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Effects of climate mitigation on carbon stocks of Hanang forest, Tanzania

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The study assessed carbon stocks of Hanang mountain forest, Tanzania. Thirty-four sample plots (40 × 50 m) were established along an altitudinal gradient. All trees with diameter at breast height ≥10 cm were identified and measured, and herb species and soil were sampled from four 1 × 1 m quadrats within 10 × 10 m subplots. Mean carbon stock was 48.37 and 0.26 t C ha^{-1} for tree and herb species, respectively. Soil organic carbon (SOC) was 64.2, 41.93 and 31.0 t C ha^{-1} in the upper, mid and lower layers, respectively. It was found that there was significant difference in tree carbon ($p<0.05$) along an altitudinal gradient. However there was no significant difference ($p>0.05$) in herbaceous carbon and SOC in the three layers along an altitudinal gradient. Tree carbon was low compared to other tropical areas where allometric models were employed. In contrast, SOC was high compared to other similar forests in the tropics. Anthropogenic threats will likely diminish the SOC hence conservation measures are needed.

Key words: Carbon, stocks, altitudinal gradient, soil organic carbon (SOC).

INTRODUCTION

Deforestation and degradation of tropical forests is estimated to contribute up to 17% of the global CO_2 emissions responsible for global warming, leading to climate change (Van der Werf et al., 2009). Climate change has direct consequences on the economy, ecosystems, water resources and sea level rise (IPCC, 2001). In recognition of the impacts caused by deforestation in developing countries, in the Conference of Parties (COP 13) in Bali it was agreed that reducing emissions from deforestation and degradation (REDD) should be included in a post-Kyoto mechanism (UNFCC, 2007). Recently UN also introduced REDD+ from the original concept of REDD to include emissions from deforestation and degradation of carbon-rich ecosystems (Burgess et al., 2010).

Tanzania took initiatives to implement REDD and REDD+ in 2008, and as part of results, there has been an established inter-ministerial REDD task force, a National REDD Framework document and a National REDD Strategy and Action Plan. To date, at least seven REDD+ pilot projects operates in Tanzania from which results will be applied to other areas in the country. Based on its experience with Participatory Forest Management (PFM),

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Tanzania REDD Readiness Preparation Proposal (R-PP) states that PFM will be the cornerstone of the national REDD+ program (URT, 2010; UN-REDD, 2011).The first proposed outcomes of the UN-REDD Programme in Tanzania that is, 2009-2011 are almost beyond its peak, yet baseline information for many forests including Hanang is still lacking. Taking into account the time factor and alarming rates of deforestation, this study is a viable option. The study aimed at providing quantitative informa-tion on the stocking characteristics and carbon stocks of Hanang mountain forest serving as part of baseline establishment for the ongoing REDD+ initiatives in the country.

Deforestation is responsible for the diminishing area of forests and woodlands in the country from the previous 35 million ha (URT, 1998) to 33.4 million ha reported recently (FAO, 2010). Some of these forests such as Hanang dominate volcanic highlands and it is the most isolated of the ancient volcanic mountains in the land-scape of Eastern Africa (Krause and Böhme, 2010). Despite its potential for biodiversity conservation, water catchment and as carbon sink, high levels of forest degradation due to illegal lumbering and encroachment are threatening the future status of the forest. Defores-tation and forest degradation is closely linked with low levels of carbon stocks hence increasing green house gas (GHG) emissions and subsequent global warming. Some studies have been conducted to determine stoc-king characteristics and carbon storage in Tanzania mainly along the Eastern Arc Mountains and Miombo woodlands (Munishi et al., 2010; Shirima et al., 2011). However, very little has been done for Hanang Mountain Forest.

Forest carbon is identified in three major pools that is, above and below ground living vegetation, dead organic matter and soil organic carbon (IPCC, 2006), whose quantities have been identified for few forest types in Tanzania (Munishi and Shear, 2004; Munishi et al., 2010). It is document that amounts of carbon stored in different forests and the extent of forest degradation on carbon storage are largely unknown for many forest types including Hanang in Tanzania (Burgess et al., 2007). Re-liable equations for forest carbon measurements also exist for few forest types (Chamshama et al., 2004), mainly the Miombo woodlands (Munishi et al., 2010), and the Eastern arc mountain forests (Munishi and Shear, 2004). Due to lack of the needed scientific data this study is set to address the questions on stocking characteristics and carbon stocks of Hanang mountain forest, as part of the ongoing research towards climate change mitigation in the country. Specifically the study assessed the above ground biomass and carbon in trees, herbs as well as soil organic carbon. Non-destructive approach involving cal-culations from inventory parameters such as diameter at breast height (DBH), height, basal area and form factor, and then multiplying the volume with respective species wood basic densities. The soil basic densities were also used in the calculation of soil organic carbon.

