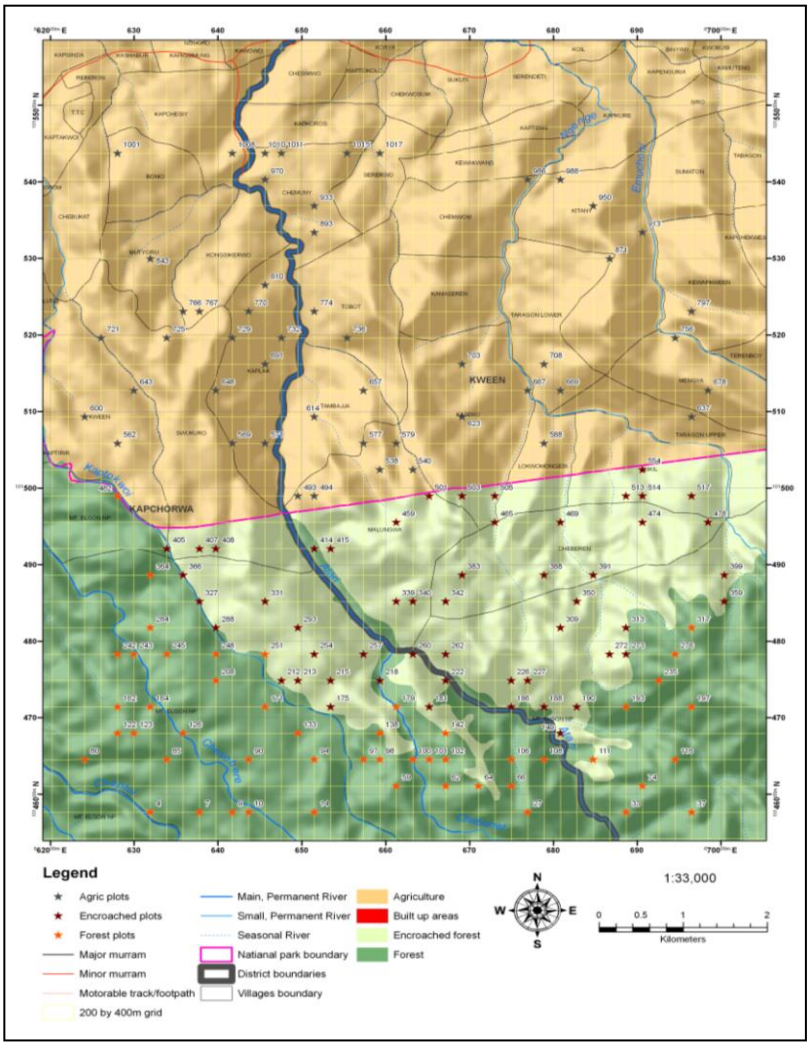

Figure 1. Map showing the land cover types of the study area with gridlines imposed on it (Source: NFA GIS)

The coordinates of each of the randomly selected grid intersections on the map were established and given a unique ID. The coordinates were then uploaded on the handheld GPS and a hard copy of the map was printed out for use in the field.

The vegetation in each land cover type was assessed at four levels: trees (dbh>10cm), poles (dbh 5<10cm), saplings (collar diameter less than 5cm or 50cm to 1m height) and the undergrowth layer (< 50cm in height). Although the plot sizes varied across land cover types, the number of plots in each land cover was the same (30 plots). The adoption of different plot sizes was a result of variation in tree densities and the sampling intensity in the three land cover types. While 10m x 10m temporary plots were established in the THF-Normal, 20m x 20m were established in the encroached forest and larger plots of 50m x 50m were established in the grassland fields for assessment of mature trees (dbh>10cm).

In each land cover type, a hand held GPS and the hard copy of the map were used to locate the grid intersections on ground. The location of the target grid intersection point was established using the GPS. At each grid intersection in the forest, a temporary plot was established. From the reference point, the plot was always established eastwards and northwards. In each plot, all individual trees of ≥10 cm diameter at breast height (dbh) were identified, and their dbh, tree height and crown width taken.

For tree density estimation, a 10 inch increment borer was used to drill and extract two small cylindrical samples at 140 cm above the ground, from all the trees in the plot, without causing harm to the sampled trees. Only a 4-5cm sample was needed and its wet weight was taken from the field. The wood samples were then dried in an 80^0C oven for 24 hours (Temilola and Amanda 2010) and dry weights measured on the same scale.

