Journal of Ecology and the Natural Environment Vol. 2(12), pp. 261-269, December 2010
Available online at http://www.academicjournals.org/jene
ISSN 2006- 9847 ©2010 Academic Journals

Full Length Research Paper

The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks

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Accepted 18 October, 2010

Inventory and monitoring of existing carbon pools in ecosystems is important for establishment of baselines for Reduced Emissions from Deforestation and Forest Degradation (REDD) as well as understanding the global carbon budget. We used tree dimensions to quantify the carbon pools of two sites in Miombo woodlands of the Southern Highlands of Tanzania. Mean above ground carbon density of the Miombo ecosystem was 19.2t ha^{-1}. Of the total carbon, 40 and 60% was contributed by stems and branches respectively. Different species contributed differently to carbon stocks in these ecosystems with *Brachystegia spiciformis* and *Julbernardia globiflora* contributing the most. The estimated carbon stocks in this ecosystem is within the range observed in dry forests elsewhere though they are in their early stages of regeneration after extensive exploitation pressure. Under proper management there is a tremendous capacity for carbon storage in these Miombo woodlands to mitigate carbon emissions. Since Miombo species tend to invest much in roots an assessment of below ground carbon in roots can add to the carbon storage potential of these ecosystems. Evaluation of the root and soil carbon in these ecosystems is important in determining the full potential of these ecosystems to act as carbon sink.

Key words: Miombo woodlands, biomass, carbon, reduced emissions from deforestation and forest degradation, emission mitigation, climate change.

INTRODUCTION

The rise in atmospheric carbon dioxide (CO_2) concentration will have varying implications on global climate (Wayburn, 2000; Munishi et al., 2000; Munishi and Shear, 2004). Land use changes and forest management activities have historically been and are currently net sources of carbon (C) as CO_2 gas to the atmosphere (Brown et al., 1996). However, depending on land use system, different ecosystems can be important sources or sinks for carbon (Levy et al., 2004).

There is a historical controversy as whether terrestrial ecosystems are releasing carbon to the atmosphere or withdrawing it and accumulating it in vegetation biomass and soils (Broecker et al., 1979; Houghton et al., 1987; Kauppi et al., 1992; Wisniewski et al., 1993). It is however, widely known that terrestrial ecosystems in general play a major role in the global carbon budget and fluxes (Brown, 1997, 1999; Dixon, 1996; Munishi, 2001; Munishi and Shear, 2004). Previous analyses have suggested that land vegetation contain as much carbon as present in the atmosphere. Furthermore, as much as 10% of the atmospheric carbon dioxide could be taken up and released annually by vegetation. Others suggest that terrestrial vegetation must be a source of carbon because deforestation proceeds faster than forest re-growth (Houghton et al., 1987).

Land use changes and forest management activities have high potential to mitigate carbon emission. Forest management offers one of important options for mitigation C emissions. Available options in forest management include avoiding emissions, conserving the existing C pools on the land (slowing down deforestation or improving forest harvesting), reduced deforestation

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and forest degradation, expanding C storage in forest ecosystems by increasing the area and/or carbon density of forests (e.g. by plantations, agro-forestry, natural regeneration, soil management) (Brown, 1999; Dixon et al., 1994; Dixon, 1996; Walker et al., 2008), increasing storage in durable wood products and substituting sustainably grown wood for energy intensive and cement based products (e.g. bio-fuels, construction materials) (Koluchigina et al., 1995; Winjum et al., 1998).

Terrestrial ecosystems especially forest vegetation have the greatest potential for mitigating atmospheric CO_2 emissions through conservation and management (Brown et al., 1996; Munishi et al., 2000; Munishi and Shear, 2004). Changes in forest cover, use, and management, produce sources and sinks of CO_2 that is exchanged with the atmosphere (Heygreen and Bowler, 1989; Jackson, 1992; Chidumayo, 1993). Assessment and monitoring of the existing carbon pools in forest ecosystems is important for understanding the global carbon budget especially when such ecosystems are relatively extensive and cover large areas.

