Above-Ground Carbon Allometric Models For Diplorhynchus Condylocarpon (Müll. Arg.) Pichon., A Common Miombo Woodland Associate

N. D. Mganga

Department of Life Sciences, Mkwawa University College of Education, Private Bag, Iringa-Tanzania

H.V.M. Lyaruu

Department of Botany, University of Dar es Salaam, P. O. Box 35060, Dar es Salaam-Tanzania

F.F. Banyikwa

Department of Botany, University of Dar es Salaam, P. O. Box 35060, Dar es Salaam-Tanzania

Researchjournali.com
Exclusive Journal publishing house

ABSTRACT

Estimation of carbon using allometric models facilitates sustainable management of forests and woodlands. Reliable estimations of carbon in most ecosystems can only be accomplished by using species-specific allometric models which are lacking for many species. The present study was carried out so as to develop the best fit above-ground carbon allometric models of various tree components; stems, branches, twigs and leaves of *Diplorhynchus condylocarpon* (Horn-pod tree), a species that is commonly associated with Miombo woodlands. Twenty one trees of *D. condylocarpon* with a ranging diameter at breast height (DBH) from 5 to 19 cm were destructively sampled from Miombo woodlands of Kitwe in Tanzania. Linear models were assessed for above-ground carbon using regression analysis. Regression analysis was carried out by relating above-ground carbon of tree components to DBH and height (H), using DBH and H as predictor variables. The best fit allometric models for above-ground carbon of total, stems, branches and twigs and/or leaves had coefficient of determination values (R^2) of 0.98, 0.98, 0.96 and 0.79 respectively at $P < 0.05$. Above-ground carbon allometric models developed have wide application in sustainable use of the species and carbon accounting particularly in Central Zambezian Miombo woodlands without future destructive sampling.

Keywords: allometric, biomass, carbon, diameter, *Diplorhynchus condylocarpon*, height, linear, model

1. INTRODUCTION

Accurate estimations of carbon in forests and woodlands are very important due to environmental-connectedness. Tropical forests are currently undergoing negative changes emanating from natural and anthropogenic disturbances. Reliable and precise estimations of carbon can predict the structure and productivity of ecosystems (Chave *et al*. 2005).

Pooled biomass or carbon allometric models have been developed in tropical woodlands and forests, such models include those developed by Stromgaard (1985); Brown *et al*. (1989); Malimbwi *et al*. (1994); Brown (1997); Nelson *et al*. (1999); Cole and Ewel (2006); Munishi *et al*. (2010). Of the three allometric relationships *viz*. species-specific, mixed species and site-specific, mixed species allometric equations are moderately accurate for estimation of above-ground biomass hence carbon (Spercht and West 2003). However, species-specific allometric models developed so far to estimate carbon sequestered in Miombo woodlands have targeted only a few species to include *Brachystegia spiciformis* Benth., *Brachystegia boehmii* Taub. and *Uapaca kirkiana* (Müll. Arg.) (Stromgaard 1985; Brown and Lugo 1992).

Pooled allometric models do not bridge the gaps of species tree sizes and geographic areas (Navar 2009). Besides, generalization of this type may not be suitable due to allometry differences in various plant species,

which again are likely to depend on regional conditions. Several factors such as genetic, edaphic, climatic, disturbance regime, wood species density influence the accuracy of biomass estimations and are known to vary with environmental factors (Cole and Ewel 2006). On the contrary, species-specific allometric equations that explore the relationships between tree species and biomass are more accurate and are flexible (Spercht and West 2003). Furthermore, regional or site-specific allometric equations are more preferable because species size-biomass relationship is likely to change when allocation pattern in response to disturbance, climate and edaphic factors are considered (Northup *et al*. 2005). Therefore allometric models intended for estimating carbon of a particular species in a given biome provide more accurate estimates than pooled models (Cole and Ewel 2006).

There is a need to develop more species-specific above-ground carbon allometric models in Miombo woodlands for valid and reliable estimations of carbon and if possible to have models for all species. *D. condylocarpon* is one of the common species in Miombo woodlands which is less browsed, with high growth rate and potential carbon store (Lawton 1979; Ribeiro *et al*. 2013).