Each of the plots were nested to obtain 5m x 5m sub plots. The understorey layer consisting of <10cm diameter trees (poles and saplings) was assessed in 1 sub plot. The poles in the subplot of 5m x 5m were identified and measured for their dbh and height. One sapling was randomly selected and uprooted. Sub-samples were then obtained from the sapling bole, foliage and roots and their corresponding wet weights measured and recorded. All sub samples were carried to the lab for biomass and carbon determination. The undergrowth and grasses were destructively sampled in the 1 sub plot of 1m × 1m and their fresh weight measured on site (kgm^{-2}). The subsamples were dried at 80^0C for 24 hours, until a constant dry weight was obtained.

Wood density determination

Wood density was measured from the wet and dry weights of the wood core samples taken with an increment borer. A beaker was filled with water and placed on a digital balance. The balance was then re-zeroed and the wood core sample was carefully sunk in the water with a thin needle, without contact on the sides or bottom of the container. The measured weight of displaced water is equal to the sample's volume, since water has a density of one gcm^{-3} according to Pythagoras' theorem (Chave 2006). Therefore the reading on the digital balance is equal to the volume of the core (with the equivalence 1 g = 1 cm^3). The electronic balance was always re-zeroed after every measurement.

Oven-dry weight was measured from the same wood core sample by drying it in a well ventilated oven at 80^0C until it achieved constant weight. The samples were weighed immediately after being taken out of the drying oven, because tropical air is often water-saturated.

Biomass estimation

Tree biomass was derived using three allometric equations developed by Velle (1997), commonly referred to as the NBS (2003) equation (because it was used in the National Biomass Study carried out in Uganda in 2003), Ketterings et al. (2001) and Brown et al. (1989).

In Uganda the equation developed by Velle (1997) and used in the National Biomass Study (NBS) of 2003 is widely used in most biomass studies. Velle (1997) developed a biomass function for a sample of 1695 trees and proposed a general formula for weight of single trees. This equation estimates above ground biomass using tree size functions (constants) single tree wet weight (kg) which is calculated based on three independent variables i.e. dbh (cm), tree height (m) and crown diameter (m).

$$Ln(PWF) = a + b*Ln(D) + c*Ln(HT) + d*Ln(CR) \qquad (1)$$

Where, PWF is fresh weight of stem and branches of one tree in kg, D is DBh in cm, HT is height of the tree in m and CR is the width of the crown in meters. In this equation, constants a, b, c and d are parameters for all the pooled trees.

Tree biomass (W, dry weight) was also estimated using the allometric equation on the basis of wood density and stem diameter at 1.3 m above the ground (Ketterings et al. 2001).

$$W = 0.11\ \rho D^{2+c} \qquad (2)$$

Where, ρ is the wood density and the coefficient c is based on the allometric relation between tree height (H) and D: $H = aDc$ (default value for $c = 0.62$).

Tree biomass was further estimated using the allometric equation on the basis of tree height, diameter at breast height and wood density (Brown et al. 1989).

$$Y= \exp \{-2.4090 + 0.9522\ \mathrm{Ln}(D^2HS)\} \qquad (3)$$

Where Exp denotes e to the power of D= dbh in cm, H= total height in meters, S= wood density in Mg/m^3 = $g/cm^3$and Y=Biomass (kg).

The equations were selected based on the independent variables in each equation and the land cover type where the equation was developed from. The assumption was that the equations may cause large errors if used to estimate biomass and carbon stocks across all land cover types.

In this study, the TAGB is the sum of mature tree biomass, poles biomass (5<10cm dbh), saplings biomass (collar diameter less than 5cm) and biomass from undergrowth/ herbaceous layer (height<50cm). The biomass of uprooted saplings was obtained by summing up the biomass from the foliage, bole and root components using their respective wet and dry (at 80°C) weights, computed independently as a product of the fresh weight of the sapling component and the ratio of the dry and fresh weight of the sub sample from that component (Brown 1997). This can be represented as:

Biomass = Fresh weight of sapling component x (Dry weight of the sub sample / Fresh weight of sub sample) (4)

Well-mixed undergrowth and grass sub-samples from each plot were oven dried to determine dry-to-wet matter ratios (Kurniatun et al. 2001). These ratios were then used to convert the entire sample to oven-dry matter and for using the calculation below.

