THE ROLE OF URBAN FORESTRY IN MITIGATING CLIMATE CHANGE AND PERFORMING ENVIRONMENTAL SERVICES IN TANZANIA

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ABSTRACT

The possibility of global climate change, due to increasing levels of CO_2 concentrations is one of the key environmental concerns today, and the role of terrestrial vegetation management has received attention as a means of mitigating carbon emissions and climate change. In this study tree dimensions and assessment of plant species composition were used to quantify the potential of urban ecosystems in acting as carbon sink and mitigating climate change through carbon assimilation and storage and the potential of the system to enhance biodiversity conservation taking Morogoro Municipality as a case study. Biomass/carbon models for trees were developed and used to predict biomass/carbon storage based on tree diameters. The model was in the form $B = 0.5927DBH^{1.8316}$ ($r^2 = 0.91$, $P < 0.01$). The carbon content was computed as 50% of the tree biomass. The tree carbon for Morogoro municipality ranged from 4.63±3.39 to 21.18±12.41t km^{-1} length of ground surface along roads and avenues. Newly established areas seemed to have lower carbon storage potential while areas established earlier have highest carbon storage potential. About 36 different tree species growing/planted in the Morogoro municipal were identified, dominated by *Senna siamea, Azadirachta indica, Polyalthia longifolia, Leucaena leucocephala, Pithecelobium dulce and Mangifera indica.* Apart from being natural amenity the tree species also act as CO_2 sink through photosynthesis and areas of ex-situ conservation of plant diversity. Urban forestry can store large amount of carbon in addition to biodiversity conservation especially where they cover extensive areas like parks, gardens and avenues managed over long periods, as is the case in urban ecosystems. Improved management of urban forests will likely improve the potential for carbon storage by terrestrial vegetation as a means of mitigating CO_2 emissions and climate change as well as biodiversity conservation.

Key words: Urban forestry - carbon emission - mitigation options - carbon sequestration - Biomass.

INTRODUCTION

The fate of 10% or more of the CO_2 added to the atmosphere by burning of fossil fuels is unaccounted for, and the missing carbon problem observed in the 1970's is still unresolved (O'Kting'ati *et al.* 1998; Cushman *et al*. 2000; Munishi & Shear, 2004). The increasing concentration of CO_2 in the atmosphere is believed to cause changes in the global climate, including increase in global temperature. With the increasing concern about the rise in the atmospheric carbon dioxide (CO_2) concentrations and its implications on global climate, terrestrial ecosystem management has been looked upon as a potential way for mitigating carbon (C) emission (Brown, 1997; Munishi *et al*. 2000; Munishi & Shear, 2004). Land use changes and forest management activities have historically been and are currently net sources of C (as CO_2 gas) to the atmosphere (Brown *et al.* 1996). However, forest management has a great potential for C emission mitigation by withdrawing C from the atmosphere and accumulating it in vegetation biomass and soil (Brown, 1997; Munishi *et al*. 2000; Munishi, 2001; Munishi & Shear, 2004). Land use changes and forestry have been identified as the most important sources and sinks of anthropogenic green house gases in Tanzania (CEEST, 1994; Omujuni, 1994) though there are no quantitative data to show which changes create net sources or net sinks.

Determining the amount of change in vegetation biomass can be important for understanding the global C budget, including the fate of CO_2 produced by burning of fossil fuels and by industries (Detwiler & Hall, 1988; Brown *et al.* 1993) and management of existing pools on the land for emission mitigation (Brown, 1999; Munishi *et al*. 2000; Munishi & Shear, 2004). Biomass and carbon estimates for forests are particularly needed since forests have high biomass and carbon content thus influencing their roles in mitigating C emissions (Bradshaw *et al.* 1995; Brown *et al*. 1996).

Changes in forest cover, use and management produce sources and sinks of CO_2 that is exchanged with the atmosphere. This is because 49% - 50% of the forest Biomass is carbon (Haygreen & Bowler, 1989; Jackson IV, 1992; Chidumuyo, 1993; Brown, 1997; Munishi, 2001; Munishi & Shear, 2004). An analysis of the potential of forests to sequester or store carbon will help to understand whether the corrective measures taken in land use changes and forest management are likely to create net carbon sources or sinks. Such assessment is also fundamental in quantifying pathways for ecosystem carbon fluxes and sequestration (Munishi, 2000; Munishi & Shear, 2004; Munishi *et al*. 2004).