2. RESEARCH OBJECTIVES

To develop above-ground carbon allometric models of *D. condylocarpon* leaves and twigs, branches, stems and the whole tree using DBH and height as predictor variables.

3. LITERATURE REVIEW

In order to evaluate models, many regression equations are developed before applying accurate measures used to select the best model. Several authors have reported on accuracy measures applied in selecting best models (Specht and West 2003). Analysis of accuracy measures plays a major role in the selection of the best fit model in relation to error factor. In any prediction, the aim is reduce the error by reducing the gap between the actual and predicted value. Linear regression when used to a set of predictor variables against dependent variable gives many accuracy measures. In this study only three reliable accuracy measures were used. These were the standard error (SE), coefficient of determination (R2) and the overall F-value.

It is argued that accuracies of allometric models that are developed for biomass estimation using only one predictor variable such as height are uncertain (Harrington 1979). Also, if the sample size is too small, even if the R2 value is higher, the model may still be statistically unfeasible. R2 shows the percentage of the variation in the dependent variable explained by the independent variables (Makridakis *et al*. 1998). To counter this when using regression analysis, alternative hypothesis can be tested that the slope of the regression line is significantly different from zero at the general accepted confidence level of 95%. Thus, the model is accepted when the calculated F-value is greater than the tabulated F-value at 95% confidence level. It follows that a

model with higher F-value can be selected as the best among many models developed and evaluated (Maraseni *et al*. 2005).

The regression equation is more accurate if it gives a lower value of SE and higher value of R2 (Malimbwi *et al*. 1994; Specht and West 2003). High F-value, R2 and lower SE values may not necessarily be the assurance of the best model. The model can be improved by removing predictor variables that have no statistically significant contribution to the model. At a particular coefficient of determination (a, b and c), t-test tells if the coefficient is statistically significant from zero in the presence of other predictor variables. The predictor variables with coefficient values statistically not different from zero could be removed from the model (Maraseni *et al*. 2005). It is also recommended that the intercept can be used even if its value is non-significant at zero because it helps in predicting the power of the model (Maraseni *et al*. 2005).

4. DATA ANALYSIS/ FINDINGS

4.1 THE STUDY AREA

The study was confined to forested ecosystem of Kitwe which is located between latitudes 4º 54' and 4º 55' S, and longitudes 29º 36' and 29º 37' E in the Western Tanzania (Figure 1). The area is characterized by tropical rainy climate and receives modest amount of rainfall varying from 900-1050 mm and experiences one long wet season lasting from November to May and one long dry season (Kigoma Water Master Plan 1980). Vegetation typology of the study area was once characterized by pristine forests of Miombo woodlands (Chepstow-Lusty et *al*. 2006), though it was severely disturbed later. Currently, the forest reserve has been protected from anthropogenic disturbances for about fifteen years by the corroboration of the United Republic of Tanzania (URT) and United States Agency for International Development (USAID) under the management of the Jane Goodall Institute (Figure 2).

4.2 TREE SAMPLING

A total of 21 trees ranging between 5 cm and 18.5 cm (based on site composition) were destructively sampled, randomly as recommended by Malimbwi *et al*. (1994) and de Gier (1999) for development of biomass allometric models. The selected trees were measured of their DBH and total heights, then felled at 0.3 m above the ground as recommended by Munishi and Shear (2004).

The felled trees were then divided into stems, branches, leaves and twigs. The stems were cut into sections of 1 to 2 m billets depending on their length as recommended by Malimbwi *et al*. (1994). The components were weighed separately in the field for green weight. Wood discs of 2 cm thick were cut from the middle part of different sections of the stem and branches. The samples were weighed immediately to determine the sub-sample green weight. Sub-samples of twigs and leaves of 50 g were collected from each tree (see Figure 3 (a) – (d)). Prior to transportation, the collected discs and leaves were air-dried to prevent rotting.

All samples were transported to the laboratory at the University of Dar es Salaam for determination of biomass and ultimately carbon.

