THE REGENERATION OF MIOMBO WOODLANDS IN CHARCOAL PRODUCTION AREAS IN KILOSA DISTRICT, TANZANIA

GODBLESS STANLEY MATOWO

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FOREST RESOURCES ASSESSMENT AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2021

EXTENDED ABSTRACT

Miombo woodlands covers 90% of the forested area in Tanzania and 10% of the African landmass. Therefore, any deforestation or forest degradation of these forests have the national and continental significance. The ability of miombo to regenerate naturally functions as the survival mechanism amongst multiple disturbances. The majority of disturbances to miombo woodlands have been imposed by humans in meeting their demands for survival. This includes the disturbance generated in obtaining the fuelwood.

Charcoal is used as an important fuelwood to both urban and rural populations. However, charcoal production is considered as the massive cause of deforestation and forest degradation in Tanzania and across the continent. Regarding the importance of charcoal to the society, Sustainable Forest Management (SFM) to ensure the sustained production of charcoal is requisite. The present study aimed to provide a better understanding of regeneration of miombo trees through the assessment of the area deliberately harvested for charcoal production. The study was conducted in eight Village Land Forest Reserves (VLFRs) in Kilosa district under Community Based Forest Management (CBFM). Specifically, the study aimed to (i) review literature on regeneration dynamics of miombo trees, (ii) assess the regeneration status of miombo trees in the charcoal kiln scars, (iii) assess the forest standing structure and above-ground biomass in harvested blocks and (iv) determine the optimum stump height and diameter for maximum coppicing in harvested miombo.

Data collection utilized different methods and sampling approaches. For the first objective, a standard literature search for documents related to miombo regeneration was performed using multiple electronic databases. More than 60 peer-reviewed published papers on the subject matter were obtained and critically reviewed. The data for the second objective was obtained by assessing the kiln scars in charcoal production blocks. The assessed blocks were only those with 4, 5 and 6 years from cessation of charcoal production where 154 kiln scars were assessed. The third objective aimed to assess the standing structure and above-ground biomass, where 106 circular plots with a radius of 15 m were assessed in the areas where charcoal production has ceased for 6 years. In the fourth objective which aimed on establishing the optimum stump height and diameter for maximization of coppicing regeneration in the areas harvested for charcoal production, the assessment was done to stumps within the plot of 50 m x 50 m. A total of 925 stumps, representing 43 species were measured in the area with 4 (2015-2019), 5 (2014 - 2019) and 6 (2013 - 2019) years from cessation of charcoal production. The stump height, stump diameter, regenerants counts and size (basal diameter and height) were measured, alongside identifying species for individual stumps.

The results revealed that vegetative propagation through coppice and root suckers are the most feasible and prominent regeneration method in miombo woodlands managed for charcoal production. Kiln scar results revealed that kiln scars occupy 1.5% of the total harvested area. The study also confirmed that trees can naturally regenerate in kiln scars to which the number of tree regenerants increases significantly *($F (2,151) = 7.1$, $p < 0.05$)* with the addition of time from cessation of charcoal production. Assessment of standing structure and composition of 6 years post charcoal production cessation recorded stand dominated by re-growing trees with the basal area, volume and above-ground biomass of $3.77 \pm 1.27 m^2 ha^{-1}$, $31.71 \pm 10.79 m^3 ha^{-1}$ and $21.5 \pm 7.24 t\ ha^{-1}$, respectively. Also in the harvested area, about 68% of trees were established from seedlings with remaining individuals established vegetatively as they were limited to the number of stumps remained. The assessment of stumps for coppicing revealed that number of living stumps

decreased significantly ($p < 0.05$) with the increase in time where 73, 68 and 51% of stumps were alive in the area terminated harvesting for 4, 5 and 6 years, respectively. Also, there is a positive relationship between the stump mortality and the increase of the stump diameter while no clear pattern for stump height. The coppicing effectiveness of the stump increases with both diameter ($r^2 = 0.31$) and height ($r^2 = 0.18$). The optimum harvesting diameter and height ranges is from 20 to 40 cm and 45 to 60 cm, respectively.

Generally, it is concluded that trees in harvested charcoal production areas are regenerating naturally and growing relatively well. Also, vegetative propagation through stump coppices and root suckers is the most feasible and suitable regeneration method in management of forest harvested for charcoal production. The coppicing effectiveness is determined by stump height, stump diameter and the time lapsed from harvesting. Harvested large diameter trees are associated with high mortality compared to small-diameter trees. The high stump survival was recorded for stumps with height between 46 and 60 compared to higher mortality of shorter and longer stumps. To reduce the recovery time of the harvested stand, it is recommended that the minimum harvesting dimensions should be revised to stump diameter between 20 and 40cm and height between 45 an 60cm. Also, the protection of regenerating areas against disturbances is highly recommended since its recovery largely depends on the seedlings which are highly vulnerable to the effects of disturbances such as fire and overgrazing.

DECLARATION

I, **GODBLESS STANLEY MATOWO** do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and it has neither been submitted nor being concurrently submitted in any other institution.

_______________________ _______________

Godbless Stanley Matowo Date

(MSc. Candidate)

The above declaration confirmed by;

_______________________ _______________

Prof. Josiah Z. Katani Date

(Supervisor)

_______________________ _______________

Prof. Anthony Z. Sangeda Date

(Supervisor)

COPYRIGHT

LIST OF PAPER CHAPTERS

ACKNOWLEDGMENTS

I would like to express my heartfelt gratitude to Almighty God for giving me strength and good health for undertaking this study. Also, I wish to extend my ingratitude to my family for their support during my studies.

I would like to thank the Swiss Agency for Development and Cooperation (SDC); Tanzania Forest Conservation Group (TFCG) and Tanzania Community Forest Network (MJUMITA) for funding this research work through their project “Transforming Tanzania’s Charcoal Sector- TTCS.” Special thanks to Dr. Theron Morgan-Brown, Project Technical Adviser and Charles Meshack, Executive Director for their technical inputs and Charles Leonard, Project Manager for logistical support.

I am very thankful to my supervisors Prof. Josiah Z. Katani and Prof. Anthony Z. Sangeda for their constant and tireless efforts in guiding this study. Their constructive and intelligible criticisms, comments and encouragement contributed much to the completion of this study. Special thanks go to Prof. R. E. Malimbwi, Dr. Wilson Mugasha and Dr. Ernest Mauya for their assistance and guidance during study development and data processing.

Last but not least, with an open heart, I express my sincere thanks to my fellow students for their cooperation. May God bless you all.

DEDICATION

The work is dedicated to my parents Mr. and Mrs. Stanley Matowo who gave me a good foundation for my life and education.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
cm	Centimeters
DBH	Diameter at breast height (cm)
FAO	Food and Agriculture Organization of the United Nations
Ha	Hectare
HTC	Hydrothermal carbonization
IPCC	International Panel of Climate Change
IUCN	International Union for Conservation of Nature
KSCPB	Kilosa Sustainable Charcoal Production Block
MJUMITA	“Mtandao wa Jamii wa Usimamizi wa Misitu Tanzania”
MNRT	Ministry of Natural Resources and Tourism
NAFORMA	National Forest Resource Monitoring and Assessment
NGO	Non- Government Organization
SFM	Sustainable Forest Management
SUA	Sokoine University of Agriculture
t	Tonne
TANAPA	Tanzania National Park Authority
TCFN	Tanzania Community Forest Network
TFCG	Tanzania Forest Conservation Group
TFS	Tanzania Forest Services
TTCS	Transforming Tanzania's Charcoal Sector
VLFR	Village Land Forest Reserve

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Miombo makes the dominant extended tropical woodland and dry forest vegetation which covers about 10% of the African dry land (Malimbwi *et al.,* 2005; Malmer, 2007). Miombo woodlands are characterized by the dominance of three Caesalpinoid genera: *Brachystegia*, *Julbernadia* and *Isoberlinia* (Campbell *et al.,* 2007). The vegetation is distributed in Central and Southern parts of Africa and is the dominant forest component in nine countries including Tanzania, Democratic Republic of Congo, Mozambique, Zimbabwe, Malawi, Burundi, Zambia, and Angola mostly referred as miombo Eco-region (Dewees *et al.,* 2010).

In Tanzania, miombo woodlands cover 90% equivalent to 44 out of 48.1 million ha of forested land (MNRT, 2015). Miombo woodlands provide the fuelwood which contributes to 90% of the energy consumed in Tanzania of which charcoal is the most preferred and utilized type of fuelwood from miombo (Luoga *et al.,* 2000; Clemens *et al.,* 2018). In Africa, charcoal production has been considered as the massive cause of deforestation and forest degradation, yet the activity is still crucial (Chidumayo and Gumbo, 2013). The increase in charcoal production is triggered by an increase in energy demand linked to population growth. Also, its affordability, less smoke production compared to firewood, less space required, high energy efficiency per unit weight and delicious food flavor are the factors determining its preference (Msuya *et al.*, 2011; D'Agostino *et al.*, 2015; Zulu and Richardson, 2013; Malimbwi and Zahabu, 2009). Considering the importance of charcoal to the livelihood and well-being of the community, the future supply sustainability relies on the current efforts in managing and using the forest resource sustainably.

Sustainable Forest Management (SFM) refers to the administration and consumption of forests resources in forest lands at the manner, and at a rate, that upholds their productivity, biodiversity constituent, regeneration capacity, vitality and potential to fulfill, present and future important ecological, economic and social functions, at different levels, with less or no damage to other ecosystems (Martin-Garca and Javier, 2012). In Tanzania, some efforts have been made with the vision of achieving sustainable charcoal production. This is through the introduction of projects targeting SFM. One of the projects is known as Transforming Tanzania Charcoal sector (TTCS) under two NGOs, Tanzania Forest Conservation Group, (TFCG) and Tanzania Community Forest Network (TCFN). This project is one of its kind involved in harvesting in natural forest (miombo woodlands) for charcoal production in Tanzania. This project was launched in 2012 involving 13 villages as pilot areas. The harvesting in the area is done in pre-determined square blocks provided by the model in such a way that re-harvesting can be done after 24 years.

Many tropical forest tree species have shown the post-harvesting potential to regenerate. Miombo woodlands regenerate through coppicing, suckers and recruitment from stunted saplings (Malimbwi and Zahabu, 2009). However, the recovery periods of the miombo stand is affected by the harvesting intensity as reported by Malimbwi *et al.* (1998) that it takes between 8 to 15 and 16 to 23 years for selective and intense harvested miombo to recover, respectively.

The manipulation of the harvesting practice to maximize regeneration in the area deliberately set for production purposes is necessary. This study gives special attention to stump coppicing as the means of regenerating the harvested area for charcoal production. Among factors affecting the number of stump coppices for the harvested tree is the stump size that includes the stump diameter and the height (Ferdinand *et al.,* 2011). Stump size affects the nature and rate of tree regeneration (Akouehou, 2017; Mtimbanjayo and Sangeda, 2018; Syampungani *et al.,* 2017).

In Tanzania, the practice of charcoal production is done in the state and village-owned forests (Sander *et al.,* 2013). Also, in Tanzania, as the case of other sub-Saharan countries, charcoal is produced largely in the earth-mound kilns (Kimaryo and Ngereza, 1989; Adam, 2009; Msuya, Masanja and Temu, 2011). The production involves tree harvesting, crosscutting it into short pieces up to 2 m length and then logs are piled up into in the kiln and then covered by soil for charcoal production. The process of charcoal production involves three steps, pyrolysis, gasification, and hydrothermal carbonization (HTC) (Demirbas *et al.,* 2016). Under these processes, the wood biomass undergoes a chemical structure breakdown with temperature release ranging between 500 to 700°C (Chidumayo, 1988).

The impact of charcoal production occurs in two levels of intensity. One includes the deforested area in which most of the tree cover is cleared by removing the above-ground woody biomass through harvesting and converting to charcoal. This is considered as low-level impact as the harvested area retains woody biomass in the form of branch wood and leaves as dead organic matter and all the below-ground biomass which positively enhances its regeneration and forest recovery.

The second impact is on the spot where the kiln was placed known as “charcoal hearth soil” (Carrari *et al.,* 2018), “relic charcoal hearths” (Young *et al.,* 1996), “kiln spot”

(Dons, 2014), “kiln scar “ (Sangeda and Maleko, 2018), “kiln site” (Butnan *et al.*, 2018; Chidumayo, 1994; 1993; Hardy *et al.*, 2016; Nelle, 2003; Schmidt *et al.*, 2016; Knapp *et al.*,2013). The term “kiln scar,” meaning exclusive area affected by extreme heat produced during charcoal production has been adopted for this study. The area experiences severe impact on soil structure, seed pool and rootstock from shared heat generated in the carbonization process (Chidumayo, 1993; Dons, 2014; Glaser *et al.*, 2002).

1.2 Problem Statement and Study Justification

1.2.1 Problem statement

An increase in energy demand and unsustainable utilization imposes a potential threat to existence of miombo vegetation (Lupala *et al.*, 2015). However, studies carried in miombo concluded that miombo has an ability to regenerate after harvesting (Malimbwi and Zahabu, 2009; Syampungani *et al.*, 2017).

The ability of trees to regenerate after disturbance especially the stump is not only related to its biological factors but depends on external factors such as the diameter of the stumps (Shackleton, 2001) and stump height (Tiwari and Das, 2010). Several studies (Akouehou, 2017; Syampungani *et al.*, 2016; Chomba 2018; Luoga *et al.*, 2004) examined the influence of stump size on regeneration. However, all studies focused on few species of commercial importance. For example, the study conducted in Zambia by Syampungani *et al.* (2016) examined the effect of stump height and diameter on the regeneration of ten miombo species while study by Chomba, (2018) examined the effect of stump diameter, height and cutting angle on three miombo trees harvested for charcoal in Zambia. Therefore, the information on the influence of stump size over the wide range of species in the area with intense harvesting for charcoal production is still missing. The influence of stump size especially stump height and diameter in forest regeneration yet is not considered in the management of miombo for charcoal production in Tanzania and their influence in forest regeneration is still not well known. Understanding the optimum height and diameter of the stump for which miombo regenerates will provide basic dimensions for harvesting miombo which ensures maximum regeneration and therefore sustainable use of forest.

Furthermore, one of the important adverse effects of charcoal making is dynamics of soil characteristics of the kiln placed areas leading to the formation of kiln scars. Studies conducted in temperate regions of Germany (Schmidt *et al.,* 2016) and Belgium (Hardy *et al.,* 2016; Hardy, 2017) have shown that charcoal kiln scars have existed for decades. This shows that kiln scars left after charcoal production are permanent and no regeneration occurs within. In miombo woodlands, the information on natural regeneration characteristics of tree species in kiln scars is still skimpy. However, initial efforts by Sangeda and Maleko (2018) have recorded the regenerated herbaceous plants within 2 years from charcoal production. This necessitates the continuous monitoring studies for regeneration in the kiln scars left in miombo woodlands.

Therefore, this study aims to provide empirical information on regeneration together with the growing condition of miombo in kiln scars and harvested areas left after charcoal production. Also, the study intends to provide the optimum harvesting dimensions (stump height and diameter) for maximum regeneration of miombo. This is to ensure the harvested area reverts to woodland and thus sustainably supply of charcoal.

1.2.2 Study justification

The study findings are useful in making informed decisions, policy review, formulation of fuelwood/charcoal policy and designing management practices and interventions in miombo woodlands. Information from this study is important to the Transforming Tanzania Charcoal sector (TTCS) project in designing management practices for harvesting miombo trees for charcoal making in villages managing their forests under the project descriptions. Furthermore, the study findings can serve as a reference point to villages willing to adopt sustainable forest management under the project model and description. Also, data collected during this study will serve as a baseline for continuous growth monitoring of the project area.

1.3 Objectives

1.3.1 Overall objective

To assess the regeneration dynamics of miombo trees species in pilot sites for sustainable charcoal production in Kilosa, Tanzania.

1.3.2 Specific objectives

i. To review the existing literature on the regeneration dynamics of miombo trees
ii. To assess the regeneration status of miombo trees in the charcoal kiln scars
iii. To assess the standing structure and above-ground biomass in harvested blocks
iv. To determine the optimum stump height and diameter for maximum coppicing of miombo trees

1.3.3 Research questions

The study will answer the following questions

i. How do literature describe or characterize the regeneration of miombo trees?
ii. How does type of regeneration, species and time taken affects regeneration in kiln scars?
iii. What is the above-ground biomass regenerated in the 6 years harvesteds (blocks harvested in 2013)?

iv. How do stump height and diameter determine the suitable regeneration of miombo woodlands?

1.4 Study Limitations

The present study can be considered as fairly robust, detailed and empirical, though there are some limitations worth acknowledging: The present study was cross-sectional but applied longitudinal data through measurement of areas harvested in different years. Since the study targeted monitoring the regeneration in areas where harvesting was ceased for more than three years, it was sometimes difficult to differentiate the seedling regenerated trees to that of root suckers. During data collection, the effort was made to get the appropriate form of regeneration though, some recordings might have suffered low precision and/or accuracy.

1.5 Dissertation Structure

This dissertation is developed in the format of publishable manuscripts comprising of six main chapters. Chapter one consists of the introduction, which provides background information of the study, problem statement and justification together with study objectives, research questions and the study limitations Chapter two (Manuscript one) explains the regeneration dynamics of Miombo tree species in Sub-Saharan Africa. Chapter three (Manuscript two) is about the performance assessment on post-harvest regeneration of miombo trees in kiln scars. A case of sustainable charcoal production blocks, Kilosa, Tanzania. Chapter four (Manuscript three) is on the assessment of standing structure and above-ground biomass in charcoal production miombo forests in Kilosa, Tanzania. Chapter five (Manuscript four) is the assessment of optimum stump height and diameter for miombo regeneration through coppicing in Kilosa, Tanzania. Chapter six summarizes the key contribution of the study, general conclusions and recommendations for future management of miombo woodlands, especially in charcoal production areas.

References

Adam, J. C. (2009). Improved and more environmentally friendly charcoal production system using a low-cost retort-kiln (Eco-charcoal). *Renewable Energy* 34(8): 1923–1925.

Akouehou, G. S. (2017). Stump diameter and height effects on early sprouting of three common firewood species used in the coastal zone of Benin in West Africa. *Science De La Vie, De La Terre Et Agronomie* 05: 44–51

Butnan, S., Toomsan, B. and Vityakon, P. (2018). Charcoal production and distribution as a source of energy and its potential gain for soil amendment in Northeast Thailand. *Pertanika Journal of Social Sciences and Humanities* 26(2): 643–658.

Campbell, B. M., Angelsen, A., Cunningham, A., Katerere, Y., Sitoe, A. and Wunder, S. (2007). Miombo woodlands–opportunities and barriers to sustainable forest management. CIFOR, Bogor, Indonesia [http: //www.cifor.cgiar. org/miombo/ docs] site visited on 12/10/2018.

Carrari, E., Ampoorter, E., Bussotti, F., Coppi, A., Garcia Nogales, A., Pollastrini, M. and Selvi, F. (2018). Effects of charcoal hearth soil on forest regeneration: Evidence from a two-year experiment on tree seedlings. *Forest Ecology and Management* 427: 37–44.

Chidumayo, E. N. (1988). Estimating fuelwood production and yield in regrowth dry miombo woodland in Zambia. *Forest Ecology and Management* 24(1): 59–66.

Chidumayo, E. N. (1994). Effects of wood carbonization on soil and initial development of seedlings in miombo woodland, Zambia. *Forest Ecology and Management* 70: 353–357.

Chidumayo, E. N. (2013). Forest degradation and recovery in a miombo woodland landscape in Zambia: 22 years of observations on permanent sample plots. *Forest Ecology and Management* 291: 154–161.

Chidumayo, E. N. and Gumbo, D. J. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development* 17(2): 86–94.

Chomba, C. (2018). Does the Cutting of Miombo Tree Species for Charcoal Production Directly Cause Deforestation? a Case Study of Kapiri Mposhi Area, Central Zambia. *Global Journal of Biology, Agriculture and Health Sciences* 7(1): 45–65.

Clemens, H., Bailis, R., Nyambane, A. and Ndung'u, V. (2018). Africa Biogas Partnership Program: A review of clean cooking implementation through market development in East Africa. Energy for Sustainable Development. *The Authors* 46: 23–31.