MATERIALS AND METHODS

Study area description

Hanang mountain forest is found in Manyara region, within 4° 25' - 4° 35' S 35° 20' - 35° 25' W (Figure 1). It had been gazetted in 1936 with an area of ca. 5871 ha and covers an isolated volcanic peak extending from 1860 to 3418 m a.m.s.l. (Lovett and Pócs, 1993). The forest soils constitute the dark brown to grey brown humus rich loams over volcanic rocks, large area of the mountain being too steep to support vegetation (Kashenge, 1986). The climate has been described as oceanic rainfall with continental temperatures; also there may be some convectional rainfall from Lake Balangida. Nearest weather station in Katesh estimated rainfall amount of 750-1000 mm on the western side to 1200-1500 mm/year on the eas-tern side. Similarly, estimated >2000 mm/year at higher altitudes with a marked mist effect. During the dry season that is, between June and October, the estimated minimum temperature is 20.5°C (July) at lower altitudes. Forest vegetation occurs between 1980-3300 m with Montane and upper Montane forest on the wetter southern, eastern and northern slopes, and dry Montane forest on the western slopes (Lovett and Pócs, 1993).

Data collection methods

Sampling procedures and measurements

In order to understand the carbon stocks thirty four sample plots measuring 40 × 20 m (800 m^2 equivalent to 0.08 ha) were esta-blished at regular intervals along an altitudinal gradient. Plots were distributed along seven line transects to represent variations of conditions that influence the forest. Each sample plot was sub-divided into 8 subplots each measuring 10 × 10 m (Figure 2). Four among the 8 subplots had nested quadrats each measuring 1 × 1 m and the remaining four subplots had 2.5 × 5 m quadrats in each. The sample plots adopted for this study were modified from 1 ha plots which were part of the tropical ecology assessment and monitoring (TEAM) protocol (Kuebler, 2006). The former (40 × 20 m) was adopted as trials for the countrywide programme on climate change impacts adaptation and mitigation (CCIAM) in Tanzania.

In each of the established 0.08 ha plots, all tree species with dia-meter at breast height (DBH) ≥ 10 cm were measured for DBH and height using diameter tape and suunto hypsometer, respectively. For the case of DBH, adjustments were done for the swollen tree bases, injured, fluted, crooked stems and other deformities (Malimbwi, 1997). Identification of the species was done in the field and samples of species that could not be identified in the field were taken to herbarium for further identification. Tree height and DBH data were used to calculate stocking parameters that is, density, basal area and volume. For carbon stock determination, multiplica-tion of tree heights and plot basal areas with appropriate form factor was used to obtain tree volumes (Philips, 1995). Estimation of tree biomass was done by multiplying tree volumes with respective species wood basic densities (Munishi and Shear, 2004). Wood basic densities were obtained from samples of wood cores that were extracted from most frequent trees using an increment borer at approximately 1.3 m from the ground and some from the litera-ture (Munishi, 2001). Tree data were converted into tree biomass per unit area (ha^{-1}). The tree carbon density was estimated as 0.50% of the biomass. The crown carbon was estimated using applicable biomass expansion factor (Munishi and Shear, 2004).