4.2.1 SAMPLE TREATMENT

The twigs and leaves were oven dried to constant weight at 70ºC as recommended by Stewart *et al*. (1992). On the other hand, sub-samples from stems and branches were oven dried at 105ºC to constant weight so as to obtain oven-dry weight in accordance with Ketterings and Bigham (2001). Biomass ratio was calculated as a ratio between the oven-dry weight and sub-sample green weight.

$$\text{Biomass ratio} = \frac{\text{Sub} - \text{sample oven dry weight}}{\text{Sub} - \text{sample green weight}}$$

Biomass = Biomass ratio x Field green weight (kg tree^{-1}) (Malimbwi *et al*. 1994)

Carbon in tree (kg tree^{-1}) = Biomass x 0.5

Tree carbon was assumed as 50% of the biomass (Munishi and Shear 2004; Basuki *et al*. 2009). Occasionally, carbon is measured directly by burning the samples in a carbon analyzer (Kraenzel *et al*. 2003).

In this study, above-ground carbon (kg) was used as a dependent variable, while DBH (cm) and height (cm) were used as independent variables. The calculated carbon for each tree component was regressed against tree DBH and H to develop above-ground carbon allometric models. Regression equations were developed from data obtained from 21 trees that were destructively sampled using steps outlined in Excel Microsoft Windows version 2007.

Linear regression was performed on the dependent and independent variables. Scatter plots were generated for all variables using the original variables initially, then with all variables transformed. Several authors have reported high positive correlation between tree diameter and height and the above-ground biomass (Jordan and Uhl 1978; Overman *et al*. 1994). Using raw data and logarithmically transformed data, carbon was first modelled as a linear function for each predictor variable. The equations were obtained through simple and multiple linear regression analysis, after testing for co-linearity between the selected variables. The data were logarithmically transformed so as to equalize the variances over the whole range of carbon values, which is a condition required for linear regression, enabling the use of parametric statistical analyses (Zar 1974). Finally, logarithmic units were converted to arithmetic units to obtain the reliable carbon content in accordance with Van *et al*. (2000).

In the present study, the criteria used to select the best fit models were: highest coefficient of determination (R^2), lowest standard error (SE) of Y estimated values (Malimbwi *et al*. 1994). Besides, overall higher F-value at 95% confidence level was considered for upgrading of the best fit models (Maraseni *et al*. 2005).

The following are the general forms of functions that were fitted to the collected data as recommended by Philip (1983):

1. $Y = a + b\ DBH$ 2. $Y = a + b\ DBH + c\ H$

3. $Ln\ (Y) = a + b\ Ln\ DBH$ 4. $Ln\ (Y) = a + b\ Ln\ DBH + c\ Ln\ (H)$

Where:

Y = Carbon (kg tree^{-1} component)

DBH = Diameter at Breast Height (cm)

H = Total tree height (m)

a, b and c = regression coefficients

b and c correspond to DBH and H value for multiple ranges

a = Y-intercept which is a constant

4.3 FINDINGS

In the present study, allometric models developed for estimation of carbon stored in tree components of *Diplorhynchus condylocarpon* are presented in Table 1. All allometric models developed to estimate above-ground carbon from stems, branches, twigs and leaves of *Diplorhynchus condylocarpon* depicted the relationship between tree carbon, DBH and height. The coefficients of determination (R^2) obtained ranged from 0.69 to 0.99, F-values ranged from 35.07 to 1085.94 and standard error of the mean ranged from 0.05 to 1.31. The coefficients of determination were low in estimation of leaves and twigs carbon compared to that of stems and branches. Stem diameter explained 98% of the variation in carbon content for *D. condylocarpon*, while the branches and leaves accounted for 96% and 79% of carbon respectively.

4.4 DISCUSSION

Table 2 shows the best fit species-specific allometric models for estimation of above-ground carbon for tree components in *Diplorhynchus condylocarpon*. In all best fit models for estimation of carbon of the tree components, the coefficient of determination (R^2) was greater than 0.5 implying good fitness of the models that were developed in the present study. In all tree-components, DBH was the only predictor variable.

Table 3 shows that allometric models developed to estimate total carbon for *D. condylocarpon* used only DBH as a predictor variable.