Total dry weight ($kg\ m^{-2}$) = Total fresh weight (kg) x Subsample dry weight (g) / (Sub sample fresh weight (g) x Sample area (m^2)) (5)

Comparing the ability of the three models to predict tree biomass

The Mean Squared Error (MSE), Prediction Sum of Squares (PRESS) statistic and the Predicted R^2 values of the three equations were computed and compared. The MSE quantifies the difference between values implied by an estimator and the true values of the quantity being estimated. The difference occurs because of randomness or because the estimator does not account for information that could produce a more accurate estimate (Lehmann and Casella 1998). The model with the least MSE would be the most appropriate for estimating biomass.

PRESS can be used to select predictor variables (Tumwebaze 2008) and also validate the chosen model (Draper and Smith 1981). The PRESS statistic was used to assess each model's predictive ability. PRESS is obtained by deleting the i^{th} observation from the data set, estimating the regression equation from the remaining n-1 observations, then using the fitted regression function to obtain the predicted value for the i^{th} observation. In general, the smaller the prediction sum of squares (PRESS) value, the better the model's predictive ability.

The Predicted R^2 indicates how well the model predicts responses for new observations, whereas R^2 indicates how well the model fits your data. Predicted R^2 can prevent over fitting the model and is more useful than adjusted R^2 for comparing models because it is calculated with observations not included in model calculation. Predicted R^2 is between 0 and 1 therefore larger values of predicted R^2 suggest models of greater predictive ability.

Choosing the appropriate model for estimating tree biomass

The choice of an allometric equation in any particular study is important, as different equations can give rise to very different AGB estimates when applied to the same forest inventory data (Araujo et al. 1999). Equation choice, therefore, poses a significant problem for regional-scale comparison of AGB estimates, because the variation caused by environmental, structural and compositional gradients may be confounded with variation resulting from the use of different regression equations (Baker et al. 2004). This study applied the MSE, the predicted R^2 and the prediction sum of squares (PRESS) statistic to conclusively assess the ability of the three equations to predict above ground biomass of mature trees (dbh>10cm). The most statistically appropriate equation was selected to compute the tree biomass in the subsequent sections of the study.

The ability of the equations to predict biomass was assessed at 2 levels. That is, (1) when each equation is used independently to estimate biomass in each land cover type and (2) when each equation is used to estimate biomass irrespective of land cover types (when all the data sets from all land cover types are combined). The first level would help determine whether the allometric equations are suited for a particular land cover type, while level 2 would identify the generally statistically acceptable equation for biomass estimation irrespective of land cover type. The model with the least MSE, the smallest prediction sum of squares (PRESS) value and a large value of predicted R^2 would be the most appropriate for estimating biomass.

When the Velle (1997) equation was used to assess biomass in the three land cover types, the least MSE and PRESS and a high Predicted R^2 values were obtained in the grassland (Table 1). The Ketterings et al. (2001) equation had the least MSE and PRESS values with a relatively high Predicted R^2 value in the grassland. When Brown et al. (1989) equation's predictability of tree biomass was assessed, the low MSE and PRESS plus relatively large Predicted R^2 values were obtained in both grassland and encroached forest land cover types (Table 1).

When the three equations were used to estimate tree biomass irrespective of the land cover type (when all the data sets from all land cover types were combined), the Brown et al. (1989) equation gave the least MSE and PRESS and a high Predicted R^2 , though not the highest Predicted R^2 (Table 2). Colton and Bower (2003) caution that predicted R^2 should not be fully relied on as it is prone to Type I and Type II errors. The Brown et al. (1989) equation best conforms to these conditions, with the least MSE and PRESS and a high Predicted R^2 values.

Table 1. The MSE, PRESS and Predicted R^2 with the different equations

Equation used and Land cover type	**MSE**	**PRESS**	**Predicted R^2 (%)**
Velle (1997)			
THF-Normal	0.73	71.23	70.58
THF-Degraded	0.51	20.31	84.41
Grassland/ agriculture fields	0.18	24.82	73.65
Ketterings et al. (2001)			
THF-Normal	3.76	301.85	80.98
THF-Degraded	1.34	44.30	67.2
Grassland/ agriculture fields	0.46	42.75	70.23
Brown et al. (1989)			
THF-Normal	1.40	112.34	86.14
THF-Degraded	0.58	19.73	69.17
Grassland/ agriculture fields	0.14	11.55	80.69