D'Agostino, A. L., Urpelainen, J. and Xu, A. (2015). Socio-economic determinants of charcoal expenditures in Tanzania: Evidence from panel data. *Energy Economics* 49: 472–481.

Demirbas, A., Ahmad, W., Alamoudi, R. and Sheikh, M. (2016). Sustainable charcoal production from biomass. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects* 38(13): 1882–1889.

Dewees, P. A., Campbell, B. M., Katerere, Y., Sitoe, A., Cunningham, A. B., Angelsen, A. and Wunder, S. (2010). Managing the Miombo woodlands of Southern Africa: Policies, incentives, and options for the rural poor. *Journal Natural Research Policy Research* 2(1): 57–73.

Dons, K. (2014). Estimation of forest degradation with remote sensing and GIS Analysis -the case of REDD+ in Tanzania. Ph.D. Dissertation for Award Degree at University of Copenhagen, Denmark. 145pp.

Ferdinand, H., Syampungani, S. and Chisanga, E. (2011). The influence of stump diameter and height on coppicing ability of selected key miombo woodland tree species of Zambia: A guide for harvesting for charcoal production. *Journal of Ecology and Natural Environment* 3(14): 461–468.

Glaser, B., Lehmann, J. and Zech, W. (2002). Ameliorating physical and chemical properties of highly weathered soils in the tropics with charcoal - A review. *Biology and Fertility of Soils* 35(4): 219–230.

Hardy, B. (2017). Pre-industrial charcoal kiln sites in Wallonia, Belgium: spatial distribution, effects on soil properties and long-term fate of charcoal in soil. Université catholique de Louvain.

Hardy, B., Cornelis, J. T., Houben, D., Lambert, R. and Dufey, J. E. (2016). The effect of pre-industrial charcoal kilns on chemical properties of forest soil of Wallonia, Belgium. *European Journal of Soil Science* 67(2): 206–216.

Kimaryo, B. and Ngereza, K. K. (1989). Charcoal Production in Tanzania Using Improved Traditional Earth Kilns. Moshi, Tanzania. [https://idl-bnc-idrc. dspacedirect.org/bitstream/handle/./ar1988-89.pdf?] site visited on 20/7/2019.

Knapp, H., Robin, V., Kirleis, W. and Nelle, O. (2013). Woodland history in the upper Harz Mountains revealed by kiln site, soil sediment and peat charcoal analyses. *Quaternary International* 289: 88–100.

Luoga, E. J., Witkowski, E. T. F. and Balkwill, K. (2000). Economics of charcoal production in miombo woodlands of eastern Tanzania: Some hidden costs associated with commercialization of the resources. *Ecological Economics* 35(2): 243–257.

Luoga, E. J., Witkowski, E. T. F. and Balkwill, K. (2004). Regeneration by coppicing (resprouting) of miombo (African savanna) trees in relation to land use. *Forest Ecology and Management* 189(1–3): 23–35

Lupala, Z. J., Lusambo, L. P., Ngaga, Y. M. and Makatta, A. A. (2015). The land use and cover change in miombo woodlands under community-based forest management and its implication to climate change mitigation: A Case of Southern Highlands of Tanzania. *International Journal of Forestry Research* 2: 1 – 12.

Malimbwi, R., Zahabu, E., Monela, G. C., Misana, S., Jambiya, G. C. and Mchome, B. (2005). Charcoal potential of miombo woodlands at Kitulangalo, Tanzania. *Journal of Tropical Forest Science* 17(2): 197–210.

Malimbwi, R. and Zahabu, E. (2009). The analysis of sustainable charcoal production systems in Tanzania. In: Criteria and Indicators for Sustainable Woodfuels. (Edited by Simmone, R., Remedio, E. and Trossero, M. A.), Viale delle Terme di Caracalla, Rome, Italy. pp. 229–261.

Malimbwi, R. E., Misana, S., Monela, G. C., Jambiya, G. and Zahabu, E. (1998). Impact of charcoal extraction to the forest resources of Tanzania: The case of Kitulangalo area, Tanzania proceedings of the 1st University Wide Scientific Conference, 5th-7th April 2000, 1998(3): 386-406.

Malmer, A. (2007). General ecological features of miombo woodlands and considerations for utilization and management. Proceedings of the First Mitimiombo Project Workshop, 5th February 2007. pp. 34 – 42.

Martin-Garca, J. and Javier, J. (2012). Sustainable Forest Management: An Introduction and Overview. Sustainable Forest Management - Current Research. 15pp.

MNRT (2015). National Forest Resources Monitoring and Assessment of Tanzania Mainland. Main Results Report.124pp.

Msuya, N., Masanja, E. and Temu, A. K. (2011). Environmental burden of charcoal production and use in Dar es Salaam, Tanzania. *Journal of Environmental Protection* 02(10): 1364–1369.

Mtimbanjayo, J. R. and Sangeda, A. Z. (2018). Effects of cattle grazing on miombo tree species regeneration and diversity in Central-Eastern Tanzania. *Journal Environmental Research* 2(13): 1–7.

Mwansa, P. (2018). Investigating the impact of fire on the natural regeneration of woody species in dry and wet Miombo woodland. Dissertation for Award of MSc Degree at Stellenbosch University. 187pp.

Nelle, O. (2003). Woodland history of the last 500 years revealed by anthracological studies of charcoal kiln sites in the Bavarian Forest, Germany. *Phytocoenologia* 33(4): 667–682.

Sander, K., Gros, C. and Peter, C. (2013). Enabling reforms: Analyzing the political economy of the charcoal sector in Tanzania. *Energy for Sustainable Development* 17(2): 116–126.

Sangeda, A. Z. and Maleko, D. D. (2018). Regeneration Effectiveness Post Tree Harvesting in Natural Miombo Woodlands, Tanzania. *Journal of Plant Sciences and Agricultural Research* 2(10): 1–7.

Schmidt, M., Mölder, A., Schönfelder, E., Engel, F. and Fortmann-Valtink, W. (2016). Charcoal kiln sites, associated landscape attributes and historic forest conditions: DTM-based investigations in Hesse (Germany). *Forest Ecosystems* 3(1).

Shackleton, M. C. (2001). Managing regrowth of an indigenous savanna tree species (Terminalia sericea) for fuelwood: The influence of stump dimensions and post-harvest coppice pruning. *Biomass and Bioenergy* 20(4): 261–270

Syampungani, S., Geldenhuys, C. J. and Chirwa, P. W. (2016). Regeneration dynamics of miombo woodland in response to different anthropogenic disturbances: forest characterization for sustainable management. *Agroforestry Systems* 90(4): 563–576.

Syampungani, S., Tigabu, M., Matakala, N., Handavu, F. and Oden, P. C. (2017). Coppicing ability of dry miombo woodland species harvested for traditional charcoal production in Zambia: a win-win strategy for sustaining rural livelihoods and recovering a woodland ecosystem. *Journal of Forestry Research* 28(3): 549–556.

Tiwari, R. K. S. and Das, K. (2010). Effect of stem cuttings and hormonal pre-treatment on propagation of Embelia tsjeriam and Caesalpinia bonduc , two important medicinal plant species. *Journal of Medicinal Plants Research* 4(15): 1577–1583.

Young, M. J., Johnson, J. E. and Abrams, M. D. (1996). Vegetative and edaphic characteristics on relic charcoal hearths in the Appalachian Mountains. *Vegetation* 125(1): 43–50.

Zulu, L. C. and Richardson, R. B. (2013). Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. *Energy for Sustainable Development* 17(2): 127–137.

CHAPTER TWO

MANUSCRIPT ONE

2.0 THE REGENERATION DYNAMICS OF MIOMBO TREE SPECIES IN SUB-SAHARAN AFRICA

Matowo Godbless S[1], Sangeda Anthony Z[2†] and Katani Josiah Z[1]

[1]Department of Forest Resources Assessment and Management, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, P.O. Box 3013, Morogoro, Tanzania.

[2]Department of Animal, Aquaculture and Range Sciences, College of Agriculture, Sokoine University of Agriculture, P.O. Box 3004, Morogoro, Tanzania.

Published in: African Journal of Ecology and Ecosystems

Publication year: 2019

Available online at: [www.internationalscholarsjournals.org]

CHAPTER THREE

MANUSCRIPT TWO

3.0 POST-HARVEST REGENERATION PERFORMANCE OF MIOMBO TREES ON KILN SCARS. A CASE OF PILOT SUSTAINABLE CHARCOAL PRODUCTION BLOCKS IN KILOSA DISTRICT, TANZANIA.

Matowo Godbless S[1], Katani Josiah Z[1] and Sangeda Anthony Z[2]

[1]Department of Forest Resources Assessment and Management, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, P.O. Box 3013, Morogoro, Tanzania.

[2]Department of Animal, Aquaculture and Range Sciences, College of Agriculture, Sokoine University of Agriculture, P.O. Box 3004, Morogoro, Tanzania.

Abstract

The management of forest/woodland for charcoal production requires successful regeneration in both kiln scar and non-scar areas. It is important to have information on tree regeneration characteristics especially in kiln scars where soil was interfered by heat during charcoal making. Therefore, the study determined the size of kiln scars, regeneration status and time involved, the species regenerated and their respective form of regeneration in the charcoal production sites. A total of 154 kiln scars harvested from 2013 to 2015 were assessed in 8 villages of Kilosa district, Tanzania. Results showed; kiln scars occupied 1.5% of the total harvested area with an average size of 0.003 ± 0.00013 ha (30 ± 1.3m^2). The percentage of regeneration in kiln scars increased as time-lapsed in charcoal production sites 17, 26, and 48% for 4, 5 and 6 years since production, respectively. Moreover, within 6 years of assessment, regeneration in kiln scars relied on seedling sprouts. The tree species composition around the harvested areas influences the composition of trees regenerated in kiln scars. This study recorded 32 tree species dominated by *Brachystegia boehmii*, *Margaritaria discoidea*, *Pterocarpus rotundifolius*, *Acacia polyacantha*, *Brachystegia bussei* and *Brachystegia spiciformis*. Conclusively; miombo trees can naturally regenerate in kiln scars. Also, the area covered by kiln scars (1.5% of the harvested area) was small to disqualify the whole idea of sustainable charcoal production. Further studies were recommended on time required for tree regenerants to mature and the influence of anthropogenic activities on the regeneration of miombo trees in kiln scars.

Keywords: Kiln scars, Charcoal production, Miombo, regeneration, sustainable forest management.

3.1 Introduction

The human population increase in many developing countries with little or no effort of increasing an alternative energy supply has resulted in unavoidable use of charcoal (Chidumayo and Gumbo, 2013). Despite the role played by charcoal as energy and income sources, charcoal production results in de-stocking of the forest area coupled with biodiversity loss. This phenomenon can be overcomed by the retention of above-ground (stumps) and below-ground (roots) biomass, which positively enhance forest regeneration and recovery.

Charcoal is primarily produced in miombo woodlands, the dominant forest type in Eastern and Central Africa using the traditional earth-mound kilns; the most common type of kiln throughout sub-Saharan Africa (Malimbwi and Zahabu, 2009). This is because it is cheap to make and has effective burning due to its geometric shape that allows complete cover by sand (Adam, 2009; Msuya *et al.,* 2011).

Charcoal making severely damages the kilns placed areas leading to the formation of forest patches devoid of tree cover known as kiln scars. Kiln scars experience modification from extreme heat produced during wood carbonization (Chidumayo, 1988). These damages result in long term modification of chemical and physical characteristics of kiln scars, including soil properties such as nutrient availability and water holding capacity (Oguntunde *et al.,* 2008; Carrari, 2015; Carrari *et al.,* 2018), and tree regeneration (Chidumayo, 1988).

In recent years, an increase in charcoal production has been reported in Tanzania and other neighboring sub-Saharan countries. This practice has resulted in a cumulative large area of deforested land caused by abandoned kiln scars. Delayed tree regeneration in kiln scars has been reported in Germany (Schmidt *et al.,* 78 2016), Brazil (Rodrigues *et al.,* 2019), and Belgium (Hardy *et al.,* 2016; Hardy, 2017). In the miombo ecoregion, it is still not known if trees can regenerate in the kiln scars. A critical study by Chidumayo (1988) reported no trees regenerated in wet miombo of Zambia. Also, a survey by Sangeda and Maleko (2018) in dry miombo woodlands found no tree regenerated in the kiln scars 2 years after kiln abandonment. Miombo woodlands are known for its good ability to regenerate after disturbance. Therefore, post charcoal production monitoring of the kiln scars is necessary.

To understand the effect of charcoal production on the natural regeneration of dry miombo tree species in kiln scars, the observatory study in the charcoal production area was done. The study aimed to determine: (1) the size of kiln scars, (2) regeneration status and time involved, (3) the species regenerated and (4) their respective form of regeneration. This study is relevant as it provides important information needed for designing management initiatives for kiln scars to achieve sustainable management of forest resources by steady supply of energy and other important ecosystem services.

3.2 Methodology

3.2.1 Study area description

The study was conducted in the selected village land forest reserves (VLFRs) found within Kilosa District, Morogoro region. The selected villages were those piloting the sustainable charcoal production under the Transforming Tanzania Charcoal Sector project which is under two Non-Governmental Organizations (NGOs), Tanzania Forest Conservation Group (TFCG) and The Community Forest Conservation Network of Tanzania (MJUMITA). In this project area, tree harvesting occurs in pre-determined square blocks provided by the model that is based on a 24 years rotation. The management of the harvested area complies to district harvesting plan (Ishengoma *et al.,* 2016) that enhances natural regeneration through mandatory protection against anthropogenic activities

Kilosa District is situated in Central-East Tanzania (Fig. 3.1) lying between latitudes 5° 55' and 7° 53' S and between longitudes 36° 30' and 37° 30' E. The district covers 14 918 square kilometers (Kajembe *et al.,* 2015) with a total area of 12 394 square kilometers covered by forests. The area has an average elevation of 635 m above sea level. The district receives bimodal rainfall with short and long rains between November to January and March to June, respectively. The mean annual rainfall ranges from 800 mm to 1300 mm while the mean annual temperature ranges between 25ºC and 30ºC. Village Land forest reserves in Kilosa account for a total area of 124 335 ha with miombo trees as the dominant vegetation.

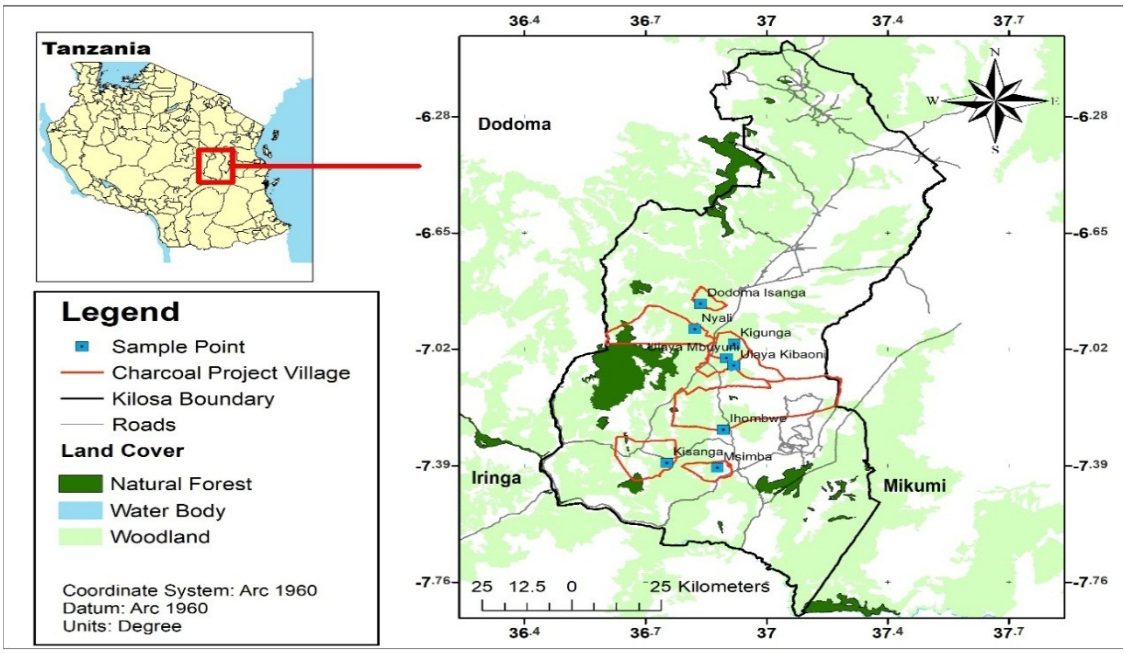


Figure 3.1: Map showing the location of study villages in Kilosa district, Morogoro, Tanzania. Modified from Sangeda and Maleko (2018).

3.2.2 Study design

Data were collected in eight villages found in Kilosa district. These villages were chosen because they had been using sustainable charcoal production since 2013. The study used a multistage sampling design (Kothari, 2004). For the first stage, harvesting blocks were selected randomly from the pre-identified blocks harvested in the respective year. The harvesting blocks has a dimension of 50 x 50m (0.25ha) arranged in alternating order of intended harvesting years (Fig. 3.2). In each village, a total of 15 blocks were surveyed, each five represented a different charcoal production year (2013, 2014 and 2015). Subsequent years (less than three years) were not considered because a previous study by Sangeda and Maleko (2018) indicated that they contain no tree regenerants. In the second stage, data were only collected in the kiln scars available in each block.

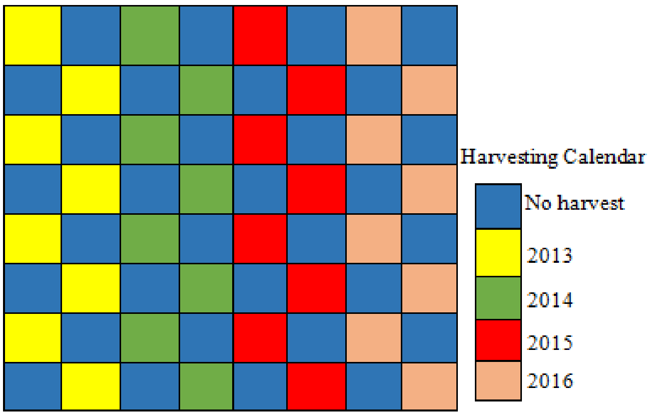


Figure 3.2: The typical model of harvesting (Charcoal production calendar) for villages practicing sustainable charcoal production. The drafts present the ground square of the 50m side, arranged in harvesting priority.

3.2.3 Data collection

Data collection was done in March 2019 within eight villages of the Kilosa District. The choice of villages was limited to only those practicing sustainable charcoal production as it was difficult to obtain the record on harvesting time of kiln scars left in non-sustainable charcoal production areas to make a comparison with. The study surveyed a total of 120 blocks and managed to collect data in 154 kiln scars. Qualitative and quantitative data were collected including the number and dimension of kiln scars present, presence of regeneration, harvesting year, the form of tree regeneration, seedling species identification and regenerants counting (Appendix 1). Seedlings were carefully examined to obtain the information on the form of regeneration whether is through seed regeneration or root sprouts. The study used the NAFORMA species list and guide to determine the scientific names of tree species identified by local names. Secondary information on species composition and stocking of the study site was obtained from preceding studies by Ishengoma *et al.* (2016) and Sangeda and Maleko (2018). Data collection mainly focused on the kiln scars (Fig. 3.3), where the extreme effect of the charcoal making process was considered to be critical. The form of regeneration assessed was if trees established from seedling or root suckers while stump coppicing was not considered as no stump remains in the kiln scar.

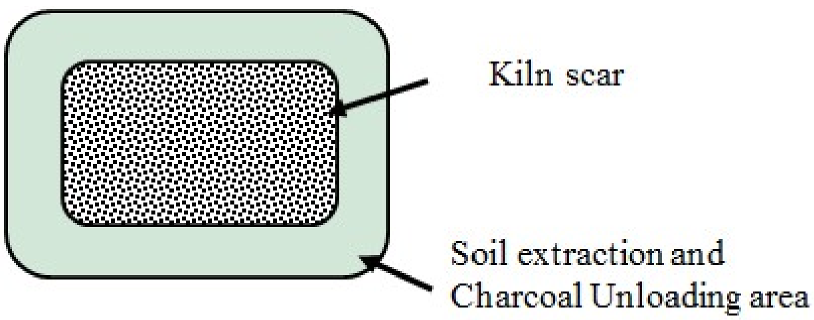


Figure 3.3: The structure of the kiln site depicting two critical areas affected by charcoal production from the earth mounded kiln type.