All developed models were obtained after logarithmic transformation. This suggests that estimations of above-ground carbon in *D. condylocarpon* suit linear regression than other functions. The best fit allometric models used only DBH as a predictor variable. In developing above-ground carbon allometric models for *D. viscosa* and *M. polymorpha* in Hawaiian forest DBH was reported as the sole predictor variable (Litton and Kauffman 2008). Furthermore, the suitability of DBH as the only predictor variable in estimating above-ground carbon has been reported in several studies (Malimbwi *et al*. 1994; Chamshama *et al*. 2004; Zianis and Radoglou 2006).

Similarly, the low coefficient of determination obtained when estimating carbon in leaves and twigs suggests that in *D. condylocarpon* such components contribute less to the total above-ground carbon stock. However, development of carbon allometric models for tree components is still crucial based on the fact that leaves/twigs and wood differ in endurance and thus, carbon compartmentalization. This finding is in agreement with Grigal and Kernik (1984). There are generally few allometric models that have been developed in the tropical region using tree components, for example, Malimbwi *et al*. (1994) developed eight equations using DBH and height to estimate biomass and volume of stem, branch and total tree for 26 species in Miombo woodlands of Kitulangalo in the Eastern Tanzania. Also, Munishi *et al*. (2010) developed four carbon allometric models of stem and branch in Miombo woodlands of the Southern highlands of Tanzania.

5. CONCLUSION

Allometric equations of *Diplorhynchus condylocarpon* obtained from this study is good to use, however, the use of the equations should consider the fact that the models were developed by utilizing diameter at breast height (DBH) ranging from 5 cm to 18.5 cm only.

In developing above-ground carbon allometric models of the tree and its components in *Diplorhynchus condylocarpon*, DBH should be used as the only predictor variable. In developing species-specific above-ground carbon allometric models during the present study, only small sized trees were used due to site conditions. Development of species-specific allometric models should not be seen as wastage of resources on the ground that collective species' models can serve the purpose for. This is because studies on the contribution of individual plant species to the global vegetal carbon stock could be reliable only if species-specific allometric models are utilized in the process.

Estimates of carbon in tropical forests and woodlands are needed due to rapid changes in these ecosystems and inadequate reliable data (Brown 1997). Accurate estimations of biomass and hence carbon are essential due to environmental and commercial reasons. Thus, by consideration of global carbon cycle, estimation of biomass in vegetation is very important and can be effectively accomplished by the use of species-specific allometric equations.

Acknowledgement

The first author would like to express her sincere gratitude to Mkwawa University College of Education (A Constituent College of the University of Dar es Salaam) under the World Bank Project for provision of funds which made this study possible. Jane Goodall Institute (JGI) is very much acknowledged for granting permission to work in Kitwe forest reserve.

6. REFERENCES

BASUKI TM, VAN LAAKE PE, SKIDMORE AK & HUSSIN YA. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland *Dipterocarp* forest. *Forest Ecology and Management* 257: 1684-1694.

BROWN, S. 1997. A Primer for estimating biomass and biomass changes of Tropical Forest. FAO Forest paper No. 134. Food and Agriculture Organization of the United Nations, Rome. pp 55.

BROWN S & LUGO AE. 1992. Aboveground biomass estimates for tropical moist forests of the Brazilian Amazon. *Interciencia* 17: 8-18.

BROWN S, GILLESPIE AJR & LUGO AE. 1989 Biomass estimation methods for tropical forests with applications to forest inventory data. *Forest Science* 35: 881-902.

CHAMSHAMA SAO, MUGASHA AG & ZAHABU E. 2004. Stand biomass and volume estimation for miombo woodlands at Kitulangalo, Morogoro, Tanzania. *The Southern African Forestry Journal* 200: 59–64.

CHAVE J, ANDALO C, BROWN S, CAIRNS MA, CHAMBERS JQ, EAMUS D, FÖLSTER H, FROMARD F, HIGUCHI N, KIRA T, LESCURE JP, NELSON BW, OGAWA H, PUIG H, RIÉRA B & YAMAKURA T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145: 87-99.

CHEPSTOW-LUSTY A, WINFIELD M, WALLIS J & COLLINS A. 2006. The importance of local tree resources around Gombe National Park, western Tanzania: Implications for humans and chimpanzees. *Ambio* 35: 124-129.