For determination of carbon stock in both herbaceous species and soil the samples were collected systematically within 1 m^2 quadrats nested in the sub-plots. Species were cut at the stem base, labelled and fresh weight recorded in the field (Munishi et al., 2010).
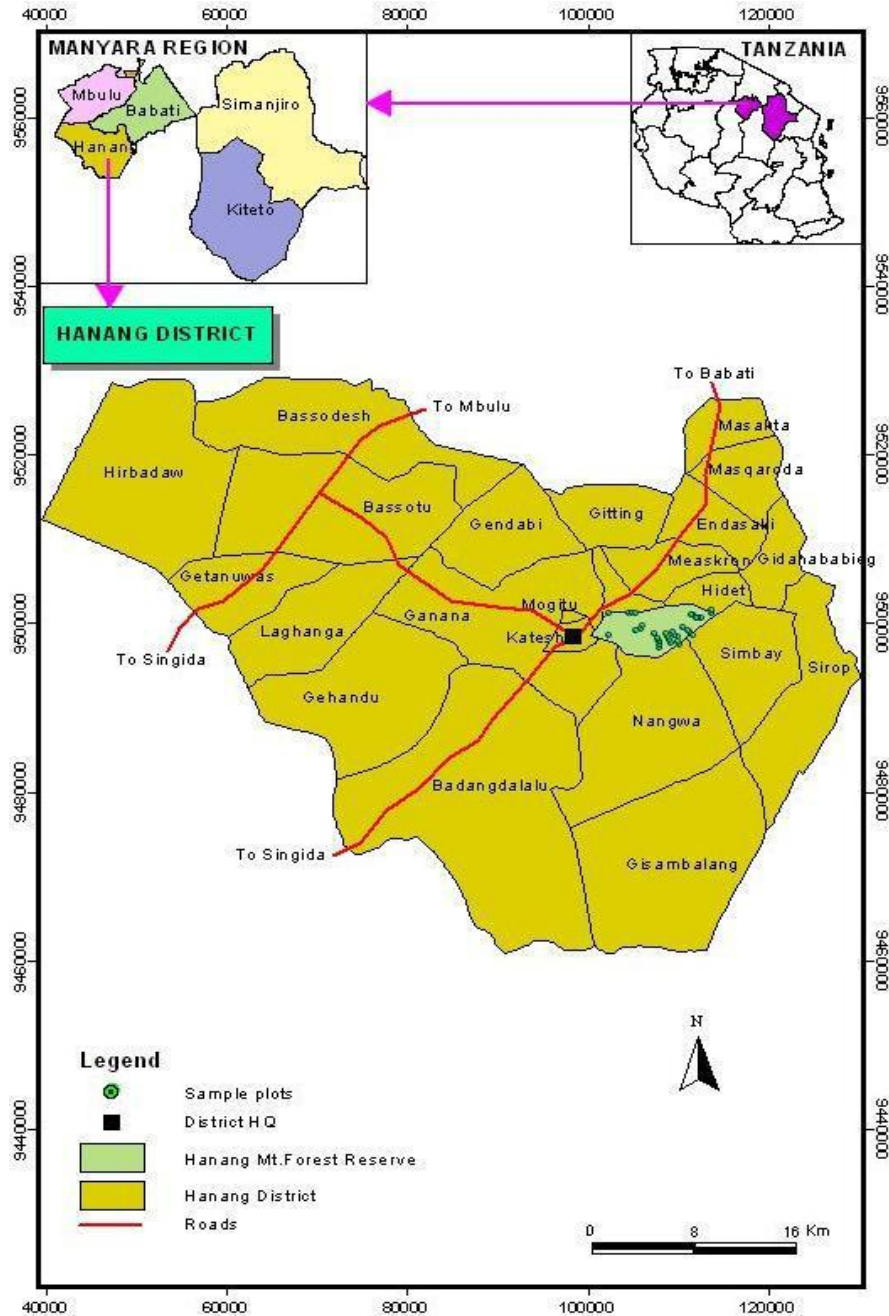
Figure 1. A map of Hanang District showing Hanang mountain forest.

Samples were taken for further laboratory analysis. Laboratory samples were oven dried at constant weight at 70°C to obtain dry mass. The loss on ignition (LOI) method was used to convert the content of the herbaceous species into percent carbon (Anderson and Ingram, 1993). For determination of soil organic carbon, soil samples were collected within four 1 m^2 quadrats in which herbaceous samples were taken. Soil samples were collected between 0-15 cm, >15-30 cm and >30-45 cm depths using a calibrated soil auger (Munishi and Shear, 2004). A composite sample obtained by mixing soil from each of the four subplots that is, $Q_1+Q_2+Q_3+Q_4$ (Figure 2) was used. Walkley- Black method (Black et al., 1965) was used to determine the SOC. Computation of soil carbon den-

sity (tons ha^{-1}) was done on the basis of soil mass per unit area obtained as the product of soil volume and estimated soil bulk density (Munishi and Shear, 2004). Determination of SOC was done at the UDSM botany laboratory.