Urban forests defined as the sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan regions are considered as one of the major land uses especially in human settlements. Like any other land use in Tanzania, urban forestry and its management can have big potential in mitigating C emissions and performing other environmental services. There is however a limited number of studies that have quantified the potential of urban forest ecosystems in Tanzania to mitigate CO_2 emissions. According to Bradshaw *et al.* (1995), mature oak forests found in urban ecosystems have very high potential for biomass and carbon storage.

Trees have been planted in urban areas for many centuries (Bradshaw *et al.* 1995). But little attention has been paid on the important roles they play. Their environmental contribution in terms of reducing air pollution (CO_2 gas emission) wind and other factors are equally important although difficult to quantify. The practice of urban forestry in Tanzania is on the rise and takes many forms. Most of the planting has been for ornamental/amenity purposes and or shade around houses, along streets and around property boundaries and to some extent economic value.

Analyses to-date suggest that there may be some inexpensive opportunities to reduce current net CO_2 emissions through forest management activities and that these projects could have additional environmental benefits through protection of biological diversity, protection of watersheds among others (Houghton *et al*. 1987; Wisconsin Department of Natural Resources, 2005; van Esch *et al*., 2005). If urban forestry projects can be integrated with the social, cultural and developmental needs, they could offer very attractive opportunities for providing carbon benefits, especially in the short-term, while alternative energy system options are developed and the understanding of the costs of global climate change improves. The magnitude of benefits available through forestry-sector activities will depend on the amount of land available, improvements of forest productivity and technical developments in the efficiency with which forest products are harvested and used. Urban forest management can likely be significant for carbon emission mitigation and can also be used as a basis for emission offset trading and conservation credits. Such credits can be effective at rising funds for conservation (Daniel, 1995; Ronald, 1997; Casey, 1997; Brown, 1997; Wisconsin Department of Natural Resources, 2005).

Despite that urban forestry save several environmental functions, the potential role of urban forestry to sequester carbon has not been adequately studied in Tanzania although analyses suggest that forest conservation, establishment and management could contribute to global C sequestration and conservation while providing goods and services to many urban populations.

The major objective of this study is to encourage urban forestry by evaluating their potential for mitigating C emission as a green house gas and performing other environmental functions in Tanzania as represented by Morogoro Municipality. Specifically we assessed the carbon storage potential of the commonly planted tree species and the diversity of tree species planted in Morogoro Urban ecosystem.

MATERIALS AND METHODS

Study Sites

This study was conducted in Morogoro municipality, eastern Tanzania, about 200 km west of Dar es Salaam City. Morogoro municipality lies between latitudes 5º 00' and 7º 40' S of the equator and longitudes 37º 10' and 38º 33' E of Greenwich Meridian. It is situated on the foothills of Uluguru Mountains approximately 200 km from the Indian Ocean. Morogoro municipality covers an area of about 65 square kilometers. The area where data was collected for development of prediction models is located about half a kilometer north-west of the Sokoine University of Agriculture (SUA) campus gate. The Morogoro municipality is characterized by flat terrain with some areas having gentle undulating slopes. Morogoro has varied climatic conditions, however, sub-humid type is the most predominant. The area experiences a bimodal rainfall regime with short rains during November to January and long rains during March to May. The annual rainfall varies between 600 mm to 1000mm. Two distinct seasons are identified as December to May as a wet season and June to November as a dry season. The mean monthly temperature varies from 21°C to 27°C. Most of the natural vegetation has been removed due to cultivation/settlements establishment and other human activities. The previous natural vegetation is considered to be miombo woodlands (Morrison *et al*. 1974). Until recently a wide range of tree species with predominance of *Senna siamea* (mijohoro in Swahili) has been planted and more trees are being planted in new settlements as an effort to improve the urban environment (Msanya *et al*. 2001).