COLE TG & EWEL JJ. 2006. Allometric equations for four valuable tropical tree species. *Forest Ecology and Management* 229: 351–360.

CONYERS D, NGUMBULLU PJ & NNKO PN. 1971. Agro-economic Zones of Kigoma and Tabora Regions. University of Dar es Salaam. BRALUP Report No. 46, University of Dar es Salaam. pp 60.

DE GIER A. 1999. Woody biomass assessment in woodlands and shrublands. Proceedings of a Workshop on Off-forest tree resources of Africa held at Arusha, Tanzania. pp 89-98.

GRIGAL DF & KERNIK LK. 1984. Generality of black spruce biomass estimation equations. *Canadian Journal of Forest Research* 14: 468-470.

HARRINGTON G. 1979. Estimation of above-ground biomass of trees and shrubs in a *Eucalyptus populnea* F. Muell. woodland by regression of mass on trunk diameter and plant height. *Australian Journal of Botany 27*: 135–143.

JORDAN CF & UHL C. 1978. Biomass of a Tierra Firme forest of the Amazon Basin. *Biologia Plantarum* 13: 387-400.

KETTERINGS QM, COE R, VAN NOORDWIJK M, AMBAGAU Y & PALM CA. 2001. Reducing uncertainity in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. *Forest Ecology and Management* 146: 199-209.

KIGOMA WATER MASTERPLAN. 1980. Hydrology: Volume 7. NorConsult Consulting Engineers, Norway.

KRAENZEL M, CASTILLO A, MOORE T & POTVIN C. 2003. Carbon storage of harvest-age teak (*Tectona grandis*) plantations, Panama. *Forest Ecology and Management* 173: 213–225.

LAWTON RM. 1979. Woodland ecology reconnaisance survey. Tabora Rural Development Programme. Tolworth UK. Land Resources Development Centre. Project Report 76. 24 pp.

LITTON CM & KAUFFMAN JB. 2008. Allometric Models for Predicting Aboveground Biomass in Two Widespread Woody Plants in Hawaii. *Biotropica* 40(3): 313–320.

MAKRIDAKIS SG, WHEELWRIGHT SC & HYNDMAN RJ. 1998. Forecasting: methods and applications 3rd edition, New York: John Wiley and Sons.

MALIMBWI RE, SOLBERG B & LUOGA E. 1994. Estimation of biomass and volume in miombo woodland at Kitulangalo forest reserve, Tanzania. *Journal of Tropical Forest Science* 7: 230-242.

MARASENI TN, COCKFIELD G & APAN A. 2005. Community Based Forest Management Systems in Developing Countries and Eligibility for Clean Development Mechanism. *Journal of Forest and Livelihood* 4: 31-42.

MUNISHI PKT & SHEAR T. 2004. Carbon storage of two Afromontane rain forests in the Eastern Arc Mountains of Tanzania. *Journal of Tropical Forest Science* 6: 78-93.

MUNISHI PKT, MRINGI S, SHIRIMA DD & LINDA SK. 2010. The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks. *Journal of Ecology and the Natural Environment* 2: 261-269.

NAVAR J. 2009. Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. *Forest Ecology and Management* 257: 427–434.

NELSON BW, MESQUITA R, PERIERA JLG, AQUINO DE SOUZA SG, BATISTA GT & COUTO LB. 1999. Allometric regressions for improved estimate of secondary forest biomass in the central Amazon. *Forest Ecology and Management* 117: 149–167.

NORTHUP BK, ZITZER SF, ARCHER S, MCMURTRY CR & BOUTTON TW. 2005. Above-ground biomass and carbon and nitrogen content of woody species in a subtropical thorn scrub parkland. *Journal of Arid Environments* 62: 23–43.

OVERMAN JPM, WITLE HJL & SALDARRIAGA JG. 1994. Evaluation of regression models for above ground biomass determination in Amazon rainforest. *Journal of Tropical Ecology* 10: 207-218.

RIBEIRO NS, MATOS CN, MOURA IR, WASHINGTON-ALLEN RA & RIBEIRO AI. 2013. Monitoring vegetation dynamics and carbon stock density in Miombo woodlands. *Carbon Balance and Management* 8:1-9.