Forest ecosystems in Tanzania occupy more than 35% of the land area (MNRT, 1998) and more than one third of this is occupied by the Miombo woodlands (MNRT, 1998; Monela et al., 2005). The Miombo ecosystem is one of the tropical wildernesses in the world covering about 3.6 million km^2 and spanning ten countries in East and Central Africa. In Africa Miombo woodlands cover an area of 2.7 mill. km^2 extending from Angola, Kongo, Zambia, Malawi, Mozambique, Tanzania and Zimbabwe. In Tanzania it covers about two thirds of the country (Fyhrquist, 2005). The vegetation of this area is primarily woodland, dominated by trees in the legume sub-family Ceasalpinoideae with the genera Brachystegia, Julbernardia and Isoberlinia dominating and a well-developed underlying layer of grass. The dominance of one family of trees provides the unifying feature for this ecosystem (Frost, 1996; Chidumayo, 1990; WWF, 2003). The miombo ecosystem contains a diverse of major woodland types including Wet Miombo, Dry Miombo, Burkea-Terminalia Woodlands, Baikiaea Woodland, Mopane Woodland, Acacia-Combretum Woodland, Dry Evergreen Forests (Cryptosepalum). The Miombo woodlands are however, undergoing the greatest change in Tanzania due to heavy use for supply of fuel wood and other sources of energy (Mapaure and Campbell, 2002). Although, the Miombo woodlands ecosystems of Tanzania are likely to have high potential for carbon storage and mitigating CO_2 emissions, reliable estimates for their potential are few and inadequate.

An analysis of the potential of the Miombo woodland ecosystems to sequester or store carbon is a key to understanding whether the correctives measures taken in land use changes and forest management within the Miombo woodland biome are likely to create net carbon sources or sinks. Such assessments are also fundamental in quantifying pathways for ecosystem carbon fluxes and sequestration in the Miombo woodlands. In this study estimate of the biomass and carbon pools of a Miombo woodland ecosystem in Southern Tanzania was made using relatively easily measured tree dimensions like Diameter at Breast Height (DBH). Such estimates are important in designing management plans for the Miombo woodlands that will ensure a sustained potential of this ecosystem's contribution to emission mitigation. Specifically carbon prediction models for Miombo woodlands of Southern Tanzania were developed using tree DBH as the predictor variable and the models were then use to make estimates of the biomass and carbon storage of the ecosystem.

MATERIALS AND METHODS

Study site

Mbozi district in Mbeya region is located in the South western corner of Mbeya region, between latitudes 8 and 9° 12" South of the equator and longitudes 32° 7' 30" and 33° 2' 0" East of Greenwich Meridian. To the South district is bordered by Ileje District, to the East by Mbeya rural District at the mark of Songwe river, to the north, Mbozi district extends to Lake Rukwa where it is bordered by Chunya District, whereas to the west it shares borders with Rukwa region and the Republic of Zambia. Mbozi District is composed of 6 divisions namely Igamba (1,754 ha), Iyula (900 ha), Kamsamba (2,708 ha), Msangano (821 ha), Ndalambo (2,454 ha) and Vwawa (750 ha) (Figure 1).

Two sites were selected based on the extent of Miombo vegetation in the region. Longisonte forest reserve is located in Vwawa division and Zelezeta village forest reserve in Igamba division. Both forests are a local authority forest reserves with an area of 1,041 and 220 ha respectively. These forests are mainly composed of Miombo woodlands dominated by genera *Brachystegi, Julbernadia* and *Isoberhinia* species (Mzoma et al., 1995). The forests have other associate species to these genera such as *Uapaca kirkiana* and *Parinari excelsa.* The climate of the area is bimodal with a rain season in October to May and a dry season in June to September. Most of the area is dominated by clay soils with high swelling and shrinkage characteristics

Data collection

A total of 30 temporary circular sample plots of radius 15 m (0.02 ha) were established systematically in each of the two sites. All trees with DBH ≥ 6 cm were measured for DBH. Each tree was identified in both the scientific and local name. For trees that were not identifiable in the field voucher specimens were collected for confirmation with an assistance of a taxonomist. Trees whose scientific names could not be ascertained were reported by their vernacular names. Based on species composition and dominance a total of 15 sample trees in each site were selected and measured for DBH. The trees were then felled, separated into stems and branches and then crosscut into billets that could be weighed. The billets were then tied into bundles and weighed in the field to obtain field tree weights of branches and stems. Finally two discs of about 2 cm thickness were crosscut from the stem and branch for laboratory analysis of basic density and biomass ratio.