3.2.4 Data analysis

Based on the data collected the following parameters were computed: kiln area, seedlings density and species composition. Kiln area was computed using the respective known geometric shape formula (Bird, 2005) as they portrayed the circular, rectangular and rocket-shaped. Seedling density (stem ha-1) was obtained as the ratio of the regenerants counts to the kiln area. Species composition was expressed as species richness computed as the total number of species in the assessed kiln scars. Descriptive statistics were used to compute the mean and standard error (SE) of kiln size, seedling density and counts of regenerants. The relationship between the natural regeneration, time required and the kiln scars areas were obtained using the multiple linear regression. To check if regeneration variables differed significantly with time, analysis of variance (ANOVA) was used. Then to uncover specific differences between the compared group means the post hoc test was done using the Tukey HSD function. All analysis was done in R-software (R Development Core Team, 2013).

3.3 Results and Discussion

3.3.1 Size of kiln scars in charcoal production blocks

A total number of 154 kiln scars were measured in 120 charcoal harvested blocks. Within blocks, at least one kiln scar was observed per block with few ones having more than one. The majority (94%) of kiln scars had a rectangular shape, while the remaining had 5% and 1% for circular and rocket-shaped, respectively. The average size of kiln scars was 0.003 ± 0.00013 ha (30 ± 1.3 m^2) which is equivalent to 1.5 percent of the total harvested area. However, the size of the kilns differed significantly among the study villages ($F_{7, 146}$ = 7.2, $p<0.001$). The minimum and maximum kiln scars size observed was 0.0007ha and 0.0085ha (7 m^2 and 85m^2), respectively.

The observed difference in kiln scars size could be attributed by the stocking characteristics of the harvested area, i.e. high vs. low stocking levels and diameter class distributions to which both positively influenced the kiln size needed for carbonization of the resource available in the harvesting area. In studying vegetative and edaphic characteristics on relic charcoal hearths in the Appalachian Mountains, Young *et al.* (1996) reported that nearby areas to the furnace with a good supply of timber experienced extreme disturbance during charcoal production as timber supply and location influenced the size of furnace and frequency of burning on the same earth kiln spot. This fact possibly suggests the reason for variation in average kiln size (Fig. 3.4) observed in the study area, where the areas with a good supply of raw materials (good stocking) are considered to have higher average kiln size. Moreover, Sangeda and Maleko (2018) mentioned the dimensions of kiln scars and placement are also linked with the topography (slope) and the presence of covering material i.e. easiness of digging the soil for placement and covering of the kiln. Knapp *et al.* (2013) also observed a high density of kiln sites in a low mountain range in Northern Germany, which is linked with the topographical reasons.

The coverage of kiln scars relative to the total harvested areas ranged between 0.9% and 1.5%, which is slightly lower than values obtained by previous studies in Zambia, which recorded charcoal areas that covered 2-3% (Chidumayo, 1993) and 5% (Chidumayo and Gumbo, 2013) of the total harvested area. Lees (1962), cited by Chidumayo (1988) estimated 15% of the total harvested area in the Copperbelt, Zambia was kiln scars as charcoal production was high due to demand from the increased population in response to mining activity in the area. The small coverage of kiln scars observed in Kilosa sustainable charcoal production blocks could be due to the principles that restrict charcoal production to once in a rotation of 24 years and by only one charcoal producer for each harvesting block, which reduces the number of kilns developed in the area.

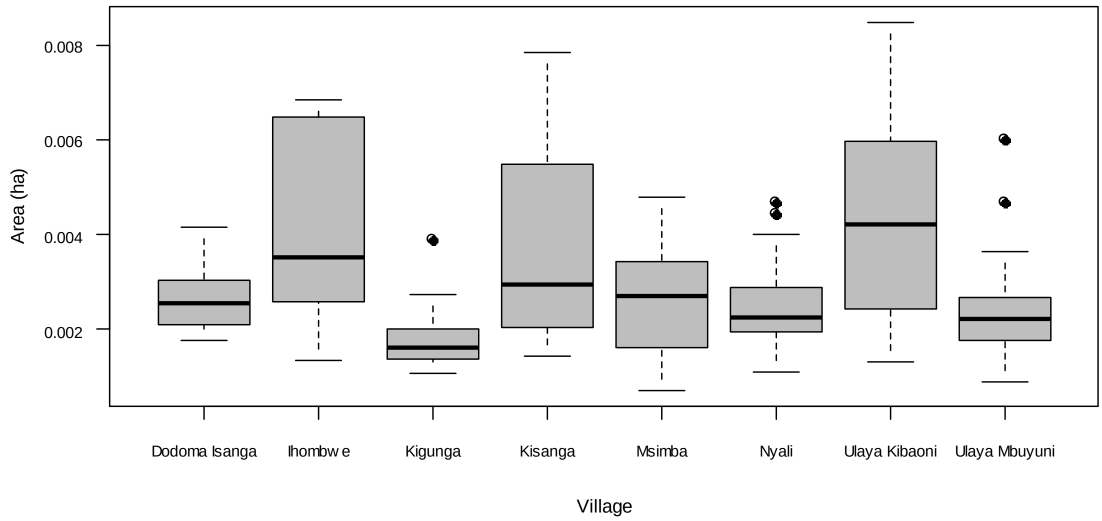


Figure 3.4: The variation of kiln scar sizes across the study villages, Kilosa district, Tanzania

3.3.2 Influence of time on natural regeneration of miombo trees in kiln scars

There was a weak positive relationship for the natural regeneration in kiln scars as a function of time (F (1,151) = 13.35, p = .00035, r^2 = 0.08074, Simple linear regression). The inclusion of kiln scar area (multilinear regression) slight improved the relationship to r^2 = 0.1046 (F (2, 151) = 8.82, p= 0.00023). Thus, the kiln size has no relationship with the natural regeneration in kiln scars. However, data showed a tendency to increase in the relative number of seedlings with time. Analyses of Variance showed the significant difference between the number of regenerants in kiln scars with 4, 5 and 6 years from charcoal production (ANOVA, F (2,151) = 7.1, $p < 0.05$). Post hoc comparisons using the Tukey HSD test indicated that the mean number of regenerants differed significantly between 4, 5 and 6 years from harvesting with more regenerants been recorded in the 6 years (Table 3.1). These results suggest that duration from charcoal production affects the rate of regeneration in kiln scars. These results further showed that when kiln scars are left for a long-time regeneration of tree species continues to occur (Fig. 3.5 and Plate 3.1).

The findings from Sangeda and Maleko (2018) documented the condition of kiln scars left for two years where no tree species was yet sprouted as some were devoided from vegetation while others found with regenerated herbaceous plants. However, the results of this study in the same area documented the presence of tree regenerants after 4 years. Therefore, the number of regenerants was directly proportional to the time lapsed from charcoal production. The current study provides evidence that miombo trees can regenerate in kiln scars. However, a study by Chidumayo (1988) recorded no tree regenerants in wet miombo woodlands of Zambia 13 years after charcoal production. This result is also similar to what has been observed in Germany (Schmidt *et al.*, 2016), Brazil (Rodrigues *et al.*, 2019) and Belgium (Hardy *et al.*, 2016; Hardy, 2017) which documented the perseverance of kiln scars up to a decade(s).

There are other factors affecting regeneration on kiln scars. Chidumayo (1988) reported recurrent fire and intense grazing as a major bottleneck to regeneration in kiln scars while other studies reported reduced growth of regenerants in cold climate countries (Schmidt *et al.*, 2016; Rodrigues *et al.*, 2019; Hardy *et al.*, 2016; Hardy, 2017; and Way and Oren, 2010). Unlike other studies, this study was conducted in dry miombo woodlands with management that is determined to reduce anthropogenic activities including grazing, illegal harvesting, and the recurrent fire incidences all of which may have affected the observed results. However, Chinuwo *et al.* (2010) found the same trend of increasing the number of regenerants with time when restoring the cultivated area.

Table 3.1: The mean regenerants density and the significant test (post-hoc-results) for the respective harvesting years and their comparisons. NOTE. P-value at 5%; * = significant.

Age of regenerants	Mean regenerants density	Standard error, SE	Comparison	P-value
4	107	± 29	6 - 5	0.26343
5	202	± 41	5 – 4	0.03853*
6	470	± 70	6 – 4	0.00098*

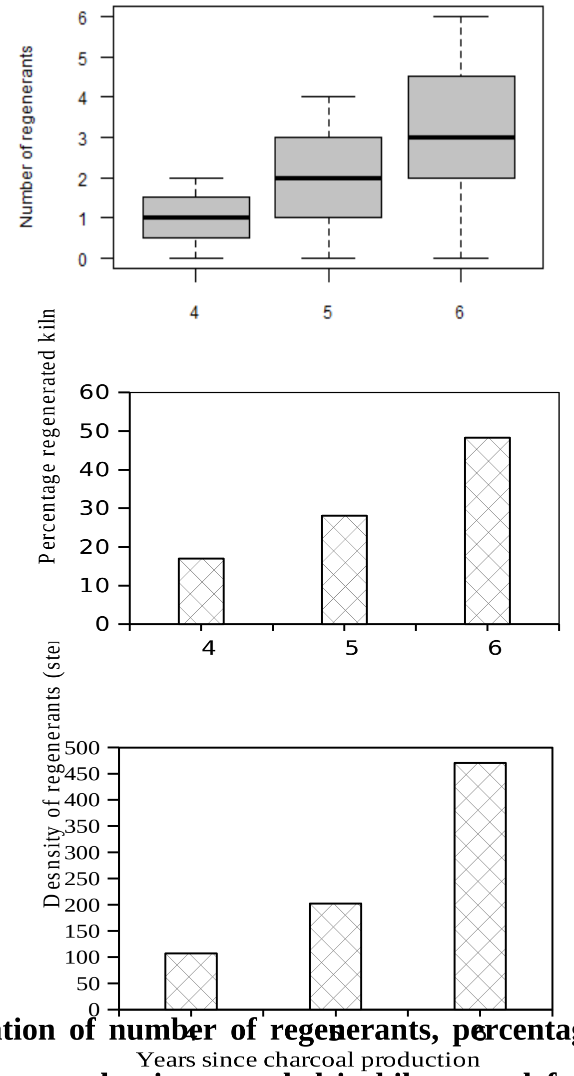


Figure 3.5: The variation of number of regenerants, percentage kilns regenerated and regenerants density recorded in kiln scars left for 4, 5 and 6 after charcoal production

Plate 3.1: The miombo seedlings regenerated in kiln scars; Photo taken in the study area, Kilosa, Tanzania

4.3.3 Species regenerated in Kiln Scars

A total of 32 tree species belonging to 14 families (Table 3.2) were observed and recorded during data collection with slight variation from one village to another. Also, there was no regeneration recorded for invasive tree species in the site as all species were previously documented in the baseline study across the southern part of Kilosa district (Ishengoma *et al.*, 2016) and other ecological studies conducted in the same area (Mtimbanjayo and Sangeda, 2018; Sangeda and Maleko, 2018).

Brachystegia boehmii and *Margaritaria discoidea* were the tree species recorded in most of the kiln scars. Other dominant species in kilns included *Pterocarpus rotundifolius*, *Acacia polyacantha*, *Brachystegia bussei* and *Brachystegia spiciformis* (Fig. 3.6). About 26% of total species observed came from Caesalpinioideae making it the dominant regenerating family, followed by Papilionoideae (17%) and Phyllanthaceae (13%) families. The abundance of Caesalpinioideae family is because, its species are the most common trees in the forest determining the miombo vegetation (Campbell *et al.*, 2007; Gumbo and Clendenning, 2018). Also, Caesalpinioideae has high production of seeds per individual tree with suitable dispersal mechanism through pod explosion (Chidumayo and Frost, 1996). Most of the species in Papilionoideae were not harvested for charcoal making due to their high value for timber (Ishengoma *et al.*, 2016) and therefore were retained in the charcoal production blocks. Papilionoideae have an outstanding ability to produce seeds even when trees are young (Kammesheidt, 1999; Schwartz and Caro, 2003), which increases the chance of regeneration in kiln scars. Tree species within Phyllanthaceae family produce small fruits which are preferred and dispersed by birds of which has increased the chance for them to be dispersed at the kiln scars.

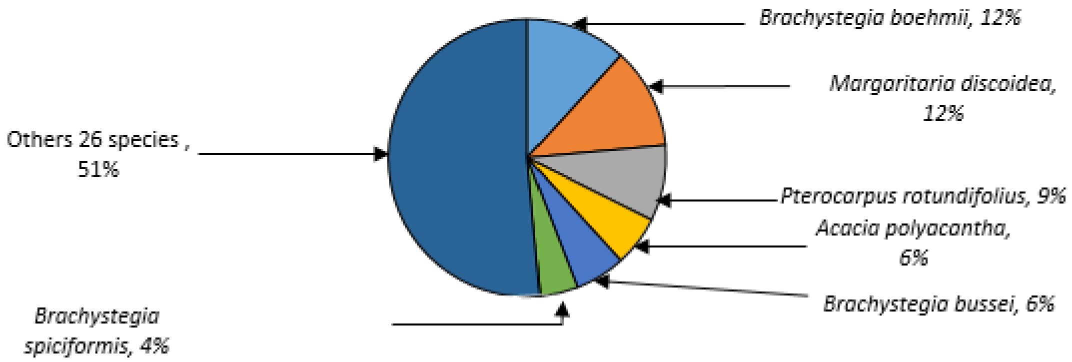


Figure 3.6: Percentage contribution of dominant tree species based on the number of seedlings regenerated in kiln scars in Kilosa, Tanzania

.

Table 3.2: Species composition in kiln scars recorded in Kilosa, Tanzania

S/N	Family	Scientific Name	Local Name	Frequency (f)*	Counts**
1	Anacardiaceae	*Lannea schweinfurthii*	Muumbu	1	2
		Sclerocarya birrea	Mng'ongo	1	2
		Sorindeia madagascariensis	Mpilipili	1	1
2	Apocynaceae	*Diplorynchus condylocarpon*	Mtogo	1	2
3	Caesalpinioideae	*Bauhinia petersiana*	Msegese	1	1
		Brachystegia boehmii	Myombo	8	35
		Brachystegia bussei	Mgelegele	4	9
		Brachystegia microphylla	Msani	1	11
		Brachystegia spiciformis	Mhani/Mtondoro	3	10
		Erythrophleum africanum	Mkarati	1	2
4	Compositae	*Vernonia myriantha*	Mtugutu	2	3
5	Ebenaceae	*Euclea divinorum*	Mdaa	1	1
6	Fabaceae	*Albizia adianthifolia*	Mkengeza	1	2
		Albizia gummifera	Mkenge	1	2
		Cassia abbreviata	Mkundule	1	1
7	Leguminosae	*Pericopsis sp.*	Mmanga	1	1
8	Mimosoideae	*Acacia gerrardii*	Mkongowe	1	1
		Acacia nigrescens	Mkambaa	1	2
		Acacia polyacantha	Mtalula	4	6
		Acacia senegal	Mzasa	1	1
		Dichrostachys cinerea	Mkulagembe	2	2
9	Moraceae	*Antiaris toxicaria*	Mikunzu/ mkunzu	1	13
		Ficus sycomorus	Mkuyu	2	7
10	Papilionoideae	*Dalbergia melanoxylon*	Mpingo	2	11
		Pterocarpus angolensis	Mninga	2	4
		Pterocarpus rotundifolius	Mzeza	6	11
		Xeroderris stuhlmannii	Mnyenye	1	3
11	Phyllanthaceae	*Flueggea virosa*	Mkwambekwambe	3	5
		Margaritaria discoidea	Msakulangw'ale	8	17
12	Rubiaceae	*Crossopteryx febrifuga*	Mkombeziko/ Mtimwiko	1	3
13	Rutaceae	*Zanthoxylum chalybeum*	Mhunungu	2	3
14	Sapindaceae	*Deinbollia borbonica*	Mmoyomoyo	2	2

* Number of kiln scars in which the species were found. **total number of seedlings counted

Concurrently, kiln scars were observed to contain other rejuvenating plants. Among them include grasses (herb), Calotropis procera (shrub), and amaranthus (herb) corresponding to 17, 8.8, and 5.5% of the total assessed kiln scars, respectively (Fig. 3.7, Plate 3.2). These results differed from Sangeda and Maleko (2018) who visually observed only 10% of kiln scars left for two years contained herb species such as wild amaranthus, while those abandoned for only one year were devoid of other plants. Hence, the number of kilns with vegetation cover were observed to increase with years from charcoal production time. Furthermore, grasses were found to be the dominant plants in the kiln scars.

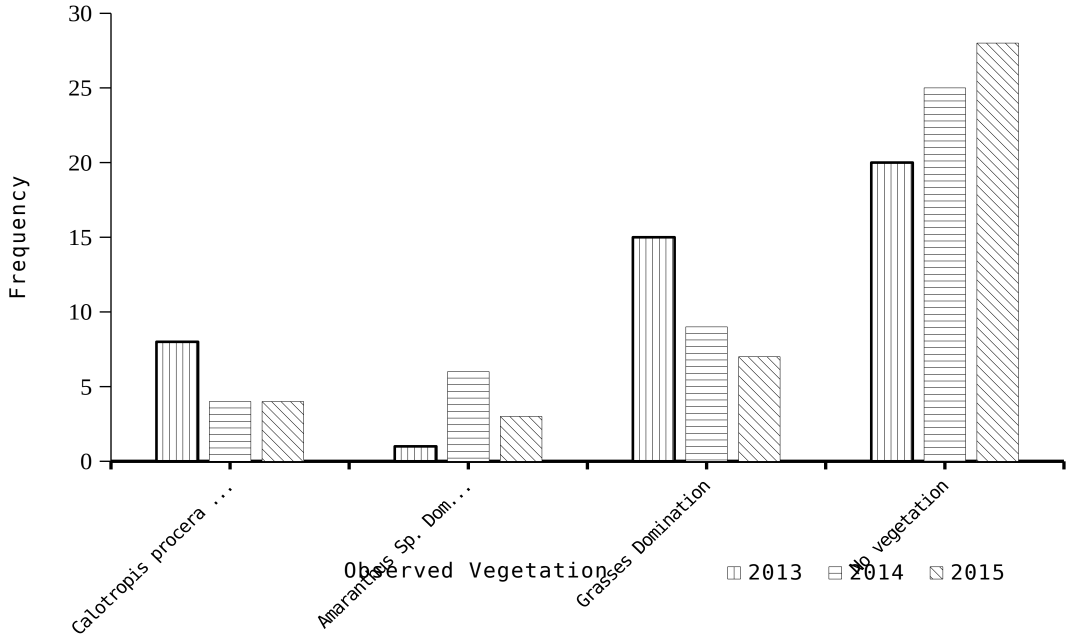


Figure 3.7: Vegetation composition observed in the corresponding harvesting year in Kilosa, Tanzania

Plate 3.2: The non-regenerated (top left), grass-covered (top right), *amaranthus* covered (bottom left) and *Calotropis procera* covered (bottom right) kiln scars as observed during the data collection in study villages, Kilosa, Tanzania.

3.3.4 The form of miombo tree species regeneration in kiln scars

The results from this study recorded 100% of the tree regenerants in the kiln scars were established from seedlings. This shows that trees regenerated from seed colonize the kiln scars early before trees regenerated from other forms thus making seedlings the most prominent method for scars recovery. Nevertheless, other studies have shown that miombo rejuvenates from various disturbances including fire, shifting cultivation and harvesting through coppicing and root-suckers (Chidumayo, 2019; Matowo *et al.,* 2019; Sangeda and Maleko, 2018). The suitability of seedlings relies on the robust nature of miombo in producing and spreading seeds through various mechanisms (Deiller *et al.*, 2003; Bognounou *et al.,* 2010; Teketay *et al.,* 2018). The burnt above-ground seed pool can easily be replaced since miombo seeds can spread by wind up to 103 m, exploded seed from pods (Brachystegia and Julbernadia) (Chidumayo, 2019) can move to the maximum distance of 20 m and fresh succulent fruits can be transported by animals and dispersed in different locations (Chidumayo, 1991; 1987). The various methods for seed dispersion increase the chance of seed landing on the kiln site. Besides, the proximity of the kiln site to the seed trees increases the possibility of massive seeds that depend on gravitation to fall on the area (Chambers and MacMahon, 1994).