Data analysis

Data pertaining to tree carbon, herbaceous carbon and soil organic carbon were processed using MS Excel spreadsheet and analysed using one way analysis of variance (ANOVA) (Zar, 1984). Where necessary an alternative non-parametric test to ANOVA Kruskall Wallis Test was used.
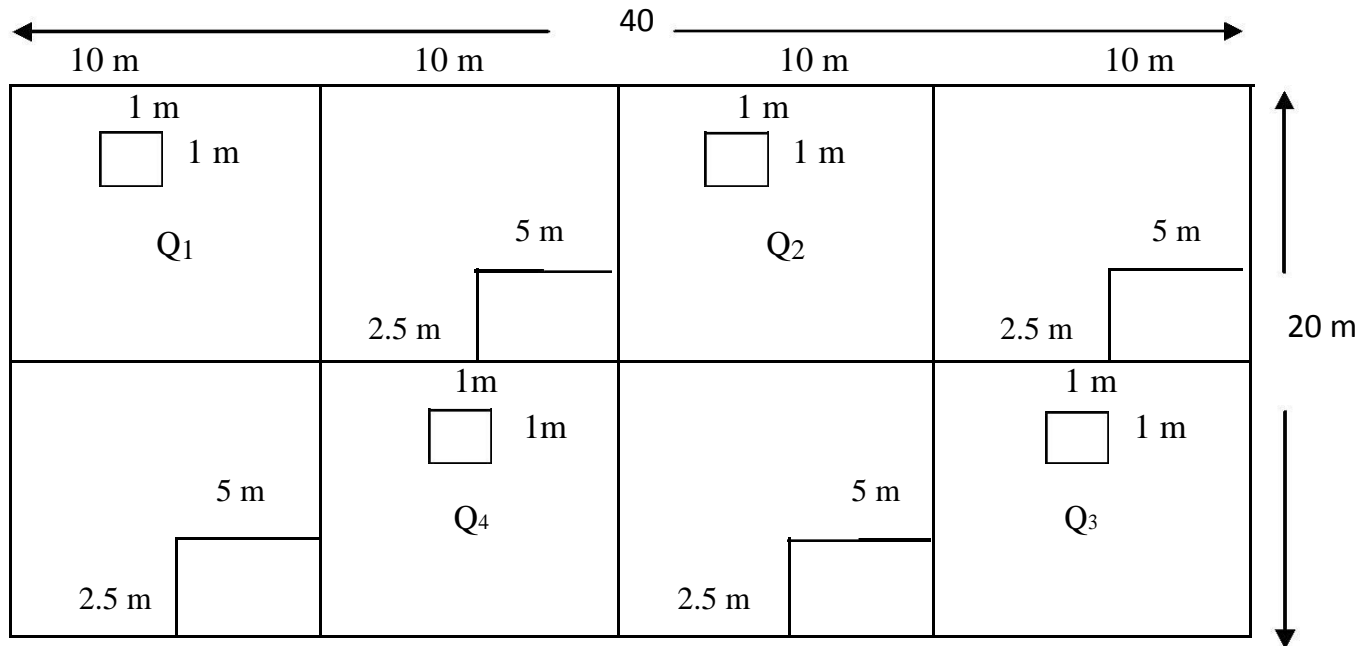
Figure 2. An illustration showing design of main plot and sub-plots.

Table 1. Above ground carbon values for tree species in Hanang FR.

Habit	DBH	Spp per Alt. Range	Alt. Range	Carbon (t/ha)	Whole forest carbon (t/ha)
Trees	≥10cm	36	L	71.46	
	≥10cm	33	M	49.83	**284,156**
	≥10cm	15	H	12.98	
	Mean tree carbon per ha			**48.37**	

Table 2. Above ground carbon values for herbaceous species in Hanang FR.

Habit	Spp per Alt. Range	Alt. Range	Carbon (t/ha)	Whole forest carbon (t/ha)
Herbs	21	L	0.22	
	36	M	0.28	**1,526.5**
	25	H	0.27	
	Mean herbaceous carbon per ha		**0.26**	

RESULTS

Above ground carbon in tree species

Tables 1 to 4 summarises the results of carbon storage for various pools. Overall carbon in tree species was 48.4±8.0 t ha^{-1} equivalent to 48.4 × 3.67t COe ha^{-1} in the area, which resulted into 284,156 t ha^{-1} equivalent to 284156 × 3.67t COe ha^{-1} for the whole forest (Table 1). It was highest at low altitude (71.5 ± 17.0 t ha^{-1}), followed by mid altitude (49.83 ± 9.94 t ha^{-1}) and lowest at high altitude (12.98 ± 7.7 t ha^{-1}) (Figure 3a). Results indicated that there was a statistically significant difference (p<0.05).

in tree carbon along altitudinal gradient (Table 4). The actual difference in mean scores between the groups was quite large. The effect size, calculated using eta squared was 0.30, hence indicating large effect. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for the low altitude (*M*=10.79, *SD*=4.79) was significantly different from mid altitude (*M*=9.17. SD= 4.08) and high altitude (*M*=8.71, SD= 4.64).