Data Collection

Sample tree data were collected from a small plantation of commonly planted tree species in Morogoro (*Senna siamea*) located at SUA plantations in Morogoro municipality. The plantation (forest) is located on the south-west of SUA main gate along the Mzinga road. The specie *Senna siamea* was used for development of allometric model due to the fact that this species dominate/have higher frequency in most municipalities in Tanzania. The trees to be measured were about 6 years old. About 25 trees were selected randomly to cover as much variation in diameter as possible. The trees were measured for diameter at breast height (dbh) and height using a calliper and a measuring tape respectively. The felled trees were separated into stem and branches and the green weight of the stem, branches (including twigs) were recorded separately using a beam balance for each felled tree. The separation of stem from branches was based on a top diameter along the main stem of about one third of the basal diameter. Wood samples were cut from each stem and branch for laboratory analysis of basic density and biomass ratio.

In the laboratory, samples measuring 2 cm x 2 cm were extracted from each wood sample and soaked in water for two days to obtain the green weight. After two days the green weight of each sample was recorded and then the samples were oven dried at 103±2^{o}C to constant weight and the weight recorded. The sample volume was determined using water displacement method.

The municipality was stratified based on administrative areas. Sample plots for tree measurements were established in different strata of the municipality. Because urban tree planting normally follows linear than aerial dimensions (patterns) the plots were also in linear and the size was 100 m long along streets (Plate 1). All trees along the plot length were identified and measured for dbh and basal diameter. At least five sample plots were established in each stratum and whenever applicable the number of plots were proportional to the area of each stratum.

The biodiversity of tree species planted in Morogoro urban were assessed based on the sample plots established whereby all the tree species apart from *Senna siamea*, which were found within the plot were recorded.

Data analysis

A common method of estimating tree biomass/carbon is to develop allometric models for biomass or carbon based on dbh and/or height of the stand by felling and weighing sample trees (stem and branches) and use the model to predict biomass and/or C (Brown *et al*. 1998; Malimbwi *et al*. 1994; Munishi *et al*. 2000; Munishi, 2001; Munishi & Shear, 2004).

The biomass ratio for the stem and branch samples were calculated as the ratio of the oven dry weight to the green weight of the wood samples (Malimbwi *et al*. 1994; Munishi & Shear, 2004). Biomass for stems and branches was then calculated by multiplying the stem and branch green weight by the biomass ration *i.e.* Biomass = Biomass Ratio x Green Weight (for stem and branches).

The dbh of the 25 sample trees were then regressed against biomass/carbon to develop a carbon prediction model of the form "biomass = a $(dbh)^{b}$ " that was used to compute plot tree biomass. The plot biomass was converted to C through multiplication by 0.50 (Chidumunyo, 1993; Haygreen & Bowler, 1989; Malimbwi *et al.* 1994; Brown, 1997; Munishi *et al.* 2000; Munishi, 2001; Munishi & Shear, 2004). The estimated carbon of the individual tree carbon contents was aggregated to plot carbon and divided by plot length to obtain carbon in (kg/100m length).

Plate1 Urban trees planted for amenity purposes can be very significant in carbon sequestration and storage in urban ecosystems

RESULTS

Wood Density and tree biomass

Wood density for stems ranged from 0.49 to 0.93 g cm^{-3} with an average of 0.73 g cm^{-3}. For branches the wood density ranged from 0.49 to 0.68 g cm^{-3} with an average of 0.58 g cm^{-3} (table 1). The average wood density is consistent with wood densities reported in other studies for tropical Africa (Brown & Lugo, 1992; Brown, 1997; Munishi, 2001; Munishi & Shear, 2004). The model developed for the determination of tree biomass was in the form $B = 0.1596*DBH^{2.179}$ ($r^2 = 0.928$, $P<0.001$) where B = tree biomass (t), DBH = diameter at breast height (cm). Wood biomass from the sample trees ranged from 11.86 kg $tree^{-1}$ (5.6 kg $tree^{-1}$ C) to 184.76 kg $tree^{-1}$ (9.42 kg $tree^{-1}$ C) with an average of 54.95 kg $tree^{-1}$ (27. 9 kg $tree^{-1}$ C) (Table 1). The carbon content by strata in the municipal based on the model ranged from 4.63 ± 3.39 t km^{-1} to 21.18 ± 12.41 t km^{-1} length (Table 2). The average values of carbon content are different for different parts of the municipality ($p < 0.01$) (Table 2). Mafiga area has highest percentage of carbon content compared to the rest of the Morogoro municipality, which may reflect high tree density and size compared to other areas.