Data analysis

The stem and branch discs from the field were cut into small samples of 2 x 2 cm, then soaked in water for one week and

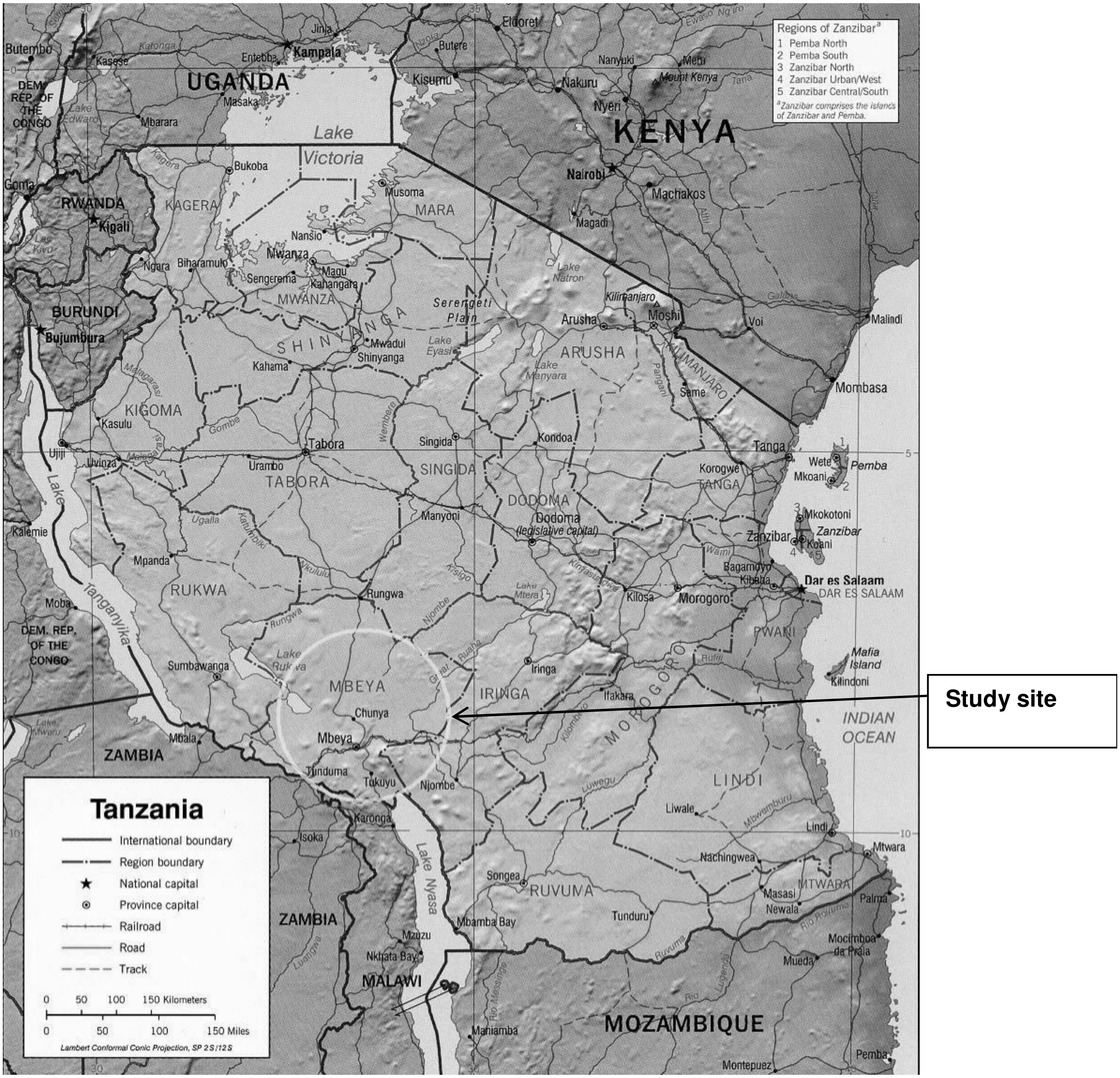

Figure 1. Map showing the study site within Tanzania (adopted and modified from Fyhrquist et al., 2002).

weighed for green weight. The samples were then oven dried at 103 ± 2°C to a constant dry weight. The biomass ratio was computed as the ratio of the oven dry weight to green weight for each tree stem and branch samples. The biomass ratio was used to convert the field tree weight (stem and branches) into biomass for the sample trees. We determined tree biomass through regression models using the diameter DBH as predictor variable for each component (Chamshama et al., 2004; Malimbwi et al., 1994; Munishi et al., 2000, Munishi and Shear, 2004).