Vegetative propagation in kiln scars through coppicing is stalled since both above and below ground tree stock is burned by fire. However, the possibility of regeneration through root suckers still exists because the branched roots of miombo trees can travel extensively and can quickly sprout in disturbed areas (Kitajima and Fenner, 2009). Consequently, regeneration through root suckers will require relatively more time for roots to penetrate to the kiln scars.

3.4 Conclusion and Recommendations

3.4.1 Conclusion

Generally, kiln scars cover about 1.5% of the total harvested area under sustainable charcoal production which is small to disqualify the whole idea of sustainable charcoal production. Although regeneration is delayed, our findings have shown that miombo trees regenerate in kiln scars through seedlings and therefore contribute to forest regrowth. At least 3 years are required to witness established tree seedlings in the kiln scars with a number of regenerants positively related to time lapsed from charcoal harvesting. Furthermore, no invasive tree species regenerated in kiln scars; for that reason, the composition of proximal trees determines the species to regenerate in the kiln scars.

3.4.2 Recommendations

The authors recommend further study on the influence of the anthropogenic activities on the regeneration of miombo trees in kiln scars as disturbances may either boost or suppress the rate of regeneration. Also, to overcome the limitation of this study that only provides the short term results of the regeneration in the study site and it does not provide the information on the time required for the tree to mature, further monitoring research is recommended since the survival of tree seedlings in miombo woodlands are affected by anthropogenic activities and invasive species may colonize over time.

Reference

Bognounou, F., Tigabu, M., Savadogo, P., Thiombiano, A., Boussim, I. J., Oden, C. and Guinko, S. (2010). Regeneration of five Combretaceae species along a latitudinal gradient in Sahelo-Sudanian zone of Burkina Faso. *Annual Forest Science* 67.

Butnan, S., Toomsan, B. and Vityakon, P. (2018). Charcoal production and distribution as a source of energy and its potential gain for soil amendment in Northeast Thailand. Pertanika *Journal of Social Sciences and Humanities* 26(2): 643–658.

Campbell, B. M., Angelsen, A., Cunningham, A. B., Katerere, Y., Sitoe, A. A. and Wunder, S. (2007). Miombo woodlands – opportunities and barriers to sustainable forest management. *Observatory.* 41pp.

Carrari, E. (2015). Legacy effects of former charcoal kiln sites on the forest vegetation of a Mediterranean area. Universita Degli studi Firenze. [http://www.dispaa. unifi.it/ %0ADichiarazione] site visited on 12/12/2018.

Carrari, E., Ampoorter, E., Bussotti, F., Coppi, A., Garcia Nogales, A., Pollastrini, M. and Selvi, F. (2018). Effects of charcoal hearth soil on forest regeneration: Evidence from a two-year experiment on tree seedlings. *Forest Ecology and Management* 427: 37–44.

Chambers, J. C. and MacMahon, J. A. (1994). A Day in the life of a seed: Movements and fates of seeds and their implications for natural and managed systems. *Annual Review of Ecology and Systematics* 25: 263–292.

Chidumayo, E. N. (1988). A re-assessment of effects of fire on miombo regeneration in the Zambian Copperbelt. *Journal of Tropical Ecology* 4(4): 361–372.

Chidumayo, E. and Frost, P. (1996). The Miombo in Transition: *Woodlands and Welfare in Africa*. (Edited by Campbell, B.), Center for International Forestry Research (CIFOR). Bogor, Indonesia. 273pp.

Chidumayo, E. N. (1987). Species structure in Zambian Miombo Woodland. *Journal of Tropical Ecology* 3(2): 109–118.

Chidumayo, E. N. (1991). Seedling development of the miombo woodland tree Julbernardia. *Journal of Vegetation Science* 2(1): 21–26.

Chidumayo, E. N. (1993). Zambian charcoal production: Miombo woodland recovery. *Energy Policy* 21(5): 586–597.

Chidumayo, E. N. (1994). Effects of wood carbonization on soil and initial development of seedlings in miombo woodland, Zambia. *Forest Ecology and Management* 70: 353–357.

Chidumayo, E. N. (2019). Is charcoal production in Brachystegia-Julbernardia woodlands of Zambia sustainable? *Biomass and Bioenergy* 125: 1–7.

Chidumayo, E. N. (2019). Management implications of tree growth patterns in miombo woodlands of Zambia. *Forest Ecology and Management* 436: 105–116.

Chidumayo, E. N. and Gumbo, D. J. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development* 17(2): 86–94.

Chidumayo, E. N. and Gumbo, D. J. (2013). The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis. *Energy for Sustainable Development* 17(2): 86–94.

Chinuwo, T., Gandiwa, E., Mugabe, P. H., Mpofu, I. D. T. and Timpong-Jones, E. (2010). Effects of previous cultivation on regeneration of Julbernadia globiflora and Brachystegia spiciformis in grazing areas of Mupfurudzi Resettlement Scheme, Zimbabwe. *African Journal of Range and Forage Science* 27(1): 45–49.

Deiller, A. F., Walter, J. M. N. and Trémolières, M. (2003). Regeneration strategies in a temperate hardwood floodplain forest of the Upper Rhine: Sexual versus vegetative reproduction of woody species. *Forest Ecology and Management* 180(3): 215–225.

Dons, K. (2014). Estimation of forest degradation with remote sensing and GIS Analysis - the case of REDD+ in Tanzania. PhD Disssertation for Award Degree at University of Copenhagen, Denmark. 145pp.

Gumbo, D. and Clendenning, J. (2018). How have carbon stocks in central and southern Africa's miombo woodlands changed over the last 50 years? A systematic map of the evidence. *Environmental Evidenc*e 7(16): 1–19.

Hardy, B. (2017). Pre-industrial charcoal kiln sites in Wallonia, Belgium: spatial distribution, effects on soil properties and long-term fate of charcoal in soil. Université catholique de Louvain.

Hardy, B., Cornelis, J. T., Houben, D., Lambert, R. and Dufey, J. E. (2016). The effect of pre-industrial charcoal kilns on chemical properties of forest soil of Wallonia, Belgium. *European Journal of Soil Science* 67(2): 206–216.

Ishengoma, R. C., Katani, J. Z., Abdallah, J. M. and Olomi, J. S. (2016). Kilosa District harvesting plan. [http://www.tfcg.org/wp-content/uploads/2018/05/Kilosa-District-Harvesting-Plan-2016-preapproval-version.pdf] site visited on

24/05/2019.

Kajembe, G. C., Silayo, D. S. A. and Vatn, A. (2015). *The Adaptation Of REDD+ Initiatives in Forest Management Regimes in two Pilot Projects of Kondoa and Kilosa Districts, Tanzania*. Noragric. 75pp.

Kammesheidt, L. (1999). Forest recovery by root suckers and above-ground sprouts after slash-and-burn agriculture, fire and logging in Paraguay and Venezuela. *Journal of Tropical Ecology* 15(2): 143–157.

Kitajima, K. and Fenner, M. (2009). Ecology of seedling regeneration. Seeds. *The Ecology of Regeneration in Plant Communities* 2009: 331–359.

Knapp, H., Robin, V., Kirleis, W. and Nelle, O. (2013). Woodland history in the upper Harz Mountains revealed by kiln site, soil sediment and peat charcoal analyses. *Quaternary International* 289: 88–100.

Kothari, C. R. (2004). *Research Methodology: Methods and Techniques*. New Age International (P) Ltd., New Delhi, India. 375pp.

Malimbwi, R. and Zahabu, E. (2009). The analysis of sustainable charcoal production systems in Tanzania. FAO: Criteria and Indicators for Sustainable Woodfuels. pp 229–261.

Matowo, G. S., Sangeda, A. Z. and Katani, J. Z. (2019). The regeneration dynamics of Miombo tree species in Sub-Saharan Africa. *African Journal of Ecology and Ecosystems* 6(5): 1–16.

Mtimbanjayo, J. R. and Sangeda, A. Z. (2018). Effects of cattle grazing on miombo tree species regeneration and diversity in Central-Eastern Tanzania. *Journal of Environmental Research* 2(13): 1–7.

Mwampamba, T. H., Ghilardi, A., Sander, K. and Chaix, K. J. (2013). Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries. *Energy for Sustainable Development* 17(2): 75–85.

Nelle, O. (2003). Woodland history of the last 500 years revealed by anthracological studies of charcoal kiln sites in the Bavarian Forest, Germany. *Phytocoenologia* 33(4): 667–682.

Oguntunde, P. G., Abiodun, B. J., Ajayi, A. E. and Van De Giesen, N. (2008). Effects of charcoal production on soil physical properties in Ghana. *Journal of Plant Nutrition and Soil Science* 171(4): 591–596.

Rodrigues, A. F., Novotny, E. H., Knicker, H. and de Oliveira, R. R. (2019). Humic acid composition and soil fertility of soils near an ancient charcoal kiln: are they similar to Terra Preta de Índios soils? *Journal of Soils and Sediments* 19(3): 1374–1381.

Sangeda, A. Z. and Maleko, D. D. (2018). Regeneration effectiveness post tree harvesting in natural miombo woodlands, Tanzania. *Journal of Plant Sciences and Agricultural Research* 2(10): 1–7.

Schmidt, M., Mölder, A., Schönfelder, E., Engel, F. and Fortmann-Valtink, W. (2016). Charcoal kiln sites, associated landscape attributes and historic forest conditions: DTM-based investigations in Hesse (Germany). *Forest Ecosystems* 3(1).

Schwartz, M. W. and Caro, T. M. (2003). Effect of selective logging on tree and understory regeneration in miombo woodland in western Tanzania. *African Journal of Ecology* 41(1): 75–82.

Teketay, D., Kashe, K., Madome, J., Kabelo, M., Neelo, J., Mmusi, M. and Masamba, W. (2018). Enhancement of diversity, stand structure and regeneration of woody species through area exclosure: The case of a mopane woodland in northern Botswana. *Ecological Processes* 7(1).

Young, M. J., Johnson, J. E. and Abrams, M. D. (1996). Vegetative and edaphic characteristics on relic charcoal hearths in the Appalachian Mountains. *Vegetation* 125(1): 43–50.

CHAPTER FOUR

MANUSCRIPT THREE

4.0 THE ASSESSMENT OF STANDING STRUCTURE AND ABOVE-GROUND BIOMASS IN CHARCOAL PRODUCTION MIOMBO FORESTS IN KILOSA DISTRICT, TANZANIA

Matowo Godbless S[1†], Katani Josiah Z[1] and Sangeda Anthony Z[2]

[1]Department of Forest Resources Assessment and Management, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, P.O. Box 3013, Morogoro, Tanzania.

[2]Department of Animal, Aquaculture and Range Sciences, College of Agriculture, Sokoine University of Agriculture, P.O. Box 3004, Morogoro, Tanzania.

Abstract

Charcoal and firewood are the primary sources of energy for most households in Tanzania as a case of other sub-Saharan countries with more than 75% of the population using it as their most common and preferred type of biomass energies. With the notion that population increase influences positively the demand for biomass energy and impose threat to forests existence, the concept and the practice of sustainable forest management (SFM) become necessary. This study aims to assess and monitor the regeneration and growth of miombo trees in Kilosa Sustainable charcoal production blocks. Specifically, to assess the standing structure, above-ground biomass and the contribution of different regeneration mechanisms in recovery of harvested blocks. Data were collected from 106 plots within eight village land forest reserves. Specifically, data was collected in harvested blocks left for 6 years. A total of 66 tree species from 16 families was recorded growing in the study area. Trees of DBH between 5-15cm were dominating the area. The average DBH was 10.65cm with the basal area, volume and above-ground biomass of 3.77 ± 1.27m^2ha^{-1}, 31.71 ± 10.79$m^3ha^{-1}$and 21.5 ± 7.24t ha^{-1} respectively. Regeneration through seedling was the dominant recovery mechanism for miombo in the blocks.

Keywords: Sustainable forest management, miombo, natural regeneration, biomass, charcoal

4.1 Introduction

Sustainability in management of the natural resource is very important for the welfare of present and future resource users. Forest resource is among natural resource that requires sustained use. The need for sustainable forest management (SFM) comes from the risen demand for resources in Africa and worldwide. As an example, the 55% forest cover of Tanzania is reported to decrease overtime caused by intensive harvesting to suffice a variety of uses including energy demands such as charcoal production. The entire countries' annual demand for different uses was estimated at 62.3 million m^3. However, the available and ability of our forests to supply wood legally is 42.8 million m^3/year creating the annual deficit of 19.5 million m^3 the amount that can be met by overexploitation of the resource including harvesting in the protected areas (MNRT, 2015).

Charcoal and firewood are the primary sources of energy for most households in Tanzania like in other sub-Saharan countries with more than 75% of the population using it as their most common and preferred type of biomass energies (Lupala *et al.,* 2015; Mataruse *et al.,* 2018). With the notion that an increase in population will positively influence the demand for biomass energy and impose threat to forests existence, the concept and the practice of SFM become necessary.

According to Doggart and Meshack (2017), charcoal production can be done without permanently deforesting or degrading a forested area simply by protecting the harvested areas from different anthropogenic activities thus enabling natural regeneration. The authors further mentioned that sustainability in charcoal production requires owners of harvested woodlands to maintain forest cover over time and to protect it from conversion to other land uses through development, adoption, implementation and emphasizing policies that explicitly support sustainable production.

Tanzania Forest Conservation Group (TFCG) and Tanzania Community Forest Network (TCFN) have the project implementing SFM in Kilosa district. The project is known as Transforming Tanzania Charcoal Sector (TTCS). This project entails; guiding villagers to manage forest resources present in the village land in such a way that harvesting will be done in previously harvested areas after a specified time. This is to take advantage of the natural regeneration ability of miombo trees while improving the livelihood of the communities around the forest.

Since the project is one of its kind and a first pilot in the country, monitoring of any change in structure and growth of the harvested area is very important and requisite for excellent and successful resource management. The post-harvest structure and composition in regenerating blocks and information on the current growing condition is skimpy. Also, there is no baseline data for continuous growth rate monitoring for the harvested area in Kilosa project.

In that regard, this study aims to establish baseline data through assessment of regeneration and growth of trees in the pilot sustainable charcoal production. Specifically, the study seeks to assess (1) the standing structure in terms of species composition, species diversity, stocking, basal area and Volume (2) above-ground biomass and (3) the contribution of different regeneration mechanisms in the recovery of the Kilosa sustainable charcoal production blocks (KSCPB) in six years after harvesting. It is against this background that the area is selected for this study since it is the piloting area practicing sustainable charcoal production in Tanzania. This study is useful as it will provide the insight to improve the management of the forest and serve as a valuable reference to villages aiming to adopt the SFM practice in Tanzania.

4.2 Methodology

4.2.1 Study site

Kilosa district in Morogoro region, Tanzania covers a total of 12 394 square kilometers (Fig. 4.1) (Kajembe *et al.*, 2015). The area is elevated at 635 m above sea level receiving bimodal short and long rains from November to January and March to June respectively. The annual mean rainfall and temperature range from 800 mm to 1300 mm and 25 to 30^{o}C, respectively. Kilosa district extends between latitudes 5° 55’-7° 53’ S and longitudes 36° 30’-37° 30’ E. The ecosystem contains natural forests with the domination of miombo woodlands, common vegetation in countries within the miombo ecoregion (Chidumayo and Frost, 1996). The coverage of woodlands and forests in Kilosa district is about 40% of the total land area. Based on the remote sensing data of 2014 (Ishengoma *et al.*, 2016) the total forest area in Kilosa is 503 727 ha.

Specifically, the study was conducted in selected eight village land forest reserves within the district which included Dodoma Isanga, Ulaya Mbuyuni, Kigunga, Ihombwe, Msimba, Nyali, Kisanga and Ulaya Kibaoni. These forests are managed by the villagers under community-based forest management (CBFM) arrangements concurrently practicing the sustainable charcoal production. The villagers depend on smallholder agriculture as their primary economic activity, with other income obtained from the forest through charcoal and timber productions.

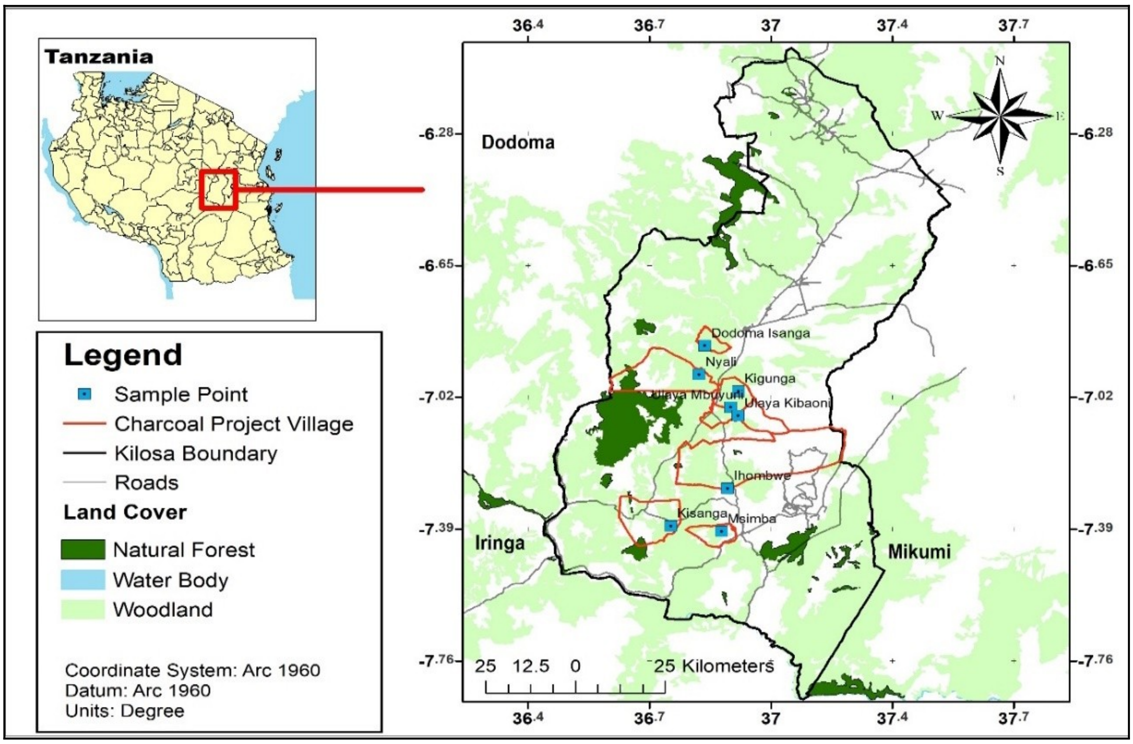


Figure 4.1: Map of the study sites showing the location of sustainable charcoal production areas and study villages, Kilosa district, Morogoro, Tanzania.

4.2.2 Data collection

The harvested blocks were visited for data collection between March and May 2019 and established a total of 106 circular plots within the selected villages. A total of 106 circular plot with a radius of 15 m (0.0707 ha) were assessed. The circular plots were opted due to the nature of the harvested blocks that had trees of more or less the same dimension dominated by trees of small diameter. In this case, if the concentric cycles were used, it would capture few trees in smaller radius cycle and with no or few trees in the larger one. This would affect the accuracy in determining the species composition. However, circular plots are convenient for rapid sampling with minimal plot layout as they have a single central marker and they minimize the number of edge decisions with their low perimeter to area ratio (Banda *et al.*, 2008).