Table 1 Summary of sample trees of *Senna siamea* showing their wood densities, biomass ratio and tree biomass in Morogoro municipality Tanzania

Tree no.	**Wood Density**		**Biomass Ratio**		**Tree Biomass**
	Stem	**Branch**	**Stem**	**Branch**	**(Kg)**
1	0.93	0.65	0.58	0.49	47.10
2	0.85	0.61	0.54	0.42	28.99
3	0.85	0.55	0.49	0.47	19.38
4	0.74	0.55	0.55	0.46	37.64
5	0.87	0.55	0.58	0.50	48.56
6	0.53	0.64	0.54	0.57	56.76
7	0.86	0.55	0.63	0.46	139.09
8	0.78	0.57	0.62	0.50	150.01
9	0.80	0.65	0.56	0.49	41.19
10	0.66	0.66	0.55	0.58	74.35
11	0.50	0.68	0.56	0.59	32.18
12	0.71	0.60	0.52	0.51	38.07
13	0.49	0.56	0.51	0.42	27.92
14	0.81	0.54	0.51	0.43	29.55
15	0.55	0.59	0.56	0.50	49.44
16	0.63	0.50	0.51	0.44	42.52
17	0.73	0.53	0.52	0.49	35.02
18	0.85	0.49	0.53	0.28	27.20
19	0.75	0.56	0.52	0.48	69.12
20	0.63	0.66	0.53	0.49	42.04
21	0.73	0.59	0.56	0.52	42.22
22	0.90	0.53	0.60	0.44	73.38
23	0.74	0.58	0.53	0.51	25.50
24	0.50	0.54	0.46	0.50	11.86
25	0.78	0.52	0.58	0.45	184.76
Average	**0.73**	**0.58**	**0.55**	**0.48**	**54.95**
Min	**0.49**	**0.49**	**0.46**	**0.28**	**11.86**
Max	**0.93**	**0.68**	**0.63**	**0.59**	**184.76**

Table 2 Mean values of carbon (t/km) per length of road/property boundary observed in different parts of Morogoro municipality Tanzania. Means with different superscript are significantly different from each other ($p < 0.05$).

Location	**Establishment**	**Mean ±SD**	**St. Error**
Mazimbu	New	4.63 ± 3.39^{b}	1.51
Kihonda	New	6.24 ± 2.37^{b}	1.06
Modeko	New	11.93 ± 8.72^{ba}	3.90
Chamwino	Old	14.29 ± 18.50^{ba}	8.27
Mafiga	Old	21.18 ± 12.41^{a}	5.55
Town–Center	Old	$11.63\pm7.03b^{a}$	3.14
Kilakala	Old	14.61 ± 8.75^{ba}	3.91
Forest Hill	Old	14.36 ± 12.56^{ba}	5.62
SUA–Main Campus	Old	12.07 ± 3.36^{b}	1.5

The Richness and Diversity of Tree Species

The study identified 36 different tree species growing/planted in the municipality (Table 3). Apart from *Senna siamea* being dominant species there were other species observed to be dominant in the municipality. Among the most dominant species order of dominance were *Azadirachta indica Polyalthia longifolia, Leucaena leucocephala, Pithecelobium dulce and Mangifera indica*. These tree species apart from being natural amenity to the municipal they also act as sink for CO_2 through the process of photosynthesis, which accumulates C in tree biomass.