Carbon prediction models were developed for each component using the diameter DBH as predictor variable (Haygreen and Bowler, 1989; Jackson, 1992; Malimbwi et al., 1994; Munishi et al., 2000). Although, other variables may influence carbon storage in trees, DBH is the most significant and easily measured predictor variable for biomass accumulation in forestry systems (Haygreen and Bowler, 1989; Jackson, 1992; Malimbwi et al., 1994; Munishi et al., 2000, Munishi and Shear, 2004). These equations were used to predict carbon storage (t/ha) by above ground vegetation from the plot tree diameter data. The amount of carbon was computed by multiplying the biomass by 50% and converted into per ha basis

Table 1. Carbon prediction models for stems and branches in Miombo woodlands in Mbozi District, Southern Highlands of Tanzania.

Location	Dependent variable	Model	R^2	P
Vwawa (Longisonte)	Stem carbon	$0.0069DBH^{2.9756}$	0.66	0.0001***
	Branch carbon	$0.0489DBH^{2.1623}$	0.46	0.0001***
Igamba (Zelezeta)	Stem carbon	$0.0172DBH^{2.5702}$	0.71	0.0001***
	Branch carbon	$0.5606DBH^{2.4067}$	0.34	0.0001***

*** = significant at 0.99 confidence limit.

Table 2. Carbon storage potential in Miombo woodlands at Longisonte and Zelezeta forest reserves in Mbozi District, Southern Highlands of Tanzania.

Location	Carbon density (t ha^{-1})				
	Stem	%	Branch	%	Total
Vwawa (Longisonte)	9.5	53	8.5	47	17.9
Igamba (Zelezeta)	5.7	28	14.6	72	20. 4
Average	7.6	40	11.5	60	19.2

(Haygreen and Bowler, 1989; Munishi and Shear, 2004). The estimates for stem and branches were done independently using respective models for each stem and branches to avoid cumulative errors that could result from an estimate of one parameter from another parameter.

RESULTS

Allometric models for carbon prediction

Table 1 shows the allometric models developed to estimate the amount of carbon stored by the Miombo woodlands ecosystem in the two sites. Though the models are all significant the branch biomass prediction models seem not to be strong enough to correctly predict the biomass of the tree branches. However, given the variations that exist in trees within these ecosystems the models can be used as the first approximation of tree stem and branch biomass in these ecosystems.

Carbon content of the Miombo ecosystem

We estimated above ground tree carbon to be 20.4 t ha^{-1} for the Zelezeta and 17.9t ha^{-1} for Longisonte forest reserves. This makes an average carbon density of 19.2 t ha^{-1} in the ecosystem. In Longisonte forest reserve 53% of the carbon density comes from stems and 47% from branches where as in Zelezeta site 28% come from stem and 72% from branches. Overall stem carbon makes about 40% of the total carbon in the ecosystem while branches contribute the larger proportion of about 60% (Table 2 and Figure 2).

Proportional contribution to C stocks by different species

We observed differences in carbon stocks as contributed by different species. *Julbernardia globiflora* store the highest amount of carbon per unit area in Longisonte forest reserve followed by *Brachystegia spiciformis, Uapaca kirkiana, Brachystegia bohemii* and *Parinari excelsa* accounting for 66.5% of the total carbon. The other 13 species accounted for the remaining portion (33.5%). In the Zelezeta site *B. bohemii* contributed the highest in carbon storage followed by *B. spiciformis, P. excelsa, Albizia antunesiana* and *U. kirkiana*. These species accounted for 98.1% of the total carbon while the remaining 5 species accounted for the remaining proportion.