The arrangement in the sustainable charcoal production area is comprised of alternate harvesting within a square block of 50 m (0.25 ha). This follows the harvesting calendar with a rotation of 24 years where one block is harvested next skipped forming a draft pattern (Fig. 4.2). The circular plot of 15 m radius was laid at the center of blocks harvested in 2013. This was to capture the information on the growth conditions on the area piloting the harvesting practice. Within the plot, tree species were identified and the diameter at breast height (DBH) and tree height were measured. Also, the form of regeneration for measured trees was identified (Appendix 2). It is known that post-harvest regeneration of miombo is based on seedling, coppices and root suckers (Chidumayo, 2013, 2019). Therefore, trees with stump sprout, root sprout and seed sprout origins were recorded accordingly. The identification of tree species relied on the knowledge of local botanist (species was identified in vernacular names based on tree observable features such as bark color, leaves and smell) then species checklist from NAFORMA (URT, 2010) was used for tree species scientific name identification. In addition, the elevation (m) and coordinates were recorded using GPS, slope (%) using Suunto clinometer, diameter tape for DBH measurements and Suunto hypsometer for measuring tree height within the plot.

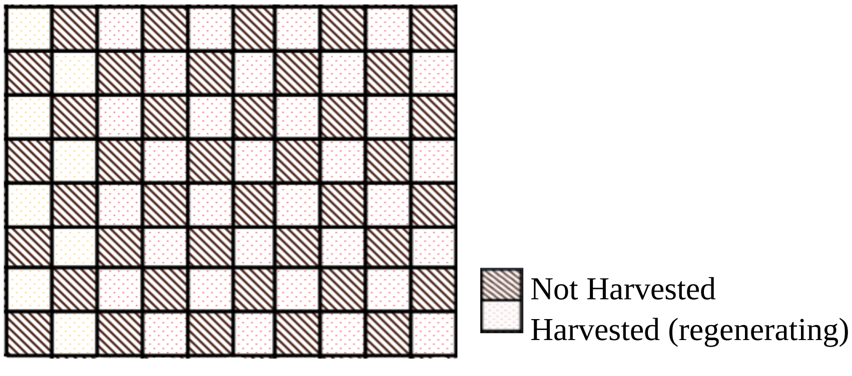


Figure 4.2: The typical model (calendar) for harvesting trees in the village engaged in sustainable charcoal production in Kilosa, Tanzania

4.2.5 Data analysis

The following variables were analyzed from the collected data; Species composition expressed through richness and diversity parameters; forest structure expressed through tree density, basal area, volume, above-ground biomass, diameter class distribution and form of regeneration. The analysis was done using R software (R Development Core Team 2013).

4.2.5.1 Diameter class distribution

The stand structure can be explained in various stand parameters and their distribution explaced through the diameter class (West, 2015). Data were grouped into five diameter classes with a class interval of 10 cm from the lowest measured diameter of 5 cm to which the number of trees in their respective diameter class was derived. The classes developed included 5-15, 16-25, 26-35, 36-45, and > 45.

4.2.5.2 Estimation of above-ground biomass and volume

Estimation of above-ground biomass and volume was done through the use of developed allometric models. The volume model (equation 1) by Mauya *et al.* (2014) and the above-ground biomass model (equation 2) by Mugasha *et al.* (2013) were selected. These equations were chosen as they were developed from a large sample size with sample distributed over a wide area and included a large number of tree species found in the miombo woodlands of mainland Tanzania.

$$V = 0.00016\, x\, (D^2\, x\, H)^{2.4630} \text{………. Equation 1}$$

$$B = 0.0763\, x\, D^{2.20468} H^{0.4918} \text{………. Equation 2}$$

Where; B, biomass (t); V, volume (m^3); D, diameter (cm) at 1.3 m (DBH, diameter at breast height) and H, total tree height (m).

Since the selected models required height and DBH as the estimator variables, the model ($Height = 1.3 + 24.3701 \times (1 - \exp(-0.0405 \times DBH^{0.8070}))$by Mugasha *et al.* (2019) was used to predict the heights of the unmeasured trees.

4.2.5.3 Species richness and diversity

Species richness was computed as the total number of tree species recorded in all plots within the respective village. Species diversity***;*** was determined using Shannon's Diversity Indices (Magurran, 2004). The Shannon Diversity Index was computed as $(H' = -\Sigma Pi * \ln Pi)$ where H' is the diversity index, Pi is a proportion of individual species to all species and ln is the natural logarithm.

4.3 Results

4.3.1 Species composition and diversity

A total of 2105 trees were measured within 106 plots distributed across eight village land forest reserves. About 66 tree species (within 16 families) were identified. Across all VLFRs *Diplorhynchus condylocarpon* (n = 399), *Brachystegia boehmii* (n = 230), *Brachystegia spiciformis* (n = 218) and *Pseudolachnostylis maprouneifolia* (n = 167) were the most common tree species. Among families recorded Fabaceae (21), was represented by the largest number of species followed by Combretaceae (6) and Phyllanthaceae (5), Leguminosae (3) while families Annonaceae, Apocynaceae, Bignoniaceae, Boraginaceae, Loranthaceae, Moraceae, Ochnaceae, Phyllanthaceae, Rubiaceae, Verbenaceae, Zygophyllaceae were each represented by single species (Appendix 4). The composition of tree species differed significantly (^{2} = 55.9, df = 7, $p < 0.05$, Kruskal-Wallis tests,) between the VLFRs under study. The most affluent forests had 32 tree species in Ulaya Kibaoni then 28 in Kisanga and Nyali VLFR while 21 tree species in Ihombwe and Kigunga (Table 4.1).

The harvested blocks had a mean Shannon-Wiener diversity index value of 2.54 ± 0.21 (Mean, M ± Standard deviation, SD). The highest and lowest Shannon indices were obtained in Nyali (2.8) and Dodoma Isanga (2.2), respectively (Table 4.1).

Table 4.1: **The species composition and diversity in the harvested blocks**

Village	Richness	Shannon (H')	Sample plots (n)
Dodoma Isanga	23	2.216	15
Ihombwe	21	2.521	15
Kigunga	21	2.307	10
Kisanga	28	2.688	15
Msimba	23	2.591	11
Nyali	28	2.797	15
Ulaya Kibaoni	32	2.744	15
Ulaya Mbuyuni	26	2.434	10
Mean	**25.25**	**2.54**	** Expression is faulty **

4.3.3 Stem density

The mean stem density of 286 ± 37 stems/ha (± standard error, SE) was recorded in the harvested blocks. The most abundant species were *D. condylocarpon* (19.02%), *B. boehmii* (10.96%), *B. spiciformis* (10.4%), *Combretum zeyheri* (8%). The remaining 62 tree species constituted 51%. The highest stand density (469 ± 97) was recorded in Kigunga village forest while the lowest (177 ±104) in Msimba village forests (Table 4.2). Generally, the stocking distribution by diameter classes displayed the typical reversed J shape (Fig. 4.3).

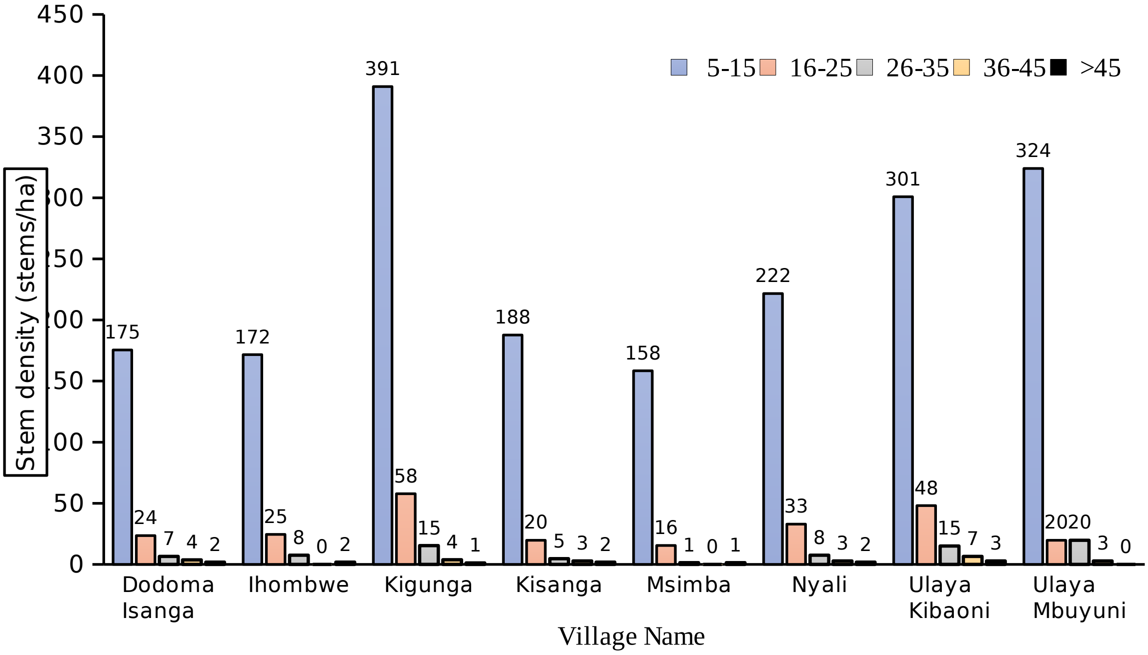


Figure 4.3: Distribution of stem density (stems per hectare) by diameter classes in the respective study villages, Kilosa Tanzania.

4.3.4 Basal area

For the all regenerating blocks in study villages, the mean basal area for trees (≥5 cm DBH) was 3.77 ± 1.27 m^2/ha (Table 4.2). The greater contributed species to the basal area were *B. boehmii* (17.6%), *D. condylocarpon* (11.9%) and *B. spiciformis* (10.8%). The highest basal area recorded in harvested blocks was 6.0 ± 1.75 m^2 ha^{-1} in harvested blocks present in Ulaya Kibaoni forests then Kigunga 5.90 ± 1.6 m^2 ha^{-1} while the least basal area 1.83 ± 0.92 m^2 ha^{-1} was recorded in Msimba (Table 4.2).

Table 4.2: The standing parameters (stem density, basal area and volume) and the above-ground biomass for regenerating blocks in study villages, Kilosa Tanzania

Villages	Stand density (stems/ ha)	Basal Area (m2/ha)	Volume (m3/ ha)	Above Ground Biomass (t)
Dodoma Isanga	211 ± 76	3.05 ± 0.93	28.8 ± 9.6	17.72 ± 0.19
Ihombwe	206 ± 56	2.59 ± .94	21.4 ± 9.4	14.53 ± 0.18
Kigunga	469 ± 97	5.90 ± 1.6	47.1 ± 16.3	31.83 ± 0.18
Kisanga	217 ± 73	2.9 ± 1.08	27.5 ± 15.3	18.71 ± 0.35
Msimba	177 ±104	1.83 ± 0.92	13.7 ± 7.9	9.22 ± 0.19
Nyali	267 ± 79	3.65 ± 1.01	30.5 ± 9.9	20.62 ± 0.18
Ulaya Kibaoni	373 ± 48	6.00 ± 1.75	52.7± 17.5	35.74 ± 0.22
Ulaya Mbuyuni	366 ± 108	4.28 ± 0.77	34.5 ± 8.05	23.33 ± 0.21
Mean	**286 ± 37**	**3.77 ± 1.27**	**31.71 ± 10.79**	**21.5 ± 7.24**

4.3.5 Volume and above-ground biomass

The weighted mean volume and above-ground biomass for harvested blocks were 31.71 ± 10.79 m^3/ha and 21.5 ± 7.24 t /ha, respectively. The highest volume and above-ground biomass observed were 52.7± 17.5 m^3/ha and 35.74 ± 0.22 t /ha in Ulaya Kibaoni while the lowest was 13.7 ± 7.9 m^3/ha and 9.22 ± 0.19 t /ha in Msimba, respectively (Table 4.2). The overall large volume and above-ground biomass contributing species included; *B. boehmii* (20.9%, of 31.71 m^3/ha and 21.5 t /ha, respectively), *B. spiciformis* (12.1%) and *D. condylocarpon* (9.4%).

4.3.4 Forms of regeneration

The regeneration form of each tree measured was recorded then categorized based on species (Appendix 4). About 68% of 2105 trees assessed in all study villages were established from the saplings or seedlings while, 18% and 13% sprouted vegetatively through the coppices and root suckers, respectively (Fig. 4.4). The one-way ANOVA was used to compare the contribution of each form of regeneration to the overall mean standing volume and above ground biomass. The regeneration from seedlings contributed significantly higher (p = 0.0048) compared to the contribution of coppice and root-suckers to the overall standing volume and above ground biomass in six years after harvesting for charcoal production.

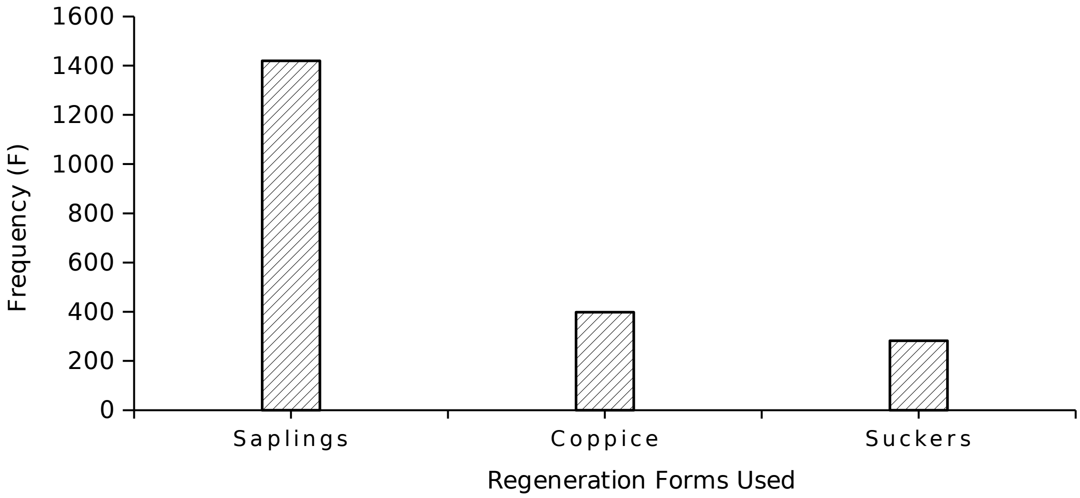


Figure 4.4: **The frequency (f) of trees regenerated through saplings, coppice and root suckers; observation from KSCPBs**

4.4 Discussion

This part discusses the analysis results obtained from data collected in 6 years regenerating blocks of harvested miombo woodlands for charcoal production in Kilosa District, Tanzania.

4.4.1 Composition, richness and diversity

Composition

The study reported the composition of trees that is dominated by species from the family Fabaceae (subfamily Caesalpinioideae), which lines with common descriptions of plant communities found in miombo woodlands (Banda *et al.,* 2008; Chidumayo and Frost, 1996; White, 1983). *B. boehmii* and *B. spiciformis* were dominant species within the family Fabaceae. This is similar to the reported domination of these species in other studies (Ishengoma *et al.*, 2016; Madoffe *et al.*, 2012; Mtimbanjayo and Sangeda, 2018) which cover the floristic composition of Kilosa district. Despite the domination of the Fabaceae family, one individual from the Apocynaceae family (*D. condylocarpon*) was the most frequently observed tree species (Appendix 4). This contrasts the commonly considered patterns for miombo woodlands that is dominated by either Brachystegia, Julbernadia or Isoberlinia. This can be explained by the preference of Brachystegia spp for charcoal production than *Diplorhynchus spp* (Malimbwi *et al.*, 1998; Sangeda and Maleko, 2018). In the study by Malimbwi *et al.* (1998), *D. condylocarpon* contributed about 0.26% of the tree volume stacked in the kiln while *B. boehmii* accounted for 2.33%. Assessment of stump by Sangeda and Maleko (2018) in blocks harvested for charcoal production in Kilosa district revealed about 36.3% and 20.8% of remaining stumps were *B. boehmii and B. spiciformis,* respectively while only 6.8% were from *D. condylocarpon.* The results suggest; the preference of species for harvesting in the natural forests affects the composition of subsequent trees generation.

Richness

The overall number of tree species recorded in regenerating blocks across all study villages was 66, which resembles well with reported composition of dry miombo species in other studies (Table 4.3). However, a slight difference between this study results and other studies exists due to spatial scale and coverage of other studies, sample size and microhabitat characteristics. For example, the higher number of species observed by Banda *et al.* (2008); Isango and Varmola (2007); Kashindye *et al.* (2013) is caused by multiple study sites reported with a combination of trees and shrubs species while this study only presents the tree species richness within few village forests in a single district. In addition, the large sample size of 133 plots by Banda *et al.*, 2008 has also caused the observed difference. According to Vazquez and Givnish (1998), the probability of capturing more species increases with sample size. In contrast, Mwakalukwa *et al.* (2014) and Shirima *et al.* (2011) obtained a large number of species despite the use of few plots which is linked to microhabitat characteristics as both studies have been conducted in Eastern arc mountain, the hotspot of various plant and animal species. Mligo (2018) recorded a large number of species (110) compared to the current study (66 species) which is caused by microhabitat heterogeneity as Mligo (2018) combined species from the coastal forest and dry woodland forests, however, unlike other studies, the current study presents the species richness of the blocks recovering from intensive harvesting for charcoal production.

Table 4.3: Comparison of recorded species richness from various studies in dry miombo woodlands

Number of plots	Plot size (ha)	Sampled area (ha)	Species richness	Source
133	0.071	9.44	229	Banda *et al.* (2008)
80	0.071	5.65	77	Kashindye *et al. (*2013)
40	0.04	1.60	81	Isango and Varmola (2007)
36	0.1	3.60	110	Mligo (2018)
35	0.071	2.47	88	Mwakalukwa *et al.* (2014a)
2	0.1	0.20	40	Shirima *et al.* (2011)
106	0.071	7.52	66	This study

Species Diversity

The harvested blocks had the mean Shannon-wiener value of 2.54 ± 0.21, which is considered as the moderate diverse. Normally, the Shannon diversity value ranges from 0 to 5 while in other cases it exceeds. Where the threshold H’ value of 2 has been documented as the minimum value for moderate to high diversity (Mwakalukwa *et al.*, 2014). Remarkably, the species diversity in harvested blocks was higher (H’= 2.54) compared that than in non-harvested blocks (H’ =1.87) reported by Sangeda and Maleko

(2018) in the same study villages using the same methodology of data collection. This reveals that tree harvesting stimulated the growth and regeneration of more species as it opens the canopy for light-demanding and suppressed seedlings to grow. Furthermore, post-harvesting regenerants are characterized by high growth rate, which is insinuated by reduced competition for sunlight with the old removed stand. In this regard, Coomes and Allen (2007) reported that shading from mature trees results in suppression of under canopy tree growth caused by obscured light penetration.

4.4.2 Volume and aboveground biomass in regenerating blocks

Volume

The standing volume for harvested blocks obtained was 31.71 ± 10.79 m^3/ha. The volume obtained was lower than in most of the reported values of dry miombo woodlands e.g. Katani *et al.* (2015) obtained 84.64, 81.68 and 81.65 m^3ha^{-1} in dry miombo of Nguja, Ngongowele and Mihumo VLFR, respectively. Mwampashi (2013) recorded 60.29 m^3ha^{-1} in Iwuma VLFR and 78.8 m^3/ha was recorded by Malimbwi *et al.* (2005) for miombo in Kitulangalo Forest Reserve. The explanation to the observed difference is the mentioned forests are composed of large number of mature trees compared to the current study which is composed of few large trees due to selective harvesting practiced in the area. However, the value obtained from this study compares well with the reported volume in degraded dry miombo woodlands by Sawe *et al.* (2014) who reported the volume of 32.6 ± 2.3 m^3/ha in the southern highlands of Tanzania.

Above-ground biomass

Likewise, the above-ground biomass of 21.5 ± 7.24t ha^{-1} obtained in harvested blocks was low compared to recorded values reviewed in documents covering the dry miombo woodlands. For example, 80t ha^{-1} and 44t ha^{-1} in old-growth miombo woodlands of

Chongwe Zambia (Chidumayo, 2014), 42.32t ha^{-1}, 42.6t ha^{-1} and 40.82t ha^{-1} obtained in Tanzania (Nguja, Ngongowele and Mihumo VLFRs, respectively) (Katani *et al.,* 2015). The higher values in these studies compared to the reported values in the current study is due to the difference in harvesting intensities. Harvesting in sustainable charcoal production areas can be considered as of high intensity despite being selective. This can be complemented by the quick drop in the number of trees as the diameter classes increase observed where very few trees with large diameters (DBH > 25cm) were recorded in this study. Conversely, the results lined to above-ground biomass of 21.7±1.6 t ha^{-1} obtained by Sawe *et al.* (2014) when assessing the degraded miombo woodlands of southern highlands Tanzania, also to 23 t ha^{-1} and 18t ha^{-1} obtained by Chidumayo (2014) when estimating changes in biomass following clear-cutting of miombo woodland in central Zambia.