Table 3 Tree species richness and dominance in the Morogoro urban ecosystem eastern Tanzania

Species	**Frequency of Occurrence**	**Percentage (%)**
Acacia nilotica	7	0.5
Acacia xanthophloea	5	0.3
Faidherbia albida	8	0.5
Albizia lebbeck	42	2.7
Anacardium occidentale	6	0.4
Annona squamosa	13	0.8
Araucaria sp.	5	0.3
Artocarpus heterophyllus	1	0.1
Azadiratcha indica	89	5.8
Bombax buenopozense	15	1.0
Calistemon citrinus	6	0.4
Casuarina cunninghamii	7	0.5
Citrus sinensis	12	0.8
Cocos nucifera	6	0.4
Delonix regia	56	3.6
Eucalyptus saligna	26	1.7
Ficus benjamina	60	3.9
Ficus sycomorus	5	0.3
Grevillea robusta	27	1.8
Jacaranda mimosifolia	45	2.9
Khaya anthotheca	12	0.8
Leucaena leucocephala	67	4.3
Mangifera indica	63	4.1
Parkinsonia aculeate	6	0.4
Persea americana	10	0.6
Phoenix dactylifera	19	1.2
Pithecelobium dulce	66	4.3
Polyalthia longifolia	67	4.3
Psidium guajava	4	0.3
Sclerocarya birrea	3	0.2
Senna siamea	649	42.1
Senna spectabilis	31	2.0
Syzygium cumini	31	2.0
Tamarindus indica	5	0.3
Tectona grandis	19	1.2
Terminalia catappa	49	3.1

DISCUSSION

Different parts of the municipality have different carbon storage potential. Chamwino, Forest hill, Kilakala, and Mafiga have higher values of tree carbon contents with Mafiga area being the highest. The highest values in these areas can be attributed to relatively higher age of the trees, minimum level of disturbances, intact condition of the trees and soil conditions allowing higher growth rates. Mazimbu and Kihonda have lowest values due to the fact that they are newly established areas thus trees are still young. As the trees grow, their potential for carbon storage will likely increase if undisturbed. The town-center has the lowest values though the trees are old. This is due to the fact that these trees were subjected to damage by cars, human disturbances, over pruning, soil compaction by heavy machinery and traffic that renders poor tree growth rates. Also dust and smoke may cover the leaves of the trees, thus reduce the ability of trees to photosynthesize. All these factors reduce the ability of trees to sequester CO_2 through the process of photosynthesis. Most of forest ecosystems that have been subjected to human disturbances tend to have lower carbon content than their potential (Brown *et al.* 1991; Brown, 1997). If urban forests are well managed, their potential contribution to continue storing large amount of carbon in form of wood biomass is very high.

The carbon storage potential will be different between different plant species planted in urban areas. A great diversity of vegetation found in Morogoro Municipality ranging from non-forested area and grassland or bush-covered site to mature forest parks, gardens (SUA-Botanical garden), selected cultivars on streets and landscaped private property are part and percel of human environment and these vegetation have the same effect in conserving the environment and mitigating C emissions.

If well managed the potential of such trees to mitigate C emissions and global climate change is enormous especially when it is considered that trees in urban ecosystems are long term investments and are not likely to be harvested in the near future. Bradshaw *et al.* (1995) observed that mature oak forests found in urban ecosystems have very high potential for biomass and carbon storage.

The more diverse an ecosystem is the more diverse is ecological functions. Principally humankind has two possible strategies/options for addressing the problem of greenhouse gas emissions and climate change; either to reduce levels of emissions or to reduce the level by using the atmospheric carbon dioxide. The latter strategy is of interest to forestry practices including urban forestry as forests use up the carbon dioxide in the atmosphere through photosynthesis. Managing diverse urban forest ecosystems and their biodiversity would therefore mean increasing the efficiency of these ecosystems to sequester carbon. Furthermore, apart from climate change issues, more diverse urban ecosystems will contribute to addressing local, regional and global biodiversity conservation efforts.

CONCLUSION AND RECOMMENDATIONS

Urban forest can store large amount of carbon especially where they are well managed. There is a need for encouraging more tree planting in urban ecosystems for carbon mitigation especially as the world community turns to terrestrial vegetation management as a means of mitigating CO_2 emissions. With the aid of municipal budget from the government, the existing urban dwellers can be encouraged to plant more trees around their houses, property boundaries, parks, garden and along the streets and avenues for conservation and mitigation purposes. Such practices will be more effective if it can go hand in hand with urban planning.

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