Above ground carbon in herbaceous species

The mean herbaceous carbon (t ha^{-1}) reported from this

Table 3. Soil organic carbon values for three soil layers in Hanang FR.

Pool	Layers	Alt. Range	Carbon (t/ha)	Whole Forest C (t/ha)
Soil organic carbon (SOC)	0-15cm	1	66.5	**376,918**
	0-15cm	2	65.4	
	0-15cm	3	55.1	
Mean soil organic carbon per ha (upper layer)			**64.2**	
Soil organic carbon (SOC)	>30-45cm	1	31.2	**246,171**
	>30-45cm	2	35.0	
	>30-45cm	3	21.8	
Mean soil organic carbon per ha (middle layer)			**41.93**	
Soil organic carbon (SOC)	>30-45cm	1	31.2	**181,942**
	>30-45cm	2	35.0	
	>30-45cm	3	21.8	
Mean soil organic carbon per ha (bottom layer)			**31.0**	
Overall mean SOC of three layers for the whole forest				**805,031**

Table 4. Differences in carbon stocks for plants of different growth habits and soil.

Habit/Pool	Variable	N-Test	F	p-value	Remarks
1. Trees	Carbon	Ko, Sh	(2.33) 5.40[*]	0.01	Sig.
2. Herbs	Carbon	Ko, Sh	(2.32) 0.36	0.69	NS
	Carbon (Tl)	Ko, Sh	(2.33) 1.0	0.42	NS
3. Soil	Carbon (Ml)	Ko, Sh	(2.33) 1.73	0.19	NS
	Carbon (Bl)	Ko, Sh	(2.33) 2.61	0.09	NS

Ko, Komolgorov-Smirnov; Sh, Shapiro-Wilcox tests of normality; S-Test, Statistical test; one way ANOVA; Sig., Significant variation; n.s., No significant variation; values in parentheses indicate degrees of freedom. Tl, Top layer (0-15cm); Ml, Mid layer (>15-30cm); Bl, Bottom layer (>30-45cm).

study was 0.26 t ha^{-1} amounting to 1,526 tons of carbon for the whole forest (Table 2). However the observed differences in herbaceous carbon were not statistically significant along altitudinal gradient (Table 4).

Carbon variation among tree species

The amount of carbon also varied between different tree species. Species with highest carbon density in descending order were *Prunus africana*, *Cassipourea malosana*, *Ekebergiacapensis*, *Calodendrumcapense*, *Oleaeuropaea*, *Teclea simplicifolia*, *Albizia schimperiana*, *Euclea natalensis* and *Maytenus senegalensis* (Table 5).

Relationship between carbon stocks and altitude

Relationship between carbon stocks and altitude in the trees, herbs and soil were analysed using Pearson correlation (Table 6). Results indicated that there was a statistically significant relationship between tree carbon (p<0.05)

and altitude forming a slight negative correlation. However there was a positive relationship between the herbaceous species carbon and altitude, that was not statistically significant (p>0.05). On the other hand there was a negative relationship between SOC and altitude in all three layers, but the relationship was also not significant. From the results only basal area and tree carbon correlated negatively with the altitude.

Soil organic carbon (SOC)