4.4.3 Forms of regeneration

The total number of 2105 trees were assessed during data collection, and it was found that regeneration through seedlings was the dominant and default form of tree regeneration in the 6 years harvested blocks. About 68% of the assessed trees were established from the saplings or seedlings, 18% and 13% sprouted vegetatively through the coppices and root suckers respectively. The findings contrast the reported trend in the harvested miombo woodlands for charcoal production by Sangeda and Maleko (2018), that the coppicing regeneration is the dominant (58% of 954) form of regeneration, followed by the root suckers (36%). Thus, seedlings regeneration contributes less compared to the vegetative form of regeneration. The variation in the dominant regeneration form can be explained by the difference in the assessment period between the two studies. Contrasting to the 6 years regeneration monitored by the current study, Sangeda and Maleko (2018) reported the regeneration of trees within a short time of two years. The large contribution of the coppicing regeneration was linked to high coppicing effectiveness of the remaining stumps immediately after tree cut. However, the negative relationship between coppicing effectiveness and time has been reported in several studies (Lévesque *et al.*, 2011; Matowo *et al.*, Unpublished, Chapter 5). The decrease in the number of coppices with time can be caused by competition for the resources among the clumped coppices leading to natural thinning. Also, seasonal fire occurrences may kill both the sprouted coppices and the stumps which over time reduces the coppicing ability of the stand.

However, the domination of seedling regeneration observed in the current study lines with the findings by Chidumayo (2013) that reported the seedling regenerated trees dominated recovered miombo woodlands in the 22 years monitored landscape after degradation in Zambia. The domination of the seedling regenerated trees is linked to the known fact that sexual regeneration is the primary forest regeneration method (Deiller *et al.*, 2003). Harvesting of trees for charcoal improves light penetration to the ground. This stimulates the rapid growth of stunted seedlings/ saplings and seeds germination. According to Pausas and Keeley (2014), this harvesting confers a competitive advantage to seedlings by enabling them to capture the space previously occupied by matured trees. Furthermore, Ribeiro *et al.* (2017) reported that fire occurrences positively influences the regeneration through seedlings as it breaks seed dormancy.

The form of regeneration varies with species. Some of the observed trees species utilized only one method while other species utilized two to all forms of regeneration (Appendix 4). This is supported by Bognounou *et al.* (2010) who found trees within the same genera had different regeneration forms preferences when studying the regeneration of five Combretaceae species in Burkina Faso. Furthermore, this findings lines with existing cumulative literature evidence that miombo trees can recover from disturbance either through the coppice, root sucker and/ or seedlings (Chidumayo, 1992; Luoga *et al.,* 2004; Sangeda and Maleko, 2018).

Despite the results showing the domination of seedling regenerated trees in the area, vegetative propagation through coppices and root suckers should never be forgotten. The vegetative propagation is limited by the number of stumps harvested in the area. However, it offers rapid recovery of the harvested area as it utilizes the advantage of a well-established root system for rapid shoot growth. Furthermore, vegetatively grown trees show high-stress tolerance and can re-sprout whenever stroke by disturbance (Deiller *et al.,* 2003). As an advantage over seedling regeneration, seed offers one shoot per seed, while one to several coppices and root-suckers can be observed per stump which shows how efficient vegetative reproduction can be in recovering the harvested blocks.

4.5 Conclusion and Recommendations

4.5.1 Conclusions

The results for forest regeneration and growth in Kilosa sustainable charcoal production blocks demonstrated good tree growth conditions. Harvested sites were dominated with re-growing trees as about 90% of trees had DBH between 5 and 25cm with the mean DBH of 10.65cm. The weighted basal area, volume and above-ground biomass were 3.77 ± 1.27m^2ha^{-1}, 31.71 ± 10.79$m^3ha^{-1}$and 21.5 ± 7.24t ha^{-1} respectively which indicated that the stand was recovering from intense harvesting. The harvested blocks had moderate species diversity (H’ = 2.54). Also, it is concluded that seedling regeneration is the default form of regeneration for species in harvested miombo woodlands as seedling regenerated trees contribute more to the volume and above ground biomass of second-generation stand compared to vegetative forms of regeneration.

4.5.2 Recommendations

The following are recommended

i. Since the volume and above ground biomass was found to vary within the villages, follow up during harvesting is recommended to control the harvesting intensity. More intense harvesting may prolong the recovery of the stand.

ii. The harvesting intensity should be reduced to aid the fast recovery of the harvested blocks since small volume and above-ground biomass values were obtained.

iii. Further monitoring studies are recommended to establish the growth rate of the harvested blocks for charcoal production.

References

Agwanda, A. and Amani, H. (2014). Population growth, structure, and momentum in Tanzania. Dar es Salaam, Tanzania. [http://esrf.or.tz/docs/THDR-BP-7.pdf] site visited on 20/4/2019.

Bognounou, F., Tigabu, M., Savadogo, P., Thiombiano, A., Boussim, I. J., Oden, C. and Guinko, S. (2010). Regeneration of five Combretaceae species along a latitudinal gradient in Sahelo-Sudanian zone of Burkina Faso. *Annual Forest Science* 67(306): 1–10.

Chidumayo, E. N. (1992). Seedling ecology of two miombo woodland trees. *Vegetatio* 103(1): 51–58.

Chidumayo, E. N. (1993). Zambian charcoal production: Miombo woodland recovery. *Energy Policy* 21(5): 586–597.

Chidumayo, E. N. (2013). Forest degradation and recovery in a miombo woodland landscape in Zambia: 22 years of observations on permanent sample plots. *Forest Ecology and Management* 291: 154–161.

Chidumayo, E. N. (2014). Estimating tree biomass and changes in root biomass following clear-cutting of Brachystegia-Julbernardia (miombo) woodland in central Zambia. *Environmental Conservation* 41(1): 54–63.

Coomes, D. A. and Allen, R. B. (2007). Effects of size, competition and altitude on tree growth. *Journal of Ecology* 95(5): 1084–1097.

Deiller, A. F., Walter, J. M. N. and Trémolières, M. (2003). Regeneration strategies in a temperate hardwood floodplain forest of the Upper Rhine: Sexual versus vegetative reproduction of woody species. *Forest Ecology and Management* 180(3): 215–225.

Doggart, N. and Meshack, C. (2017). The marginalization of sustainable charcoal production in the policies of a modernizing african nation. *Frontiers in Environmental Science* 5: 1–13.

Ishengoma, R. C., Katani, J. Z., Abdallah, J. M. and Olomi, J. S. (2016). Kilosa District Harvesting Plan. [http://www.tfcg.org/wp-content/uploads/2018/05/Kilosa-District-Harvesting-Plan-2016-preapproval-version.pdf] site visited on 20/4/2019.

Kajembe, G. C., Silayo, D. S. A. and Vatn, A. (2015). *The Adaptation of REDD+ Initiatives in Forest Management Regimes I\in T\two Pilot Projects of Kondoa and Kilosa Districts, Tanzania. Noragric Report.* 75pp.

Katani, J. Z., Mustalahti, I., Mukama, K., and Zahabu, E. (2015). Participatory forest carbon assessment in south-eastern Tanzania: Experiences, costs and implications for REDD+ initiatives. *Oryx* 50(3): 523–532.

Kothari, C. R. (2004). Research Methodology: Methods and Techniques. [https://doi.org/10.1017/CBO9781107415324.004] site visited on 20/5/2019.

Luoga, E. J., Witkowski, E. T. F and Balkwill, K. (2004). Regeneration by coppicing (resprouting) of miombo (African savanna) trees in relation to land use. *Forest Ecology and Management* 189(3): 23–35.

Lupala, Z. J., Lusambo, L. P., Ngaga, Y. M. and Makatta, A. A. (2015). The land use and cover change in miombo woodlands under community-based forest management and its implication to climate change mitigation: A Case of Southern Highlands of Tanzania. *International Journal of Forestry Research* 2: 1 – 12.

Malimbwi, R., Zahabu, E., Monela, G. C., Misana, S., Jambiya, G. C. and Mchome, B. (2005). Charcoal potential of miombo woodlands at Kitulangalo, Tanzania. *Journal of Tropical Forest Science* 17(2): 197–210.

Malimbwi, R. and Zahabu, E. (2009). The analysis of sustainable charcoal production systems in Tanzania. *FAO: Criteria and Indicators for Sustainable Woodfuels* 229–261..

Malimbwi, R. E., Misana, S., Monela, G. C., Jambiya, G. and Zahabu, E. (1998). Impact of charcoal extraction to the forest resources of Tanzania: The case of Kitulangalo area, Tanzania. pp103-121.

Malimbwi, R. E., Solberg, B. and Luoga, E. (1994). Estimation of biomass and volume in miombo woodland. *Journal of Tropical Forest Science* I: 230–242.

Martin-Garca, J. and Javier, J. (2012). Sustainable forest management: An introduction and overview. In sustainable forest management - Current Research. [https://doi.org/10. 5772/45839] site visited on 10/5/2019.

Mataruse, L. R., Nyakudya, I. W., Jimu, L., Musemwa, L. and Chimweta, M. (2018). Smallholder farmers’ perceptions and constraints on the use of alternative energy sources to Miombo wood and energy-efficient barns. *Forests Trees and Livelihoods* 27(1): 43–53.

Matowo, G. S., Sangeda, A. Z. and Katani, J. Z. (2019). The regeneration dynamics of Miombo tree species in Sub-Saharan Africa. *African Journal of Ecology and Ecosystems* 6(5): 1–16.

Mauya, E. W., Mugasha, W. A., Zahabu, E., Bollandsås, O. M. and Eid, T. (2014). Models for estimation of tree volume in the miombo woodlands of Tanzania. *Southern Forests* 76(4): 209–219.

Mcroberts, R. E., Tomppo, E. O. and Czaplewski, R. L. (1992). Sampling Designs for National Forest Assessments. In: *Knowledge reference for national forest assessment.* pp. 1–19.

MNRT (2015). *National Forest Resources Monitoring and Assessment of Tanzania Mainland. Main Results Report.*124pp.

Mtimbanjayo, J. R. and Sangeda, A. Z. (2018). Effects of cattle grazing on miombo tree species regeneration and diversity in Central-Eastern Tanzania. *Journal of Environmental Researh* 2(13): 1–7.

Mugasha, W. A., Eid, T., Bollandsås, O. M., Malimbwi, R. E., Chamshama, S. A. O., Zahabu, E. and Katani, J. Z. (2013). Allometric models for prediction of above- and belowground biomass of trees in the miombo woodlands of Tanzania. *Forest Ecology and Management* 310: 87–101.

Mugasha, W. A., Mauya, E. W., Njana, A. M., Karlsson, K., Malimbwi, R. E., & Ernest, S. (2019). Height-diameter allometry for tree species in tanzania mainland. *International Journal of Forestry Research* 2019: 1-18

Mwakalukwa, E. E., Meilby, H. and Treue, T. (2014). Volume and aboveground biomass models for dry miombo Woodland in Tanzania. *International Journal of Forestry Research* 2014: 1–11.

Mwampamba, T. H. (2007). Has the woodfuel crisis returned? Urban charcoal consumption in Tanzania and its implications to present and future forest availability. *Energy Policy* 35(8): 4221–4234.

Mwampashi, Y. (2013). Woodland structure, basic density and above ground carbon stock estimations of wet miombo woodlands in Mbozi District Tanzania. dissertation for Award of MSc. Degree at Sokoine Universty of Agriculture, Morogoro, Tanzania. 88pp.

Pausas, J. G. and Keele, Y. J. E. (2014). Evolutionary ecology of resprouting and seeding in fire-prone ecosystems. *New Phytologist* 204: 55–65.

Sangeda, A. Z. and Maleko, D. D. (2018). Regeneration effectiveness post tree harvesting in natural miombo woodlands, Tanzania. *Journal of Plant Sciences and Agricultural Research* 2(10): 1–7.

Shirima, D. D., Munishi, P. K. T., Lewis, S. L., Neil D., B., Marshall, A. R. and Zahabu, Eliakim, M. (2011). Carbon storage, structure and composition of miombo woodlands in Tanzania's Eastern Arc Mountains. *African Journal of Ecology* 49(3): 332–342.

Vazquez, J. A. and Givnish, T. J. (1998). Altitudinal gradients in tropical forest composition, structure and diversity in the Sierra de Manantlan. *Journal of Ecology* 86(6): 999-1020.

West, P. W. (2015). *Tree and Forest Measurement.* (3rd Ed.), Springer International Publishing, Australia. 192pp.

CHAPTER FIVE

MANUSCRIPT FOUR

5.0 OPTIMUM STUMP HEIGHT AND DIAMETER FOR MIOMBO REGENERATION THROUGH COPPICING: A CASE OF KILOSA DISTRICT, TANZANIA

Matowo Godbless S[1], Sangeda Anthony Z[2] and Katani Josiah Z[1]

[1]Department of Forest Resources Assessment and Management, College of Forestry, Wildlife and Tourism, Sokoine University of Agriculture, P.O. Box 3013, Morogoro, Tanzania.

[2]Department of Animal, Aquaculture and Range Sciences, College of Agriculture, Sokoine University of Agriculture, P.O. Box 3004, Morogoro, Tanzania.

Abstract

Coppicing offers an important post-disturbance regeneration mechanism to miombo woodlands. However, little is known on the long-term dynamics of the coppice shoots in relation to the dimensions (height and diameter) of the remaining stump. Furthermore, the manipulation of the stump size has been ignored as a means to maximize the subsequent regeneration of miombo in harvested areas. This study presents the optimum stump height and diameter for the harvesting of miombo woodlands from data collected in the forests harvested for charcoal production. The total of 925 stumps, representing 43 species were measured in the area with 4 (2015-2019), 5 (2014 - 2019) and 6 (2013 - 2019) years from cessation of charcoal production. The stump height, stump diameter and the regenerants counts and size (basal diameter and height) were measured, alongside identifying species for the individual stump. The results show that number of living stumps decreased significantly ($p < 0.05$) with an increase in cessation time where 73, 68 and 51% of stumps were alive in the area terminated harvesting for 4, 5 and 6 years. There is a positive relationship between the stump mortality and the stump diameter while no clear pattern for stump height. The coppicing effectiveness of the stump increases with both diameter ($r^2 = 0.31$) and height ($r^2 = 0.18$). Harvesting stumps with a diameter at breast height range from 20 to 40 cm and height from 45 to 60 cm is recommended as optimum dimensions for effective regeneration and sustainable harvesting. It is also recommended that larger diameter trees should be selectively left as the seed trees during the harvesting to reduce the risk of increasing the number of stumps with no regeneration status.

Keywords: Stump height, stump diameter, coppicing, miombo, sustainable forest management

5.1 Introduction

Miombo tree species demonstrates the great resilience from disturbance once the above-ground biomass is removed. This is through sprouting from the roots (root suckers) and the remaining stumps (coppices) *(Luoga et al.,* 2004). This regenerative ability provides important functionality for the survival and existence of miombo trees amongst multi-disturbance imposed on them (Handavu *et al.,* 2011). Despite the ability of miombo to regenerate sexually and vegetatively, vegetative means offer a great deal of survival. These advantages include the fast growth rate of sprouts compared to the newly established seedlings (Grundy, 1995), vegetative propagation does not face challenges associated with seed predation, seed dispersal and seedling survival as encountered in the sexual regeneration. Furthermore, stumps and roots used for vegetative regeneration can re-sprout after being disturbed thus offering the prominent regeneration method after fire occurrence, timber harvesting, shifting cultivation, grazing and other forms of disturbances.

Survival of the cut stem and growth rate of the resulting sprouting shoots is influenced by several factors, including the tree size, stump height, and post-harvesting root/shoot ration, cutting season and cutting angle (Grundy, 1995; Kaschula *et al.,* 2005; Luoga *et al.,* 2002; M. Shackleton, 2001; Matilo *et al.,* 2017; Shackleton, 2000). Some of these factors can be manipulated by forest managers to maximize or suppress subsequent coppice regeneration and re-growth rates (Shackleton, 2000). For this reason, understanding these factors is crucial. Unfortunately, little attention has been given by forest managers for utilizing coppice regeneration as a means of managing miombo woodlands. Consequently, the execution of harvesting activities in miombo woodlands is done in the conventional way ignoring the maximization of regrowth from stump coppicing. Some researches (Kaschula *et al.,* 2005; Luoga *et al.,* 2004; Shackleton, 2001;

Matilo *et al.,* 2017; Sangeda and Maleko, 2018; Shackleton, 2000) reported the initial exploration of the relationship between the stump characteristics and number of shoots coppiced in miombo woodlands. However, sustainably managed stand should not only focus on the number but also growth of regenerated shoots. Some studies present results from shortly sprouted tree stumps while their survival may change with time.

This study determined the optimum stump diameter and height for harvesting in miombo woodlands aiming to maximize subsequent regeneration. These results will provide insight and guidance to policy and regulations related to the management of miombo woodlands.

5.2 Methodology

5.2.1 Study area description

The study site is located in Kilosa district, Morogoro region in Tanzania. The district covers a total of 12 394 square kilometers. The area is elevated at 635 m above sea level receiving bimodal rainfall. The annual mean rainfall and temperature range from 800 mm to 1300 mm and 25 to 30°C, respectively. Kilosa district extends between latitudes 5° 55’-7° 53’ S and longitudes 36° 30’-37° 30’ E. The area is dominated by miombo woodlands vegetation. The coverage of woodlands and forest is 503,727 ha equivalent to 40% of the total land area (Ishengoma *et al.,* 2016).

The study was conducted in selected eight Village Land Forest Reserves (VLFR) within the district with the production of charcoal. The villages with VLFR included Dodoma Isanga, Ulaya Mbuyuni, Kigunga, Ihombwe, Msimba, Nyali, Kisanga and Ulaya Kibaoni (Fig. 5.1). The VLFRs are managed by the villagers under a Community-Based Forest Management (CBFM) arrangement.

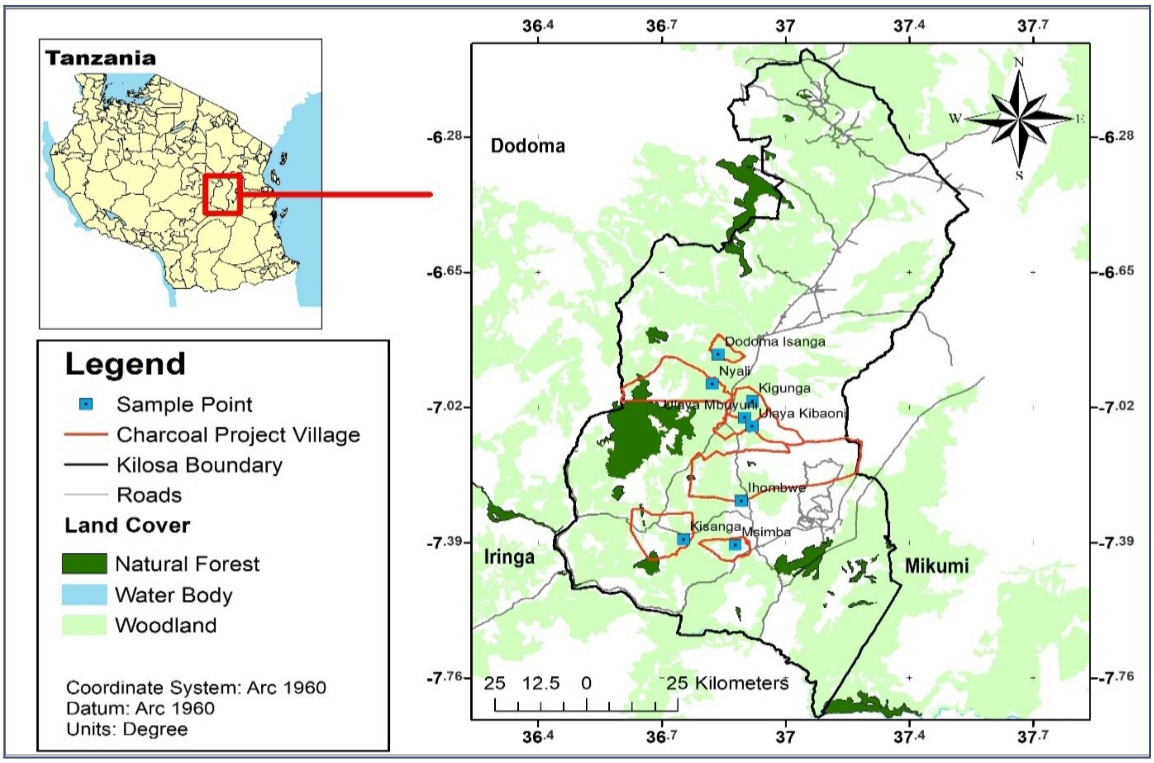


Figure 5.1: Map of the study sites showing the location of regenerating blocks and study villages, Kilosa district, Morogoro, Tanzania.