The four species accounting for the most carbon are common in Miombo woodlands in the South though the most common Miombo species are *B. spiciformis, B. bohemii* and *J. globiflora*. *Uapaca* and *Parinari* sometimes form unique associations in these ecosystems with *Uapaca* forming pure stands on well drained areas thus their high contribution to carbon storage in this Miombo ecosystems (Tables 3 - 4 and Figures 3 - 6).

DISCUSSION

We estimate carbon density in this study to an averaged of 19.12 t ha^{-1} and which is relatively higher than earlier estimates of 6.45 t ha^{-1} C for a coastal Miombo at Kitulanghalo forest reserve (Malimbwi et al., 1994) and a highland Miombo in Tabora (Backeus et al., 2006). These

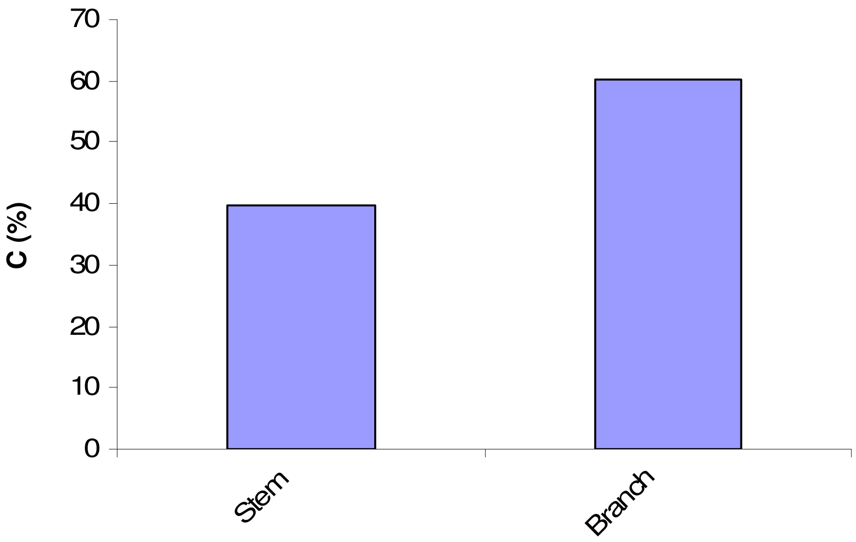

Figure 2. Percent contribution of ecosystem C by different tree parts in the Miombo woodlands, Southern Tanzania.

Table 3. Aboveground carbon as contributed by different species in Miombo woodlands at Longisonte reserve, Southern Highlands of Tanzania.

Species	Carbon density (t/ha)			%
	Stem	Branch	Total	
J. globiflora	2.52	1.67	4.21	23.6
B. Spiciformis	1.42	1.11	2.47	13.8
U. kirkiana	1.01	1.11	2.12	11.9
B. Bohemii	0.82	0.78	1.60	9.0
Parinari excelsa	0.72	0.75	1.48	8.3
Hymenocardia acida	0.51	0.58	1.12	6.3
Lannea schimperi	0.60	0.41	1.04	5.8
Combretum zeyherii	0.59	0.41	0.96	5.3
Crossopteryx februfugia	0.40	0.34	0.73	4.1
Pseudolachynostylis maprouneifolia	0.21	0.28	0.50	2.8
Combretum molle	0.19	0.26	0.46	2.6
Commiphora fischeri	0.18	0.21	0.39	2.2
Dalbergia nitidula	0.07	0.11	0.18	1.0
Diplorhynchus condylocarpon	0.09	0.10	0.18	1.0
Afromosia angolensis	0.05	0.08	0.13	0.7
Syzigium guineense	0.04	0.07	0.11	0.6
Commiphora mossambicensis	0.04	0.07	0.10	0.6
Lonchocarpus bussei	0.05	0.03	0.08	0.5
Total	9.49	8.36	17.86	100

differences in carbon densities might be due to varying degree of exposure to human degradation, difference in age of the tree species and the type of Miombo woodlands involved. Williams et al. (2007) clearances due to agriculture are estimated reduce carbon stocks by 19.0 t C ha^{-1} in Miombo woodland of Mozambique. Various studies show that different ecosystems have different biomass and carbon densities. For example the C density estimates from Afromontane Rain Forests of the Eastern Arc Mountains were found to be between 252 and 581 t C ha^{-1} (Munishi, 2001; Munishi and Shear, 2004; ECCM, 2007; Munishi and Shirima, 2010a, b). The

Table 4. Above ground carbon as contributed by different species in miombo woodlands at Zelezeta, Mbozi District, Southern Highlands of Tanzania.