SPECHT A & WEST PW. 2003. Estimation of Biomass and Sequestered Carbon on Farm Forest Plantation in Northern New South Wales, Australia. *Biomass Bioenergy* 25: 363-379.

STEWART JL, DUNSDON AJ, HELLIN JJ & HUGHES CE. 1992. Wood biomass estimation of Central American dry zone species. Tropical forestry papers: University of Oxford, Oxford Forestry Institute, Department of Plant Sciences, Oxford, 83 pp.

STROMGAARD P. 1985. Biomass, growth and burning of woodland in a shifting cultivation area of south central Africa. *Forest Ecology and Management* 12: 163-178.

VAN TK, RAYACHHETRY MB & CENTER TD. 2000. Estimating Above-ground Biomass of *Melaleuca quinquenervia* in Florida, USA. *Journal of Aquatic Plant Management* 38: 62-67.

ZAR JH. 1974. Biostatistical Analysis. Prentice-Hall, EnglewoodCliffs, NJ. 620 p.

ZIANIS D & RADOGLOU K. 2006. Comparison between empirical and theoretical biomass allometric models and statistical implications for the stem volume predictions. *Forestry* 79: 477-487.

7. TABLES AND FIGURES

Table 1: Allometric models and their goodness of fit for estimation of above-ground carbon of stem, branch, and twigs and leaves in Diplorhynchus condylocarpon

Part	Model	Allometric relationship	R^2	SE	F-value
Stem	1	$Y = -17.335 + 0.928\ DBH + 0.033\ H$	0.96	0.98	284.22
	2	$Y = -6.175\ DBH^{1.226}\ H^{0.882}$	0.99	0.05	948.87
	3	$Y = -7.093 + 1.654\ DBH$	0.95	1.21	370.45
	4*	$Y = -1.422\ DBH^{1.564}$	0.98	0.07	1085.94
	5	$Y = -28.463 + 0.072\ H$	0.94	1.31	310.69
	6	$Y = -20.531\ H^{3.619}$	0.90	0.15	176.43
Branches	1	$Y = -13.968 + 0.405\ DBH + 0.026\ H$	0.94	0.77	160.84
	2	$Y = -10.973\ DBH^{1.821}\ H^{1.262}$	0.97	0.12	356.15
	3	$Y = -5.953 + 0.973\ DBH$	0.91	0.95	207.68
	4*	$Y = -4.175\ DBH^{2.304}$	0.96	0.13	576.84
	5	$Y = -18.830 + 0.043\ H$	0.93	0.85	263.43
	6	$Y = -32.291\ H^{5.327}$	0.88	0.25	149.79
Twigs and leaves	1	$Y = -2.054 + 0.139\ DBH + 0.005\ H$	0.79	0.42	35.07
	2	$Y = -7.071\ DBH^{0.918}\ H^{0.900}$	0.80	0.21	35.57
	3	$Y = -0.463 + 0.252\ DBH$	0.78	0.43	68.39
	4*	$Y = -2.221\ DBH^{1.263}$	0.79	0.21	69.73
	5	$Y = -3.721 + 0.011\ H$	0.77	0.43	66.06
	6	$Y = -2.021\ H^{0.005}$	0.69	0.25	42.26

Table 2: Best fit species-specific allometric models for estimation of above-ground carbon in tree components of D. condylocarpon

Dependent variable	Allometric relationship	R^2	SE	F-value
Stem	$Y = -1.422\ DBH^{1.564}$	0.98	0.07	1085.94
Branch	$Y = -4.175\ DBH^{2.304}$	0.96	0.13	576.84
Leaves and twigs	$Y = -2.221\ DBH^{1.263}$	0.79	0.21	69.73

Table 3: Allometric models for estimation of total tree above-ground carbon in D. condylocarpon

Model	Allometric relationship	R^2	SE	F-value
1	$Y = -33.357 + 1.473\ DBH + 0.064\ H$	0.96	1.71	286.493
2	$Y = -7.019\ DBH^{1.282}\ H^{1.070}$	0.98	0.06	697.48
3	$Y = -13.510 + 2.879\ DBH$	0.94	2.19	340.91
4*	$Y = -1.253\ DBH^{1.692}$	0.98	0.08	825.91
5	$Y = -51.011 + 0.126\ H$	0.94	2.19	341.29
6	$Y = -22.032\ H^{3.933}$	0.90	0.16	182.34