5.2.2 Data collection

Field data were collected between March and May 2019, using forty-two 50 m x 50 m plots. The cross-sectional research design combining qualitative and quantitative approaches was used to capture data from eight village land forest reserves in Kilosa district harvested for charcoal production. From each village, 6 plots were measured which is two plots per block harvested in 2015, 2014 and 2013 with 4, 5 and 6 years, respectively from harvesting to the assessment year in 2019. Since harvesting for charcoal is done in blocks of 50 x 50 m following the harvesting calendar (Fig. 5.2), the detection of time lapsed from tree cutting was enhanced.

In each plot, species for all tree stumps were identified, stump diameter and heights were measured. The measurement of stump diameter and height was done using the diameter tape and height rod, respectively where 15 cm was the minimum stump height measured.

The identification of stump species utilized leaves of coppices, wood and bark characteristics, and symmetry of the stump. The condition of the stump was recorded if living or dead. The dead stump included all stumps with no sign of tree regeneration such as rotten (heart rot), burned and dried. Stumps were considered as living if they had regenerated. In living stumps with coppiced shoots, number of coppices were counted for all individuals with diameter of less than 4 cm as adopted from Luoga *et al.* (2004) while for the individual with greater than 4 cm, the height and basal diameter (BD) of each coppiced shoot were measured. The minimum diameter of 4 cm was selected as most regenerating trees poorly resists to annual fires that occur in miombo woodlands, therefore, their survival is not assured (Luoga *et al.*, 2004).

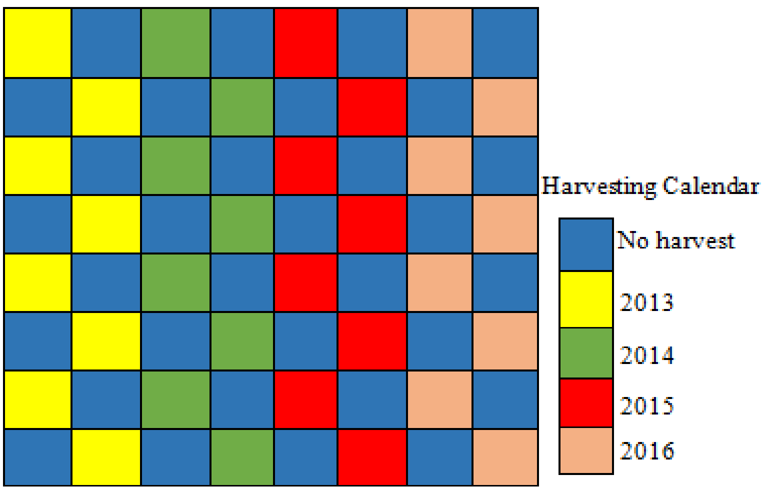


Figure 5.2: The harvesting calendar for charcoal production in Kilosa. The drafts present the ground square of the 50 m side, arranged in harvesting priority differentiated by colors.

5.2.3 Data analysis

To study the effects of stump size on the sprouting of miombo tree species, the height and diameter classes were developed for analysis purposes. Since, there was no uniform harvesting dimensions, eight (8) diameter classes with interval of 10 cm (<10, 11-20, 21-

30, 31-40, 41-50,51-60, 61-70 and >70 cm) and five (5) height classes with the interval of 15 cm from the minimum of 15 cm measured stump (15-30, 31-45, 46-60, 61-75 and >75 cm) were developed. A model by Luoga *et al.* (2002) was adopted to estimate the diameter at breast height (DBH) for the removed tree from the Basal diameter (Bd) (equation 1). The conversion of Bd to DBH was necessary to simplify the assessment for management purposes.

$$Dbh = 0.87 * BD - 1.003,\ r^2 = 0.98 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

The stump regeneration capacity across the height and diameter classes were computed as the percentage number of the assessed stump with living status and differentiated between the harvesting years and species. Coppicing effectiveness was calculated as the average number of coppice shoots per stump. The coppicing effectiveness of greater than one (> 1 Coppice/ stump) indicated the stump ability to produce multiple stems.

To examine the effect of predictor variables (stump diameter, stump height, time, species) on the dependent variable (number of coppice shoots and coppice effectiveness), data were subjected to a generalized linear model (GLM) under poison distribution. The non-parametric Kruskal-Wallis test with Tukey's HSD multiple comparison tests was used to compare the regeneration status (number of regenerants, number of living stumps and coppicing effectiveness) for stumps of different species, harvested in a different time and different harvesting dimensions. To realize the relationship between the stump height and stump diameter to the number of sprouts, simple and multiple linear regression (LR) analyses were performed with the coefficient of determination (r^2) presented. All analyses were done in R-software (R Core Team, 2013).

5.3 Results

5.3.1 Coppicing dynamics

The total of 925 stumps harvested in 2013, 2014 and 2015 with 6, 5 and 4 years, respectively from harvesting were assessed. The Kruskal-Wallis test results (F (2, 21) = 4.243, p = 0.0283) indicated the number of stumps regenerated differs significantly with age from harvesting. The percentage of stumps regenerated was decreasing with the increase of time from harvesting where, 73, 68 and 51% of stumps with 4, 5 and 6 years regenerated respectively (Table 5.1). The GLM revealed that the number of shoots per stump (coppicing effectiveness) differed significantly (F (2, 21) = 6.9; P = 0.03158) with time. Tukey's HSD multiple comparison tests showed the number of coppices was low and high for stumps with the age of six and four years since harvesting, respectively (Table 5.1). This suggests, number of sprouts per stump decreases as they grow

Table 5.1: The comparison of stump coppicing effectiveness with age in study villages, Kilosa district, Morogoro, Tanzania. (NOTE: * indicates statistically significant at P = 0.05)

Time since harvest (Years)	Living stumps (%)	Coppice effectiveness (±SD)	Comparison (Age)	P-value
4	73	5.5 ± 3.3	4 – 5	0.480554
5	68	3.4 ± 2.1	4 – 6	0.040346*
6	51	3.2 ± 1.6	5 – 6	0.334975

Although some of the species were represented by only few stumps, 93% of the 43 harvested species were found regenerating well in the harvested forest reserves. The Kruskal-Wallis Test showed that coppicing effectiveness differs significantly between species, χ^2 (39) = 44.587, p < 0.05. The highest and lowest number of coppices per stump was observed in *Sclerocarya birrea* and *Syzygium guineense*, respectively (Appendix 3). This indicates that coppicing characteristics differ with species. The regeneration characteristics of the harvested species with ≥ 10 assessed stumps are presented in Table 5.2.

Table 5.2: The regeneration performance of selected species from harvested miombo woodlands in the study villages of Kilosa Tanzania

Botanical Name	Coppiced stumps	No. of assessed Stumps	Percentage Coppiced	Coppicing effectiveness (±SD)
Combretum molle	18	19	94.74	3.8 ± 2.4
Combretum zeyheri	29	31	93.55	4.3 ± 2.1
Diospyros sp.	11	13	84.61	4.1 ± 1.5
Diplorynchus condylocarpon	18	22	81.81	4.5 ± 3.3
Muhanga	8	10	80.00	4.2 ± 2.2
Xeroderris stuhlmanii	12	15	80.00	5.6 ± 3.2
Pseudolachnostylis maprouneifolia	35	52	67.31	3.8 ± 2.2
Brachystegia boehmii	221	334	66.17	3.6 ± 2.6
Pericopsis sp.	9	14	64.28	2.8 ± 0.9
Brachystegia spiciformis	108	197	54.82	3.6 ± 2.5
Brachystegia longifolia	51	101	50.49	4.3 ± 3.1

5.3.2 Stump height and stump diameter

For determination of the optimum stump height and diameter for regeneration of miombo trees, data were subjected to linear regression. The present study revealed the weak but positive relationship (r^2 = 0.31), between the stump diameter and the number of coppices per stump (Fig. 5.3). This indicates that number of sprouts (coppices) increases with the stump diameter where stumps with large diameters than 60 cm exhibited better coppicing effectiveness than smaller diameter stumps (Table 5.3). It was also found that the stump mortality was positively correlated to stump diameter which suggests that, the probability of the harvested trees not to sprout (die) increases with stump diameter. This study reports more than 50% of the harvested trees with stump diameter greater than 60 cm were dead (Table 5.3).

Table 5.3: **The coppicing regeneration performance of harvested miombo trees across the stump diameter classes in study villages of Kilosa district, Tanzania**

SD* classes (cm)	Mean SD* ±SD (cm)	Total Number (living & Dead)	Living stumps	Living stump (%)	Stump mortality (%)	Number of coppices	Coppice effectiveness (±SD)
≤ 10	8.88 ± 1.59	85	61	71.76	28.24	182	2.9 ± 2.1
11 -20	16.11 ± 2.76	327	258	78.90	21.10	981	3.8 ± 2.8
21 - 30	26.03 ± 2.75	239	145	60.67	39.33	567	3.9 ± 2.5
31 - 40	35.25 ± 2.82	164	86	52.44	47.56	332	3.8 ± 2.5
41 - 50	45.05 ± 2.74	71	32	45.07	54.93	152	4.7 ± 2.6
51 - 60	54.61 ± 2.58	29	11	37.93	62.07	52	4.7 ± 3.5
61 - 70	65.99 ± 1.40	6	2	33.33	66.67	12	6.0 ± 2.8
≥ 70	76.39 ± 2.59	4	2	50.00	50.00	10	5.0 ± 4.2
Total	25.41 ± 12.5	925	597	64.54	35.46	2288	3.8 ± 3.68

Where SD* = Stump diameter, SD = Standard deviation

On other hand, there is a weak positive relationship between the coppicing effectiveness (r^2 = 0.18) and the stump height (Fig. 5.3). Also, there is no significant statistical difference (p = 0.046) in stump mortality across the stump diameter classes. However, the number of living stumps recorded across the height classes showed a bell-shaped distribution with number of living stumps increasing with an increase in stump height and start decreasing beyond 46 to 60 cm height class (Fig. 5.3). Consistently, the coppicing effectiveness (number of sprouts per stump) slightly increased with stump height which indicates the positive influence of stump height to the coppicing characteristics of the individual stump (Fig. 5.3). However, the difference between coppicing effectiveness across diameter class was not statistically significant (χ^2 (4) = 8.4596, p = 0.07612, Kruskal-Wallis test). Furthermore, adding the stump height and the interaction of stump height and stump diameter to the model slightly improved the relationship (r^2 = 0.34), of which both stump height and the interaction showed no significant contribution (p > 0.05) to the stump coppicing. These results indicated the presence of other factors (intermediate) that contributed to the observed coppicing effectiveness other than the diameter and height of the stump.

Table 5.4: The regeneration performance of the harvested miombo trees across different stump height classes in study villages of Kilosa district, Tanzania

SH classes (cm)	Mean SH ±SD (cm)	Total Number (living & Dead)	Living stumps	Living stump (%)	Stump mortality (%)	Number of coppices	Coppice effectivenes s ±SD
15 - 30	23.74 ± 4.33	57	31	54.39	45.61	108	3.4 ± 2.33
31 - 45	38.43 ± 4.14	198	130	65.66	34.34	463	3.5 ± 2.62
46 - 60	52.41 ± 4.18	315	210	66.67	33.33	816	3.9 ± 2.8
61 - 75	65.52 ± 3.96	203	126	62.07	37.93	517	4.1 ± 2.96
>75	90.09 ± 14.6	152	100	65.79	34.21	384	3.8 ± 2.27
Total	**56.3 ± 20.26**	**925**	**597**	**64.54**	**35.46**	**2288**	**3.8 ± 2.68**

Where SH = Stump height, SD = Standard deviation

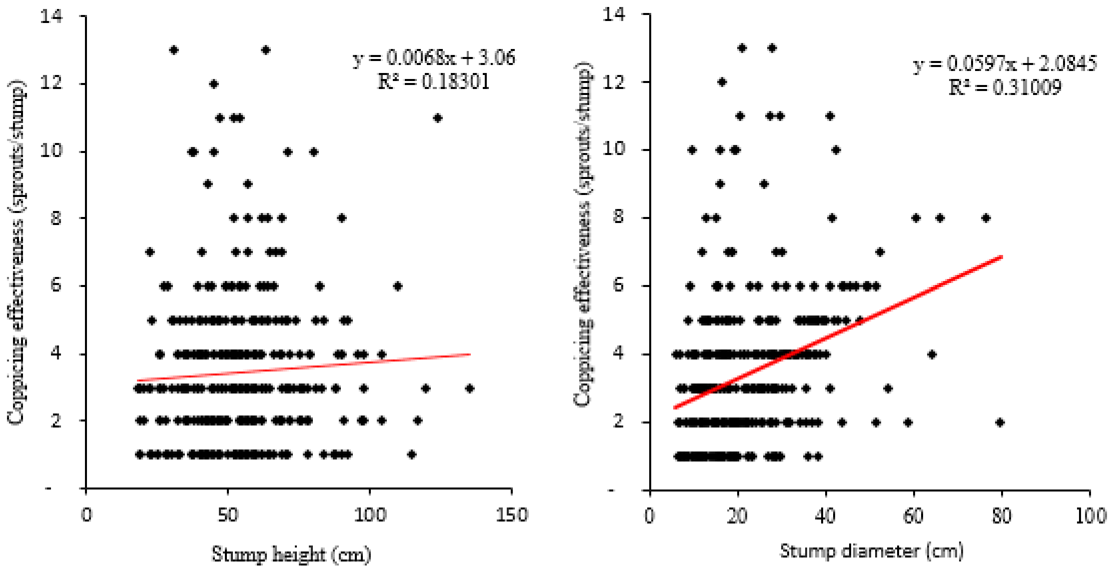


Figure 5.3: **Scatter plot showing the relation between (a) stump height (b) stump diameter and the coppicing effectiveness in study villages of Kilosa district, Tanzania**

5.4 Discussion

5.4.1 Coppicing dynamics

The current study reported the negative trend of decrease in number of living stumps with an increase of time elapsed from harvesting termination where 73, 68 and 51% of stumps were found living after 4, 5 and 6 years respectively. One of the explanations to this trend is the occurrence of annual wildfires which is the common phenomena in miombo woodlands. The wildfire burns the coppices and the remaining stumps. The wildfire normally occurs in the dry season where the stump moisture content is low which leads to effective burning of the remaining stump. In addition to wildfires, Grundy (1995) mentioned prolonged dry seasons and disturbances from grazing and browsing animals lowers the survival of sprouting shoots. A similar trend of decrease in the number of living stumps with an increase of time elapsed has been observed by Lévesque *et al.* (2011) when monitored stump coppices for 10 years in the tropical dry forest of Jamaica where about three stump species regenerated initially had all died after 10 years. Furthermore, Lowore (1999) reported the 25% decrease of stump survival within 4 years of assessment in miombo woodlands.

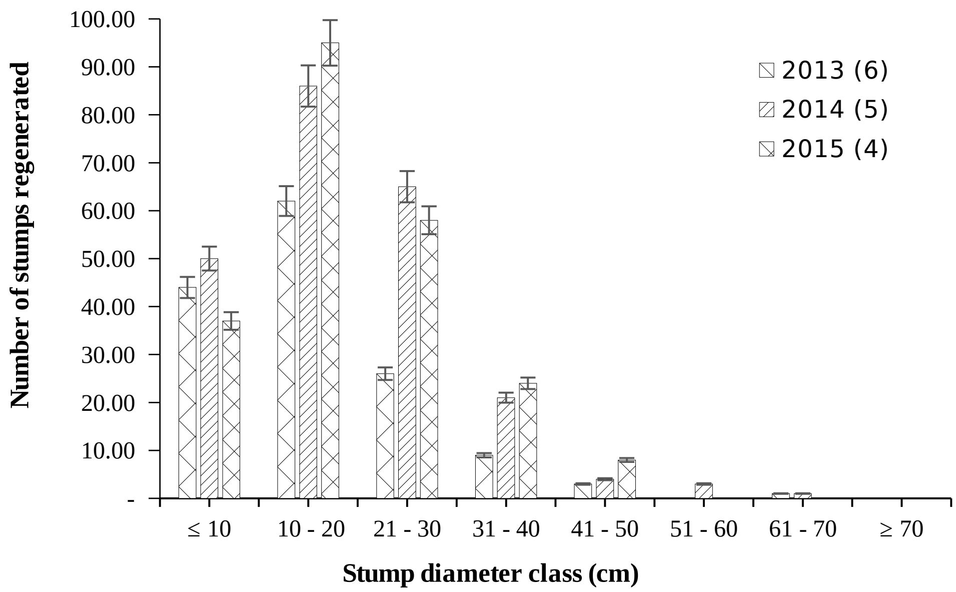
The coppicing effectiveness was also found to decrease significantly with increase in elapsed time. The highest and lowest mean coppice shoots per stump was recorded for 4 and 6 years harvested stumps, respectively. The highest mean coppicing effectiveness observed in this study is in lines with immediate assessment results of coppicing performance in miombo woodlands by Sangeda and Maleko (2018), Luoga *et al.* (2004) and Handavu *et al.* (2011) who presented the mean coppicing effectiveness of 6, 5.1 and 9.8, respectively. According to Lévesque *et al.* (2011), the inverse relationship between the coppicing effectiveness and time is explained by the tendency of stumps to produce the multiple shoots rapidly after tree harvesting. This is to maintain and restore the supply of carbohydrates used for root respiration and shoot production where the collectively large number of coppiced shoots gives the larger leaf area necessary to supply the food required by the roots. However, with time the leaf area per shoot increases. The increased capacity of the shoot to supply food and the intense resource competition among the clumped coppices leads to natural coppice shoots thinning. Other factors such as the management initiatives (Luoga *et al.*, 2004), species composition, soil characteristics (Grundy, 1995), harvesting timing, and topographical factors affects coppicing effectiveness.

5.4.2 The influence of stump diameter on coppicing

The results have shown a strong negative correlation (r^2 = -0.49) between the stump diameter and stump regeneration capacity. This was supported by the decrease in the percentage number of living stumps with the increase in stump diameter where more than 50% of the stump with a diameter greater than 50cm was found dead (Table 5.3). The observed trend can be explained by the fact that tree girth is positively related to the tree age while increase in age is negatively correlated to the coppicing vigor. Thus, as age increases the capability of the stump to rejuvenate vegetatively decreases (Luoga *et al.,* 2000; Ashish *et al.,* 2010). Therefore, harvesting larger diameter trees is associated with low stump regeneration possibilities. A similar trend of decrease in stump survival with stump diameter increase in miombo woodlands has been reported by Sangeda and Maleko, (2018) where greater than 70% of stumps with diameter greater than 45 cm were dead. Similar trend has been observed in subtropical vegetation by Khan and Tripathi (1989), Mishra *et al.* (2003), Tripathi and Khan (1986) and Ashish *et al.* (2010).

Contrasting to the negative trend observed in stump regeneration capacity, the stump coppicing effectiveness relates positively to the stump diameter. The increase in stump diameter is linked to the increased number of stump sprouts produced. This trend is associated with the positive relationship between the stem size and the below-ground biomass observed in miombo (Mugasha *et al.*, 2013). According to Ashish *et al.* (2010), the sprouting effectiveness of the stem cut depends on the amount of food accumulated in both the remaining stump and the below-ground roots. Therefore large-diameter stump is considered to have more food reserves and therefore bigger stumps have higher coppicing effectiveness compared to small diameter stumps. Lévesque *et al.* (2011) reported the coppicing effectiveness of 22 tree species harvested in dry tropical forest increased with the stump diameter which lines with the trend in the current study. Similar trend was reported by Shackleton (2000) where eight of twelve species studied had number of stump sprouts increased with the stump size while for the remaining four species, the increase in stump size either had no or negative effect to the number of the sprouts.