Velle (1997) equation is $\ln(PWF) = a + b*\ln(D) + c*\ln(HT) + d*\ln(CR)$, Ketterings et al., (2001) equation is $W = 0.11\ \rho D^{2+c}$ and Brown et al., (1989) equation is $Y= \exp\{-2.4090 + 0.9522 \ln(D^2HS)\}$

Table 2. The general MSE, PRESS and Predicted R^2 irrespective of land cover type

Allometric equation	**MSE**	**PRESS**	**Predicted R^2 (%)**	**Source of equation**
$\ln(PWF) = a + b*\ln(D) + c*\ln(HT) + d*\ln(CR)$	1.64	224.82	88.76	Velle (1997)
$W = 0.11\ \rho D^{2+c}$	2.92	468.81	77.72	Ketterings et al. (2001)
$Y= \exp\{-2.4090 + 0.9522 \ln(D^2HS)\}$***	1.37	206.89	80.54	Brown et al. (1989)

***Best model

Diameter is the most common predictor in all biomass allometric models (Gower et al. 1997), but adding tree height and density as additional independent variables could have contributed to the good predictive ability of the Brown et al. (1989) equation. Ketterings et al. (2001) also noted that adding tree height as an independent variable statistically significantly improves the DBH-only equations, even though they did not apply tree height in their equation. However, tree height is rarely used in practice (Bond-Lamberty et al. 2002) mainly because it is much more difficult and time-consuming to be estimated than DBH. The weakness of the

Velle (1997) equation to predict biomass could be attributed to the fact that it has crown width as one of the independent variables, which is difficult to measure especially in the THF-Normal land cover type. Most trees in the THF-Normal have intertwining canopies, which make it difficult to estimate individual tree crown width in the field. The Velle (1997) equation may however be more applicable in the grass lands and the encroached land cover types. The second setback with the Velle (1997) equation is that it has no wood density as one of the independent variables. Some authors conclude that species-specific allometric relationships are not needed to generate reliable estimates for forest C stocks (Gibbs et al. 2007), while others show that species-specific allometric equation will improve biomass estimation (Pilli et al. 2006). Wood density is a key variable for calculating greenhouse gas emissions (Woodcock 2000) and this dictates the use of an equation with density as one of the independent variables. The assumption is that the diameter and tree height would always be measured and density would be available if species were recorded. However, this is not usually an easy task in the tropics, where identification may require a very experienced botanist and density may be known for a few species. Although universal allometric equations, like the Velle (1997) equation, simplify the conversion of inventory measurements to estimates of biomass (Wirth et al. 2004), the use of species specific equations is preferred because trees of different species may differ greatly in tree wood density. Considering these reasons and the fact that the Brown *et al.,* (1989) equation gives the least MSE and PRESS and a high Predicted R^2 values, we suggest that an equation that includes wood density, tree height and stem diameter as independent variables may be more reliable.

Estimating total above-ground Carbon stocks

Estimating the above-ground carbon stocks involved conversion of biomass to carbon content, followed by conversion to carbon sequestered. Carbon pools were derived from biomass by halving the dry biomass. It isassumed that half of the total biomass is carbon (Levine 1995; IPCC 2003). Subsequently carbon was converted into carbon sequestered (CO_2 equivalents) by multiplying it with a factor of (44/12) the carbon dioxide – carbon molecular weight ratio (IPCC 2003). One-way ANOVA was used to assess the variation in biomass and carbon stocks estimated for the different land cover types.

Results

Total Above Ground Biomass (TAGB)

Mature tree biomass was highest in the THF-Normal, there were more poles biomass in the grassland than the Natural forest and least in the encroached area (Table 3). The saplings had more biomass than poles in both the THF-Normal and THF-Degraded. The general trend found was sapling (dbh<5cm) biomass decreased from the natural forest to the grassland while the biomass from undergrowth increased.This is because heavy shading by the mature trees in the natural forest results in bare ground while the large spacing of the scattered vegetation in the grasslands favors growth of the undergrowth. The TAGB in the THF-Normal of Mt. Elgon national park was the highest, followed by encroached forest and least in the grassland (Table 3).

Total Above ground carbon stocks

The TAGC is the sum of carbon stocks from mature trees, poles and saplings of 5-10cm dbh, saplings less than 5cm diameter and the undergrowth/ herbaceous layer. The study found that THF-Normal had the largest TAGC stocks while the grasslands had the least carbon stocks (Table 4). In the THF-Normal, mature trees and saplings of a diameter less than 5cm contributed the largest proportions of carbon. In the grassland, the undergrowth, poles and saplings that had a diameter of 5-10cm contributed the largest proportions of carbon to the TAGC stocks in Mt. Elgon National park (Table 4).