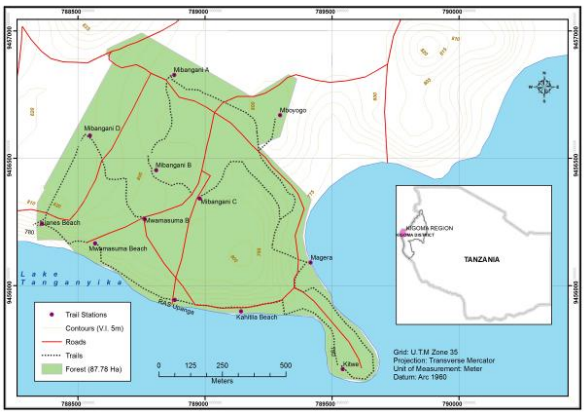


Figure 1: Location of Kitwe Forest Reserve in Western Tanzania

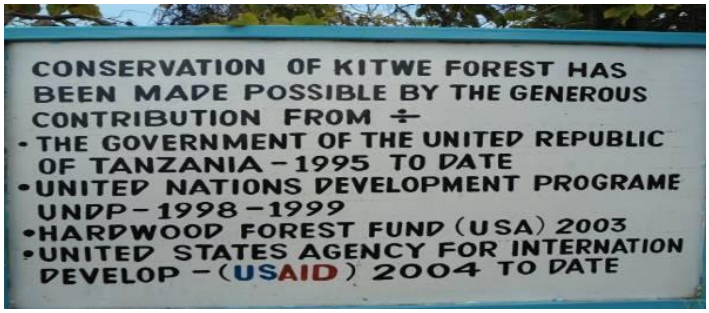
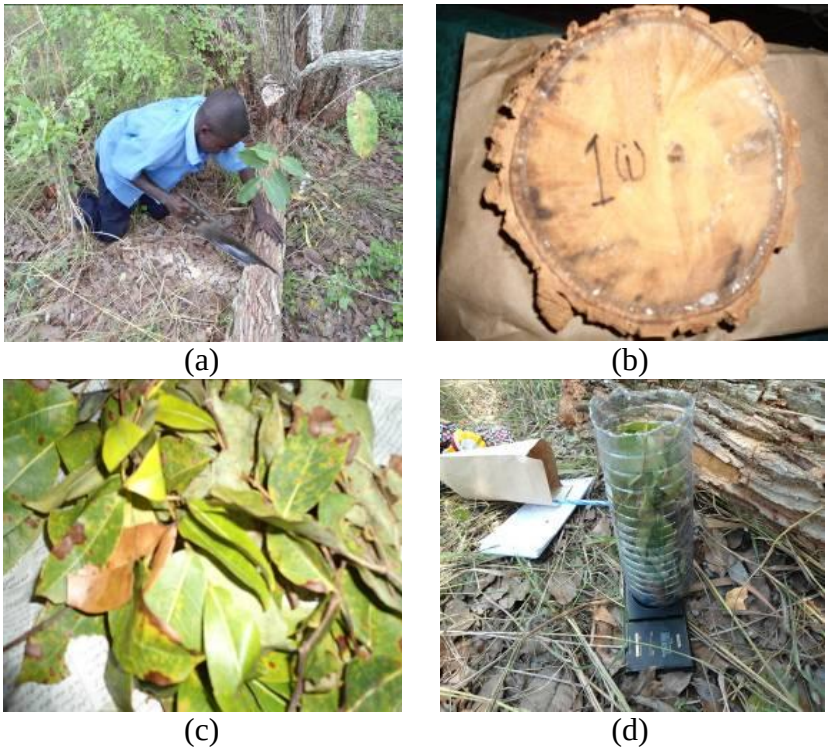


Figure 2: Conservation Initiative of Kitwe Forest



(a) (b)

(c) (d)

Figure 3 (a) – (d): (a) Billets formation from bole of D. condylocarpon Tree (b) Labelled disc after field weighing (c) Leaves of D. condylocarpon (d) Weighing of leaves sub-sample in the field