Species name	Carbon Density (t/ha)			%
	Stem	Branch	Total	
B. bohemii	2.46	9.48	11.94	58.5
B. spiciformis	1.71	3.01	4.72	23.1
P. excelsa	0.74	1.04	1.78	8.8
A. antunesiana	0.41	0.52	0.93	4.6
U. kirkiana	0.28	0.37	0.65	3.2
C. molle	0.05	0.06	0.11	0.5
Cussonia arborea	0.04	0.06	0.10	0.5
Ochna ovata	0.04	0.06	0.09	0.5
Bridelia micrantha	0.03	0.04	0.07	0.4
Total	5.75	14.6.3	20.39	100.0

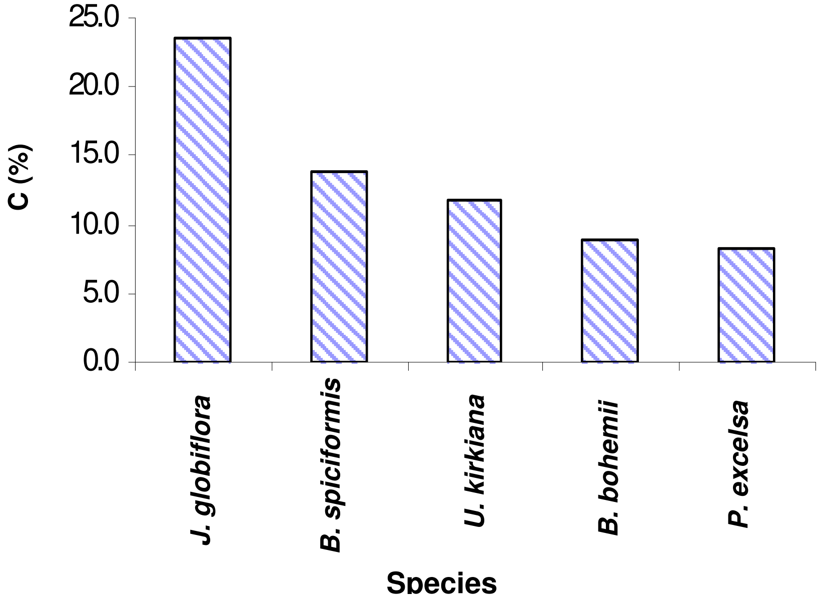

Figure 3. Percent contribution to ecosystem carbon by the most dominant species in Miombo woodlands at Longisonte Reserve in Mbozi District, Southern Highlands of Tanzania.

Eastern Miombo woodlands in Tanzania have been shown to have C storage potential of between 25 and 80 t ha^{-1} (ECCM, 2007; Shirima, 2009). Brown et al. (1993) observed that only about 6% of mature forests in tropical Asia had more than 122.5 t ha^{-1} C while a 60-year rotation plantation of *Tectona grandis* (Teak) in Tanzania had 244 t ha^{-1} C, (O'Kting'ati et al., 1998 quoted in Munishi, 2001; Munishi and Shear, 2004). It is very possible that the amount of C stored by these ecosystems will be higher if other carbon pools like the undergrowth of herbaceous layer, litter and other organic debris and tree samplings with DBH below 6 cm which are relatively numerous in some parts of the forests were included. Further soil C adds much to the potential for C storage in these ecosystems. Disturbance in the study site due to human utilization may also have contributed to lowering the C stock in these forests. Forests that have been subjected to human disturbances tend to have lower biomass and hence C storage than their potential (Brown, 1997).