Table 3 and Figure 3c, show the differences in SOC among layers of soil from the upper (0-15 cm), mid layer (>15-30 cm) and bottom layer (>30-45 cm). Overall mean SOC in the sampled area for the three soil layers was 64.20±3.03 t ha^{-1} (upper layer), 41.93 ± 2.0 t ha^{-1} (mid layer) and 31.0 ± 2.3 t ha^{-1} in the bottom layer. Mean SOC also varied between the three layers along the gradient such that it was highest in the upper layer (66.51 ± 5.94 t ha^{-1}) at the lower altitude, followed by mid altitude
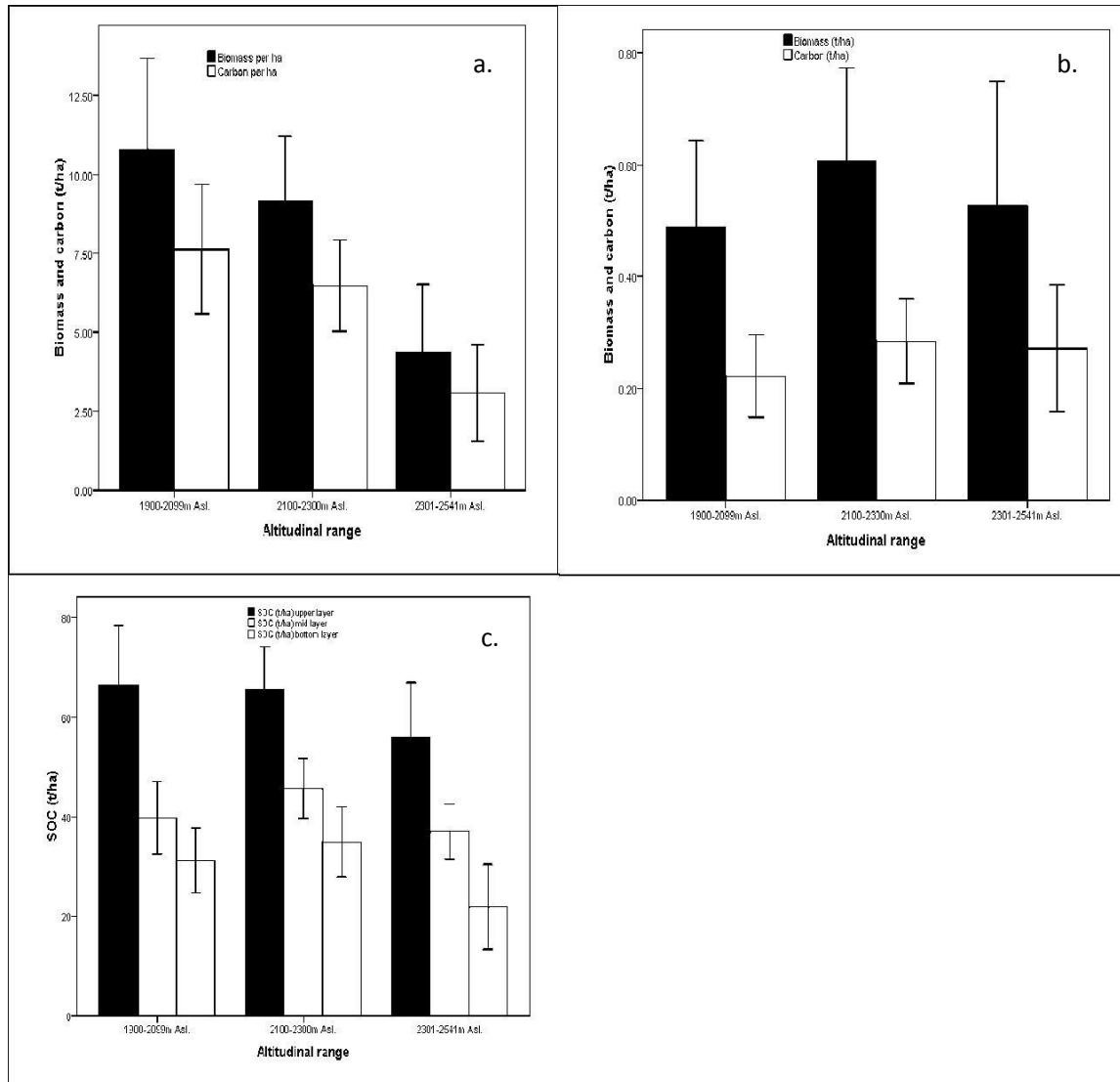
Figure 3. Biomass and carbon density for different growth forms and soil pools (a) trees (b) herbs (c) soil organic carbon (SOC).

(65.41 ± 4.36 t ha^{-1}) and high altitude (55.91 ± 5.49 t ha^{-1}). The mean SOC in the mid layer was much lower thanthe top layer such that it was 39.73 ± 3.64 t ha^{-1}, 45.62 ± 3.01 t ha^{-1} and 36.99 ± 2.75 t ha^{-1} in the low, mid and high altitude, respectively. The amount also decreased in the lower layer and the values were 31.17±3.30 t ha^{-1} in the low altitude, 35.0±3.53 t ha^{-1} in the mid altitude and 21.84±4.26 t ha^{-1} in the high altitude. However, there was no significant differences (p>0.05) in the SOC stocks for the three soil layers, respectively (Table 4).