Table 3. Total Above Ground Biomass using the Brown et al. (1989)

Category	**Above ground biomass in per land cover (t/ha)**		
	THF-Normal	THF-Degraded	Grassland
Mature trees (dbh >10 cm)	616.99	33.39	5.15
Poles (dbh 5<10cm)	1.07	0.34	1.80
Saplings (collar diameter <5cm)	2.47	2.66	0.12
Undergrowth (height<50cm)	9.84	19.16	34.63
Total	652.15	55.16	41.70

Table 4. Total Above Ground Carbon (TAGC) in the different land cover types

Categories	Land cover type			% of Carbon lost due to land cover change from THF-Normal to THF-Degraded
	FOR (tC/ha)	ENC (tC/ha)	GRS (tC/ha)	
Mature trees (dbh >10cm)	277.65	15.03	2.32	94.58
Poles (dbh 5-10cm)	0.48	0.15	0.81	68.75
Saplings (dbh <5cm)	11.09	1.20	0.05	89.18
Undergrowth	4.43	8.62	15.58	94.58*
TAGC	293.65	25.00	18.76	91.48**

FOR- THF-Normal, ENC- THF-Degraded and GRS- Grassland area, *gain and **Average Carbon lost due to land cover change from THF-Normal to THF-Degraded

Discussion

Total Above Ground Biomass (TAGB)

Biomass is a critical part of recent discussions on estimates of greenhouse gas emissions and of carbon stocks in natural ecosystems. The TAGB was highest in the THF-Normal, followed by THF-Encroached and least in the Grasslands. When Brown and Lugo (1982) synthesized data from the literature on total biomass of tropical forest vegetation estimated by direct measurements on experimental plots, they obtained a weighted average TAGB for closed forest of 282t/ha and for open forest of 55t/ha. In the second analysis, Brown and Lugo (1984) used data reported by country for all major forest types as given by FAO (1999). They converted commercial wood volumes to TAGB using average wood densities and expansion factors and obtained a weighted average TAGB of 150 t/ha for undisturbed tropical closed forests and 50t/ha for open forests. The two methods gave totally different estimates for closed forest but similar estimates for the open forest. In the current study, the TAGB estimate obtained from the THF-Encroached (50.04t/ha) is comparable to the one obtained by Brown and Lugo (1992) and Brown and Lugo (1984) in the open forest suggesting that the level of disturbance in the two studies could have been similar.

However, none of the earlier Aboveground Biomass estimates for the closed forest (Brown and Lugo 1984; 1992) can be compared to the one obtained from the THF-Normal of the current study. The aboveground biomass in THF-normal wasmuch higher. According to (Brown 1997) biomass in a forest is determined by the difference in production through photosynthesis, consumption by respiration and harvesting processes. These may have varied between the two studies hence the difference in aboveground biomass. It is therefore important to obtain more accurate and precise biomass estimates for THF-Normal (closed forests) in order to improve understanding of the role of tropical forests in the global carbon cycle.

Total Above ground carbon stocks in the different land cover types

Estimates of carbon stocks in tropical ecosystems are of high relevance for understanding the global carbon cycle and the management of ecosystems for carbon sequestration purposes. Current efforts to mitigate the impact of climate change are through ways that increase carbon sequestration (Sedjo and Salomon 1989) and the mitigation of carbon emissions. Estimating carbon stocks and their distribution in different ecosystem pools is important to understand the degree to which carbon is allocated to labile and stable components. In terms of Carbon stocks, the study site is a spatially complex landscape because it comprises a large number of patches of different land use histories, soils, altitudes and ecosystems for regenerating secondary forests. The interaction of these factors produces a high variation in forest cover within the landscape.

This study found significant variation in carbon stocks in the different land cover types in the Mt. Elgon region ($P<0.05$). The findings from the current study are in tandem with (Brakas and Aune 2011) who reported that above ground carbon stocks were very low in grasslands and degraded forests compared to preserved forests. There is an estimated average of 91.48% loss in carbon sequestered as a result of land cover change from THF-Normal to THF-Degraded, which poses a policy implication to the legislators to consider appropriate formulation and implementation of land use laws and policies in Uganda. Clearing of forests results in their stored carbon being released into the atmosphere as carbon dioxide which contributes to global greenhouse gas emissions (Gibbs et al. 2007).