Human destruction of tropical forests is estimated to contribute up to 17% of global carbon dioxide emissions, resulting in accelerated global warming. One mechanism proposed to mitigate these emissions is Reduced Emissions from Deforestation and Forest Degradation (REDD) in developing countries, otherwise known as Reduced Emissions from Deforestation and Degradation (REDD+; that is the original concept of REDD, plus

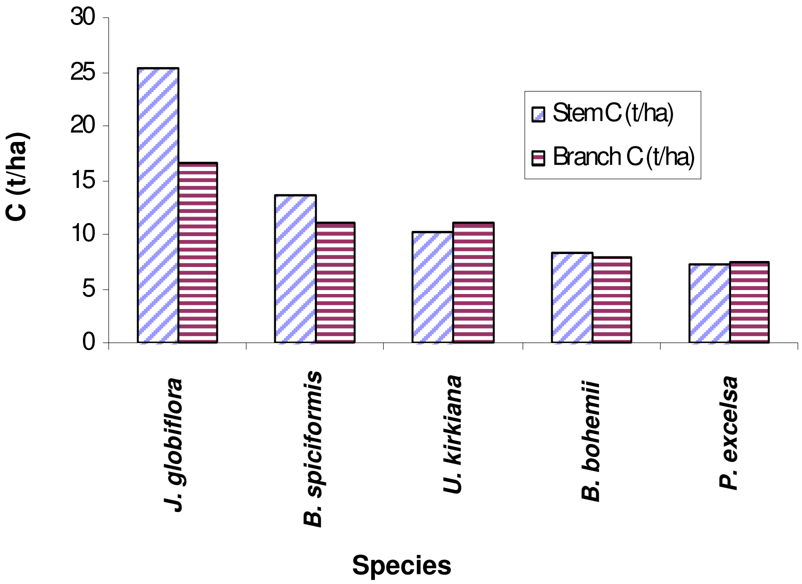

Figure 4. Total contributions to ecosystem carbon by the stem and branches of the most dominant species in Miombo woodlands at Longisonte and Zelezeta forest reserves in Mbozi District, Southern Highlands of Tanzania.

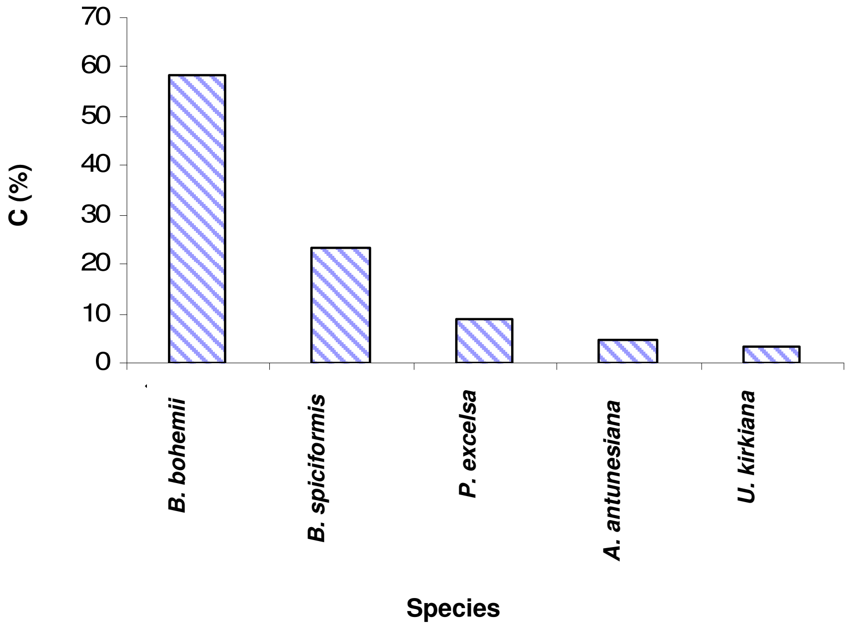

Figure 5. Percent contribution to ecosystem carbon by the most dominant species in Miombo woodlands at Longisonte and Zelezeta forest reserves in Mbozi District, Southern Highlands of Tanzania.

sustainable management of forests and conservation and enhancement of forest carbon stocks). This proposed mechanism forms part of an international move to include emissions from habitat change (especially the loss of carbon-rich ecosystems such as forests) in a more comprehensive agreement under the UN Framework Convention on Climate Change (UNFCCC), which it is hoped will become operational in 2012. If an international REDD+ mechanism is to be successful, with minimal displacement of greenhouse gas emissions between countries (known as international leakage), it is important that developing countries hosting a large proportion of the