DISCUSSION

Above ground carbon in tree species

The amount of 48.4±8.0 t ha^{-1} (Table 1) recorded for tree carbon, is lower compared to 517 and 388 t ha^{-1} reported

earlier for Usambara and Uluguru Moutain forests, respectively (Munishi and Shear, 2004), 236.74 Mg C ha^{-1} reported for Moutain Makiling FR in Philippines (Lasco et al., 2000) and 118-306 t ha^{-1} also reported from Philippines (Lasco and Pulhin, 2003). It has been explained that reliance on allometric equations could be one of the limitations resulting in large variations in such estimates (Lasco et al., 2000). However a recent study in tropical forests in Thailand (Kaewkorm et al., 2011), reported a reasonable tree carbon stock of 24.79 and 50.58 t ha^{-1} in two forest sites which conform to amount reported by this study. The observed anthropogenic threats including previous logging, ongoing pit sawing, grazing and encroachment could be a reason for the low carbon amounts. Variations in the methods for calculation and sampling techniques used compared to other studies also could be a reason for the varying results.

Table 5. Altitudinal variations in carbon stocks for the most dominant tree species

Species name	Carbon per species (t ha^{-1})			Overall Carbon
	L	M	H	
Prunus africana (Hook.f.) Kalkman	154.89	57.84	0.00	212.73
Cassipourea malosana Alston	0.00	211.46	0.00	211.46
Ekebergia capensis Sparrm.	57.90	129.08	0.00	186.98
Calodendrum capense Thunb.	157.51	0.00	0.00	157.51
Olea europaea L.	61.76	78.24	0.00	140.00
Celtis africana Burm.f.	120.49	0.00	0.00	120.49
Teclea simplicifolia I. Verd.	34.27	65.79	0.00	100.06
Albizia schimperiana Oliv.	0.00	65.67	0.00	65.67
Euclea natalensis A.DC.	31.51	34.13	0.00	65.64
Maytenus senegalensis (Lam.) Ex	0.00	43.09	19.47	62.56
Ficus sp.	28.73	0.00	0.00	28.73
Protea petiolaris (Hiern) Bak.	0.00	0.00	28.04	28.04
Catha edulis (Vahl) Endl.	0.00	27.11	0.00	27.11
Apodytes dimidiata E.	18.76	0.00	0.00	18.76
Schefflera volkensii Harms	0.00	17.49	0.00	17.49
Clausena anisata (Willd.) Hook. f.	13.85	0.00	0.00	13.85
Ekebergia capensis Sparrm.	0.00	0.00	12.78	12.78
Hagenia abyssinica J.F.Gmel.	0.00	0.00	9.11	9.11
Nuxia congesta R.Br.	0.00	0.00	5.27	5.27
Lepidotrichilia volkensii (Gürke) J.	0.00	0.00	4.94	4.94
Cussonia spicata Thunb.	0.00	0.00	3.47	3.47
Pavetta lanceolata Eckl.	0.00	0.00	2.94	2.94
Maesa lanceolata Forssk.	0.00	0.00	1.72	1.72
Juniperus procera Hochst	0.00	0.00	1.50	1.50

[1]L=1900-2099m a.s.l., M=2100-2300m a.s.l., H=2301-2541m a.s.l.

Table 6. Results of correlation between various carbon pools with altitude

Habit/Pool	Dependent variable	Independent variable	Coefficient (r)	Ref. level (2 tailed)	p-value	Remarks
1. Trees	Carbon	Altitude	-0.46[**]	0.01	0.006	sig.
2. Herbs	Carbon	Altitude	0.19	0.05	0.28	NS
3. SOC	Carbon (Tl)	Altitude	-0.14	0.05	0.44	NS
	Carbon (ML)	Altitude	-0.07	0.05	0.69	NS
	Carbon (Bl)	Altitude	-0.16	0.05	0.40	NS

[a]richness based on absolute number of species, [b]richness based on Margalef's values

[+]all sample species evenness, [++]each sample species evenness, [*]correlation is significant at 0.05 level (2-tailed), [**]correlation is significant at 0.01 level (2-tailed), Sig. =correlation is significant, n.s. = no significant correlation, Tl= Top layer (0-15cm), Ml= Mid layer (>15-30cm), Bl=Bottom layer (>30-45cm)

Above ground carbon in herbaceous species

The reported amount for herbaceous carbon is lower compared to a mean 0.57 t ha^{-1} reported from a dipterocarp forest in Philippines (Lasco et al., 2006). However it was higher than a mean 0.07 t ha^{-1} reported from a secondary forest in Moutain Makiling FR in Phillipines (Lasco et al., 2004), also higher than 0.11 t ha^{-}

[1]reported from a tropical forest in Eastern Panama (Kirby and Potvin, 2007). Despite the highest amount observed in the mid altitude and lowest in the low altitude, the observed differences were not statistically significant (p=0.53) along the altitudinal gradient (Figure 3b). There is higher limitation in the literature related to carbon storage by herbaceous species for many forests in Tanzania. Many previous studies have focused on quantifying

carbon stock of tree species mainly in the eastern arc mountains and Miombo woodlands.