Conclusion

Trees have the potential to mitigate carbon emissions through the conservation of existing carbon reservoirs and improvement of carbon storage in vegetation. Mature trees (dbh >10 cm) represent more than 90% of TAGB in the THF-Normal. However, undergrowth contributes more to AGB in the grasslands than in the THF-Normal and THF-Degraded, though in minute proportions. Most land use changes are occurring in closed tropical forests, where biomass varies the most, thus the need to protect them. The use of the Brown et al. (1989) equation emphasizes the importance of species-specific allometric equations for more precise estimates of above ground biomass and carbon stocks. The findings of this study can be used to estimate the role of the assessed land use types as sinks of atmospheric carbon. With over 90% of sequestered Carbon being lost due to land cover change from THF-Normal to THF-Degraded, appropriate policy guidelines (including national policies, bye-laws and ordinances) need to be put in place to facilitate restoration of degraded areas and control further land cover changes in Uganda. The belowground biomass component is estimated to represent about two thirds of the terrestrial C stocks (Jobbagy and Jackson, 2000) and the rooting system contributes a significant part of it. However this study did not consider the below ground component and further work should consider it.

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Supplementary material

Wood densities

Wood density is an important component for estimating biomass in terrestrial ecosystems (Woodcock and Shire 2002) hence a key variable for calculating greenhouse gas emissions from different land cover types. The wood densities of the common tree species in Mt. Elgon National Park are presented in Table 5. The tree species with the highest mean wood density was *Acacia sieberiana* Scheele, followed by *Celtis Africana* Burm.f. while the tree species with the least mean wood density were *Persea americana* Mill., *Cordia Africana* Lam. and *Eucalyptus grandis* W. Hill. Both *Entada abyssinica* Steud. and *Afrocrania volkensii* Hutch. tree species had equal mean wood densities but with different standard deviations. The wood density of the most abundant tree species, *Podocarpus latifolius* R.Br., *Afrocrania volkensii* Hutch. and *Markhamia lutea* K. Schum. was 0.492 ± 0.166 gcm^{-3}, 0.586 ± 0.186 gcm^{-3} and 0.466 ± 0.087 gcm^{-3} respectively.

Table 5. Wood densitities of common tree species in Mt. Elgon National Park

Species name	Family	N	Mean wood density g/cm^3	St Dev
Acacia sieberiana Scheele	Mimosaceae	13	0.779	0.202
Afrocrania volkensii Hutch.	Cornaceae	28	0.586	0.186
Allophylus abyssinicus Radlk.	Sapindaceae	12	0.550	0.024
Bersama abyssinica Fresen.	Melianthaceae	16	0.533	0.135
Buddleja polystachya Fresen	Loganiaceae	13	0.516	0.252
Celtis africana Burm.F	Ulmaceae	15	0.759	0.121
Clerodendrum silvanum Henriq.	Verbenaceae	13	0.464	0.220
Cordia Africana Lam.	Boraginaceae	12	0.396	0.057
Croton sylvaticus Hochst.	Euphorbiaceae	12	0.606	0.084
Erythrina abyssinica Lam.	Papilionaceae	15	0.415	0.039
Entada abyssinica Steud.	Mimosaceae	08	0.586	0.003
Eucalyptus grandis W.Hill	Myrtaceae	21	0.395	0.187
Ficus mucuso Welw. Ex Ficalho	Moraceae	14	0.574	0.140
Grevillearobusta A. Cunn.	Proteaceae	16	0.543	0.081
Juniperus procera Hochst. Ex Endl.	Cupressaceae	16	0.553	0.118
Markhamia lutea K.Schum.	Bignoniaceae	23	0.466	0.087
Neoboutonia macrocalyx Pax	Euphorbiaceae	13	0.474	0.174
Persea americana Mill.	Lauraceae	15	0.376	0.189
Podocarpus latifolius R.Br.	Podocarpaceae	36	0.492	0.166
Schefflera volkensii Harms	Araliaceae	14	0.624	0.226
Teclea nobilis Delile	Rutacee	08	0.528	0.084
Xymalos monospora Baill.	Monimiaceae	05	0.653	0.034

The mean wood density of all the tree species sampled=0.540gcm^{-3}

Photograph 1. A section of a grassland and THF-Degraded land cover types on the slopes of Mt. Elgon in Kapchorwa district, Eastern Uganda