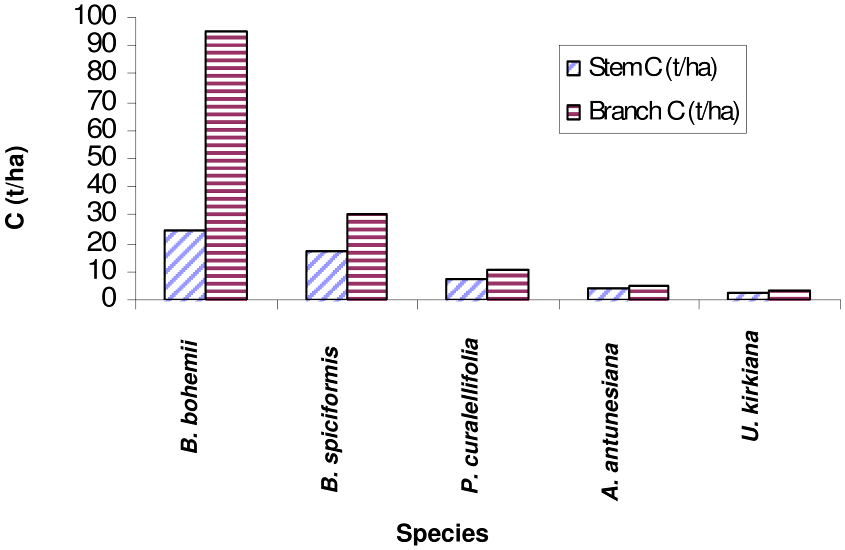

Figure 6. Total contributions to ecosystem carbon by the stem and branches of the most dominant species in Miombo woodlands at Longisonte and Zelezeta forest reserves in Mbozi District, Southern Highlands of Tanzania.

world's forest are ready to participate shortly after its launch.

A key aspect of determining the carbon benefit of any forest carbon project is to accurately quantify the levels of carbon changes to known levels of precision. Determination of carbon changes requires baselines that is historical trends against which additional carbon benefits as a result of carbon project can be determined. Under REDD, the reference scenario will be the baseline against which achievements made by a country can be measured and credited. Possible options for crediting forest carbon management include reduction in emissions from deforestation; reduction in emissions from degradation; enhancement; forest conservation; and conservation of the existing carbon stock. The last two options relate to forests with long protection status which would be credited based on the maintenance of carbon stock which would be compensated through a "conservation" fund that would be included under REDD.

Since the REDD policy is likely to be undertaken nationally, the country deforestation baseline need to be determined by depicting historical land use changes and typical carbon stock data for different types of forests to calculate the changes in C stocks over time.

Assessments of carbon stocks in different land use systems especially forests and woodlands are therefore among the important national REDD - readiness activities that portrays the baseline information on C stocks as Tanzania prepares for the anticipated REDD mechanism.

CONCLUSIONS AND RECOMMENDATIONS

Given their extent there is apparently a tremendous capacity for the Miombo ecosystem of Southern Tanzania to store carbon and act as C sink if properly managed. Efforts to ensure proper management of the Miombo ecosystem putting emphasis on the dominant species e.g. *B. spiciformis, B. boehmii and P. excelsa* can contribute to the creation of a considerable carbon sink and will ensure persistent potential for the Miombo woodlands to store C as sinks rather than emission sources thus contribution to the REDD process in Tanzania and global initiatives at large. On the other hand the Miombo ecosystem is widely utilized by the adjacent communities for various purposes, creating high degradation pressure on the ecosystem. In this respect managing the carbon stocks of these ecosystems require a concerted effort to reduce the human related degradation. This can partly be achieved by allowing the adjacent communities to harvest wood products from the forest under proper management to recover some of their socio-economic values and ensure local community participation in the management and conservation of the Miombo ecosystem. Such carbon can as well be a source of revenue from carbon trading and under proper benefit sharing mechanism can contribute to poverty reduction among the adjacent local communities. Further managing the carbon stocks in this extensive carbon rich ecosystem will contribute to global initiatives in combating global warming. If this is realized it will as well contribute to sustainable forest and woodland management in Tanzania.

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