Relationship between carbon stocks and altitude

From the results only tree carbon correlated negatively with the altitude. However the relationship between herbaceous carbon as well as soil organic carbon and altitude for three soil layers was not statistically significant (Table 6). In a similar study conducted in Achanakmar-Amar-Kantak Biosphere Reserve in India, significant relationships against altitude were only observed for basal area and stem density, respectively (Sahu et al., 2008). In a study conducted in Southern Appalachian spruce-fir forest, soil carbon did not show a trend with altitude, likewise the carbon dynamics did not show a consistent pattern with altitude (Tewksbury and Miegroet, 2007). It was further pointed out earlier that ecosystem processes and attributes affecting soil carbon dynamics along elevation gradients are the product of long term interaction between climate, vegetation and soil type (Garten, 2004). However, various findings reviewed in the course of this study indicated limitation in studies examining the relationship between carbon stocks of different habits/ pools and altitude for montane forests in Tanzania. From these findings a complex of environmental factors apart from altitude including temperature, precipitation, edaphic factors, mineral contents and anthropogenic disturbances are also likely having an influence on the parameters that did not show significant relationship with altitude.

Soil organic carbon (SOC)

The mean SOC reported from this study, is lower com-pared to 246 t ha^{-1}(0-15 cm) and 176 t ha^{-1} (15-30 cm) reported earlier from Usambara and 246 t ha^{-1} (0-15 cm) and 176 t ha^{-1} (15-30 cm) from Uluguru afromontane forests (Munishi and Shear, 2004). The mean SOC for the whole forest area (5871 ha) that is, 805,031 t C is higher than mean SOC (554, 262 t C) reported from 6177 ha of a selectively logged dipterocarp forest in Phillipines (Lasco et al., 2006). The SOC amount in three layers that is, 137.13 t ha^{-1} is also higher than a range of 33-117 t ha^{-1} reported from the same forest in Philippines (Lasco et al., 2006), besides it is also slightly higher than the default value of 130 t ha^{-1} given by IPCC for volcanic soils (Lasco et al., 2004). However, it is lower than the mean SOC of 183 t ha^{-1} (upon conversion from Mg C ha^{-1}) reported from moutain Makiling FR in Philippines (Lasco et al., 2004). The total SOC obtained accounts for 72.9% of the total forest carbon including trees, herbs and soil hence preliminarily conforming to observed findings that below ground carbon in the tropical forests comprises 2/3 of the terrestrial carbon (Bolin and Sukumar, 2000; Lasco et al., 2004). Similarly studies in Tanzanian afromontane forests also reported higher amounts of carbon in the soil.

than for above ground biomass (Munishi et al., 2000; Munishi and Shear, 2004). Further studies are needed in the area to account for the amount of carbon comprising the leaf litter, dead wood and roots in Hanang Mt. Forest.

CONCLUSIONS AND RECOMMENDATIONS

Tree carbon stocks were relatively low compared to similar forests in the tropics especially where allometric models were employed. Herbaceous carbon was relatively higher compared to many areas where similar findings were reported elsewhere in the tropics. Existence of widely employed techniques for forest carbon estimation and the controversies underlying the actual methods to be adopted, affects reliability of the existing data on forest carbon stocks. Increasing application of allometric models contri-butes potentially towards forest carbon estimation. How-ever the extent of its assumptions and limitations which tend to overestimate results as pointed in various studies impose many unresolved questions towards further research in the area. Existing soil organic carbon pools have potentially high amounts of carbon compared to similar areas in the tropics particularly in tropical Africa and Asia. However, ongoing threats from observed human activities such as pit sawing, pole harvesting, grazing and encroachment will likely diminish the SOC pools if effective measures will not be enforced. Further research should focus on quantifying the carbon content of the leaf litter, dead wood and root biomass. This will contribute towards a clear understanding of the existing carbon dynamics in the area.

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