Figure 5.4: The influence of stump diameter on stump regeneration capacity



(percentage number of stumps regenerated) in study villages of Kilosa district, Tanzania

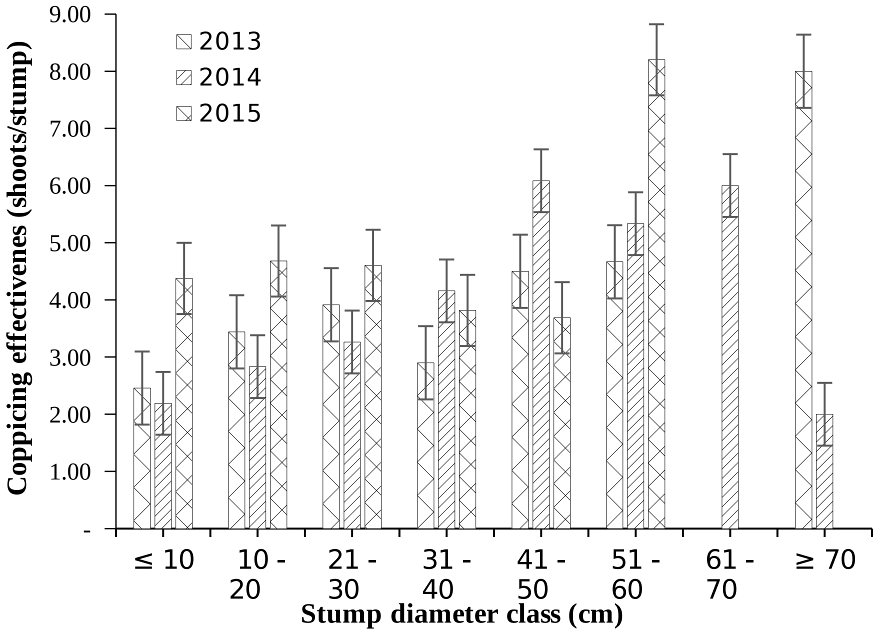


Figure 5.5: The influence of stump diameter on coppicing effectiveness (average number of sprouts per stump) in study villages of Kilosa district, Tanzania

Taking all together it is uncovered that increasing in the stump diameter is linked to an increase in coppicing effectiveness while decrease in the stump regeneration vigor leading to high mortality of harvested larger diameter stumps. However, when larger stumps regenerate, they are expected to have many shoots per stump than small diameter stumps. Taking the trend from Table 5.3, Fig. 5.4 and Fig 5.5, the sustainable harvest will rely on the basal diameter class of 21 to 30, 31 to 40 and 41 to 50 cm (equivalent to 20 and 40 cm DBH range). This range is slightly higher compared to the optimal range of 20 to 30 cm DBH proposed by Sangeda and Maleko (2018). Despite high stump sprouting, harvesting below the diameter (<20 cm) will be associated with low biomass production while above (>40 cm) will have high biomass produced and more risk of no regeneration hence affecting forest sustainability.

5.4.3 The influence of stump height on coppicing

The study results did not give a clear pattern on the relationship between the stump height and percentage stump survival. The stump mortality had no significant ($p > 0.5$) difference across stump height classes (Table 5.4). The bell-shaped distribution was recorded (Fig. 5.6) between the number of stumps regenerated and stump height classes with a peak between 46 and 60 cm height class. This showed the high survival possibilities of stumps with a height between 46 and 60 cm. Despite, the stump height being an important parameter for managing miombo for coppicing purpose, literature remains quiet on the optimum harvesting dimension for miombo trees. However, in other vegetations, a similar trend was observed. Tripathi and Khan (1986) reported less mortality for stumps of medium height classes (25-30 and 45-50 cm) in the subtropical forest. Likewise, Jobidon (1997) reported high stump regeneration for cutting height between 30 and 75 cm of two montane tree species in Canada.

Furthermore, the study reported the positive influence ($r^2 = 0.18$) of cutting height (stump height) on the coppicing effectiveness where the number of coppices per stump was found to increase with the stump height (Fig. 5.7). Similar trend has been documented by several researchers in miombo woodlands (Handavu *et al.,* 2011; Luoga *et al.,* 2000; Luoga *et al.,* 2004), savanna tree species (Kaschula *et al.,* 2005; Shackleton, 2000), subtropical forests (Tripathi and Khan, 1986) and temperate forests (Ashish *et al.,* 2010). The higher coppice effectiveness for longer stumps has been linked to the large surface area for coppice shoot placement it as compared to short stumps. Neke *et al.* (2006) found that short stumps influences the root sprouts (root suckers) while long stumps influences the stump coppicing.

The manipulation of cutting height is an easy and implementable management action with remarkable effects on coppice regeneration. However, Shackleton (2001) insisted on balancing the positive effects of increased stump height against the loss of useful woody biomass that is left behind as a stump. Therefore, considering the trend in Fig. 5.6 and Fig. 5.7, this study recommends the medium cutting height between 46 and 60 cm. This is in line with an optimum height of 50 cm used in harvesting trees for charcoal production in Jamaica (Lévesque *et al.*, 2011) and the medium range of 45 to 50 cm which provided higher survival for trees in the sub-tropical forest of India (Tripathi and Khan, 1986). Harvesting beyond the 60 cm will lead to higher coppicing effectiveness but with loss of the valuable wood biomass. However, leaving short stump will increase the amount of wood biomass while increasing the risk of unsuccessful regeneration.

Based on studies by Khan and Tripathi (1989) and Tripathi and Khan (1986) the maximization of regeneration through coppicing should base on the manipulation of the stump diameter, stump height, angle and season of tree cutting. Apart from the stump dimensions (stump height and diameter) discussed in this study, the consideration of harvesting angle and cutting season can also be done.

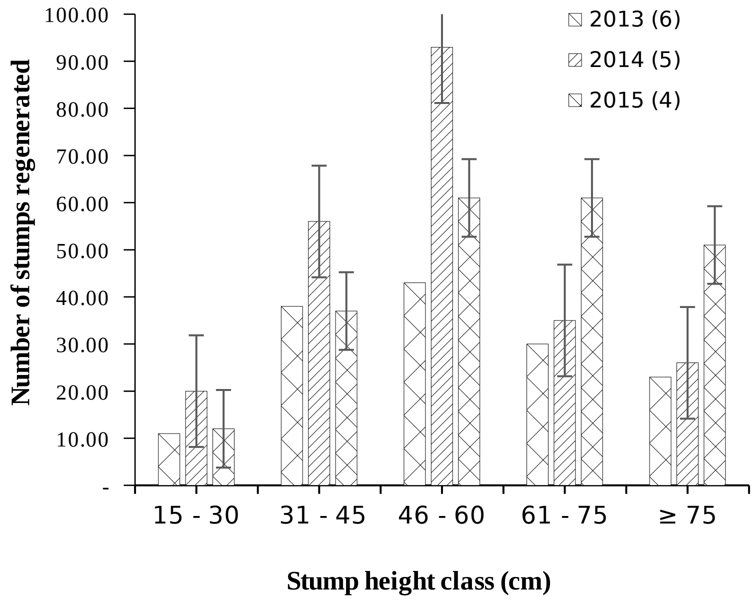


Figure 5.6: The influence of stump height on stump regeneration capacity (percentage number of stumps regenerated in study villages of Kilosa district, Tanzania

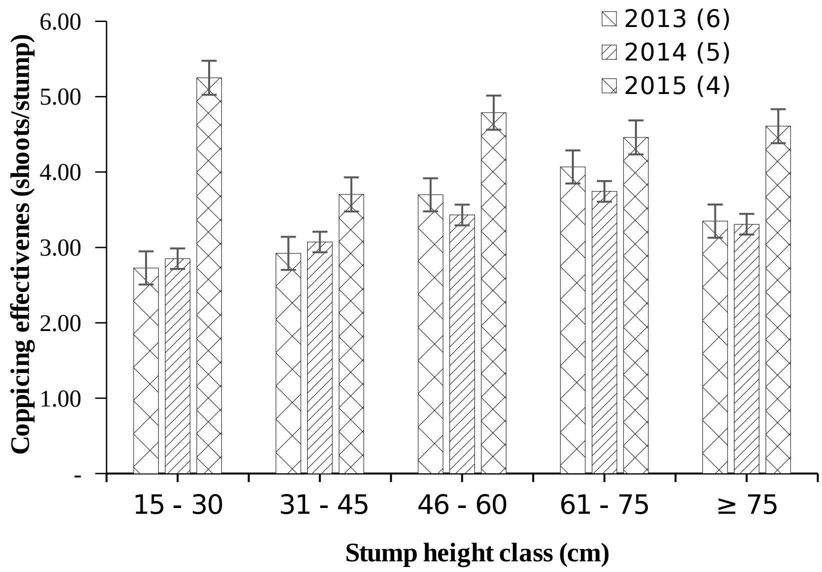


Figure 5.7: **The influence of stump height on stump coppicing effectiveness (average number of sprouts per stump) in study villages of Kilosa district, Tanzania**

5.5 Conclusion and Recommendations

The results from the present study revealed that maximization of the coppicing for miombo can be done by harvesting trees with a diameter at breast height (DBH) ranging between 20 and 40 cm while leaving the stump with height between 45 to 60 cm. Therefore, it is recommended that trees with larger diameters should be selectively left as source of seeds during harvesting for charcoal production to encourage seedling regeneration. Also, apart from the stump dimensions (stump height and diameter) discussed in this study, further studies on the influence of cutting angle and harvesting season on the regeneration of miombo trees in Tanzania is recommended.

Reference

Ashish, P., Latif, K. M. and Kumar, D. A. (2010). Effect of stump girth and height on resprouting of Rhododendron arboreum following disturbance in temperate mixed broad leaved forest of Arunachal Pradesh, India. *Journal of Forestry Research* 21(4): 433–438.

Chomba, C. (2018). Does the Cutting of Miombo Tree Species for Charcoal Production Directly Cause Deforestation? a Case Study of Kapiri Mposhi Area, Central Zambia. *Global Journal of Biology, Agriculture and Health Sciences* 7(1): 45–65.

Grundy, I. (1995). Regeneration and management of Brachystegia spiciformis Benth. and Julbernardia globiflora (Benth.) Troupin in Miombo woodland, Zimbabwe: towards a sustainable management strategy. A Thesis for Award Degree of Doctor of Philosophy at the University of Oxford. 167pp.

Handavu, F., Syampungani, S. and Chisanga, E. (2011). The influence of stump diameter and height on coppicing ability of selected key Miombo woodland tree species of Zambia: A guide for harvesting for charcoal production. *Journal of Ecology and the Natural Environment* 3(14): 461–468.

Ishengoma, R. C., Katani, J. Z., Abdallah, J. M. and Olomi, J. S. (2016). Kilosa District harvesting plan. [http://www.tfcg.org/wp-content/uploads/2018/05/Kilosa-District-Harvesting-Plan-2016-preapproval-version.pdf] site visited on 24/05/2019.

Jobidon, R. (1997). Stump height effects on sprouting of mountain maple, paper birch and pin cherry - 10 year results. *Forestry Chronicle* 73(5): 590–595.

Khan, M. L. and Tripathi, R. S. (1989). Effects of stump diameter, stump height and sprout density on the sprout growth of four tree species in burnt and unburnt forest plots. *Ecologia Applicata* 10(4): 303–316.

Kaschula, S. A., Twine, W. C. and Scholes, M. C. (2005). The effect of catena position and stump characteristics on the coppice response of three savannah fuelwood species. *Environmental Conservation* 32(1): 76–84.

Lévesque, M., McLaren, K. P. and McDonald, M. A. (2011). Coppice shoot dynamics in a tropical dry forest after human disturbance. *Journal of Tropical Ecology* 27(03): 259–268.

Lowore, J. D. (1999). Coppice regeneration in some miombo woodlands of Malawi. FRIM Report No.: 99001, 32.

Luoga, E J, Witkowski, E. T. F. and Balkwill, K. (2000). Economics of charcoal production in miombo woodlands of eastern Tanzania: Some hidden costs associated with commercialization of the resources. *Ecological Economics* 35(2): 243–257.

Luoga, E. J., Witkowski, E. T. F. and Balkwill, K. (2002). Harvested and standing wood stocks in protected and communal miombo woodlands of eastern Tanzania. *Forest Ecology and Management* 164(1–3): 15–30.

Luoga, E. J., Witkowski, E. T. F. and Balkwill, K. (2004). Regeneration by coppicing (resprouting) of miombo (African savanna) trees in relation to land use. *Forest Ecology and Management* 189(1–3): 23–35.

Matilo, T, B., Akouehou, G. S. and Sinsin, B. (2017). Stump diameter and height effects on early sprouting of three common firewood species used in the coastal zone of Benin in West Africa . *Science de La Vie, de La Terre et Agronomie* 05: 44–51.

Mishra, B. P., Tripathi, R. S., Tripathi, O. P. and Pandey, H. N. (2003). Effect of disturbance on the regeneration of four dominant and economically important woody species in a broadleaved subtropical humid forest of Meghalaya, northeast India. *Current Science* 84(11): 1449–1453.

Mugasha, W. A., Eid, T., Bollandsås, O. M., Malimbwi, R. E., Chamshama, S. A. O., Zahabu, E. and Katani, J. Z. (2013). Allometric models for prediction of above- and belowground biomass of trees in the miombo woodlands of Tanzania. *Forest Ecology and Management* 310: 87–101.

Neke, K. S., Owen-Smith, N. and Witkowski, E. T. F. (2006). Comparative resprouting response of Savanna woody plant species following harvesting: the value of persistence. *Forest Ecology and Management* 232(1–3): 114–123.

Sangeda, A. Z. and Maleko, D. D. (2018). Regeneration Effectiveness Post Tree Harvesting in Natural Miombo Woodlands, Tanzania. *Journal of Plant Sciences and Agricultural Research* 2(10): 1–7.

Shackleton, C. M. (2000). Stump size and the number of coppice shoots for selected savanna tree species. *South African Journal of Botany* 66(2): 124–127.

Shackleton, M. C. (2001). Managing regrowth of an indigenous savanna tree species (Terminalia sericea) for fuelwood: The influence of stump dimensions and post-harvest coppice pruning. *Biomass and Bioenergy* 20(4): 261–270.

Syampungani, S. (2009). Vegetation Change Analysis and Ecological Recovery of the Copperbelt Miombo Woodland of Zambia. Thesis for Afaward Degree of Doctor of Philosophy in Forest Ecology. University of Stellenbosch. 159pp.

Tripathi, M. L. and Khan, R. (1986). Tree regeneration in distributed sub-tropical wet hill forest of North-East India. Effect of Stump Diameter and Height on Sprouting of four tree species. *Forest Ecology and Management* 17: 199–209.

CHAPTER SIX

5.0 KEY CONTRIBUTIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter highlights the key contributions the present study has made to the body of existing knowledge. The chapter further presents the conclusions drawn from this study and highlights several recommendations.

5.2 Key Contributions of the Study

The present study has made several key contributions. In the first objective (Chapter two). The study has shown different disturbances to which miombo woodlands are subjected to and their respective feasible and best regeneration methods. In addition, the study has discussed the influence of different disturbances on the regeneration of miombo.

The second objective (Chapter three) has managed to confirm that trees can naturally regenerate through seedlings in the kiln scars. This makes the important observation in miombo woodlands as there are limited studies that report regeneration in the kiln scars. This result contrasts the previous reports in template regions and the existed norm that there is no regeneration in kiln scars.

The third objective (Chapter four) presents results from the monitored 6 years harvested blocks for charcoal production. The study has empirically shown the structure of the harvested miombo woodlands presenting; species composition, diversity, volume, the above ground biomass and the contribution of different forms of regeneration to the recovery of the harvested area. The study has clearly shown the above ground biomass values and reflected the harvesting intensity of the area.

The last objective (Chapter five) has presented the optimum stump dimensions (height and diameter) for maximum coppicing of miombo tree species. This study is useful to forestry practitioners, policymakers and researchers as it provides the insights necessary for designing the appropriate practice for harvesting in miombo woodlands. Additionally, the study provides empirical evidence which can be used as the reference to other villages willing to adopt the same forest management approach.

5.3 Conclusions

The main objective of this study was to assess the regeneration of miombo in the area piloting sustainable charcoal production in Tanzania. Therefore, the following conclusions have been drawn from study-specific objectives.

i. The vegetative propagation through stump coppices and root sucker is the most feasible and suitable regeneration method in management of forest harvested for charcoal production and forest recovering from other disturbances. The method offers robust regeneration due to the presence of well-established below ground rootstock.
ii. The kiln scars in miombo woodlands are not permanently deforested, however they are characterized by delayed regeneration. Thus, more time is required to witness tree regenerants as at least 3 years were observed for this study.
iii. Seedling regeneration is dominant as 68% of trees regenerated in the harvested blocks and 100% of trees regenerants in kiln scars originated from seedlings. However, coppicing regeneration is limited to the number of stumps present in the harvested area.

iv. Trees in the pilot charcoal production blocks were found to regenerate and grow relative well as the basal area, volume and above-ground biomass were 3.77 ± 1.27m^2ha^{-1}, 31.71 ± 10.79m^3 ha^{-1} and 21.5 ± 7.24t ha^{-1} respectively which lines with other reported growth value in miombo woodlands.

v. The coppicing effectiveness of the harvested stumps is influenced by stump height, stump diameter and the time lapsed from harvesting. Both stump height (r^2 = 0.18) and stump diameter (r^2 = 0.31) have positive influence on coppicing effectiveness while the increase in time from harvesting relate negatively with the coppicing effectiveness. Harvested large diameter stumps are associated with high mortality compared to low diameter stumps and the survival of middle height class is high compared to higher mortality of shorter and longer stumps.

5.4 Recommendations

Based on the results of this study, it is recommended that;

i. The minimum harvesting size should be modified to fasten the recovery of the harvested area.

ii. Harvested blocks should be protected from different anthropogenic activities including forest fire as most trees regenerates from seedlings which are highly sensitive to fire. This is to avoid prolonging the time required for regenerating the area.

iii. Timely monitoring researches is recommended since the survivor of tree seedlings in miombo woodlands is much affected by the fire and other anthropogenic activities.

iv. For sustainability of miombo regeneration, harvesting should base on trees with a diameter at breast height (DBH) ranging between 20 and 40 cm while leaving the stump with a height of 45 to 60 cm.

v. The larger diameter trees beyond the recommended range (> 60 cm) in the areas harvested for charcoal production, should be selectively left out as a source of seeds since they are characterized by high stump mortality.

vi. Further studies on the influence of cutting angle and harvesting season on the regeneration of miombo trees in Tanzania is recommended.

APPENDICES

Appendix 1: Field form for kiln scars data collection

Village__ __ ___ ___ ___ __ Altitude _ __ __ ___ __ ___ ____ Slope _ ___ ___ ___ __ _

Kiln Scar id __ __ __ __ __ __ Kiln Area/ Size __ __ __ __ __ (m^2) Harvested year __ __

Measurer ____ ___ ___ ___ __ __ ___ __ ___ ___ ____ Date ___ ___ ___ ___ ___ ___

Observation __ __ __ __ __ __ ___ __ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ _

Regeneration happened (1) Yes (2) No (_ _ _) Forms of regeneration (1) Coppice (2) Saplings (3) Suckers

Co-ordinates: Easting _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ Northing _ _ _ _ _ _ _ _ _ _ _ _ _ _

Other vegetation:

____

Number	**Species Name**	**Count of regenerants**	**Form of Regeneration**	**Remarks**
1				
2				
3				
4				
5				
6				
7				
8				
9				

Appendix 2: Field form for inventory data

Village__ __ ___ ____ __ __ ___ __ Altitude _ __ __ ___ __ ___ ____ Slope _ ___ ___

Plot id __ __ __ __ __ __ ___ __ __R-corrected __ __ __ __ __ ___Harvested year __ __

Measurer ____ ___ ___ ___ ____ ___ __ ___ ___ ____ Date ___ ___ ___ ___ ___ ___

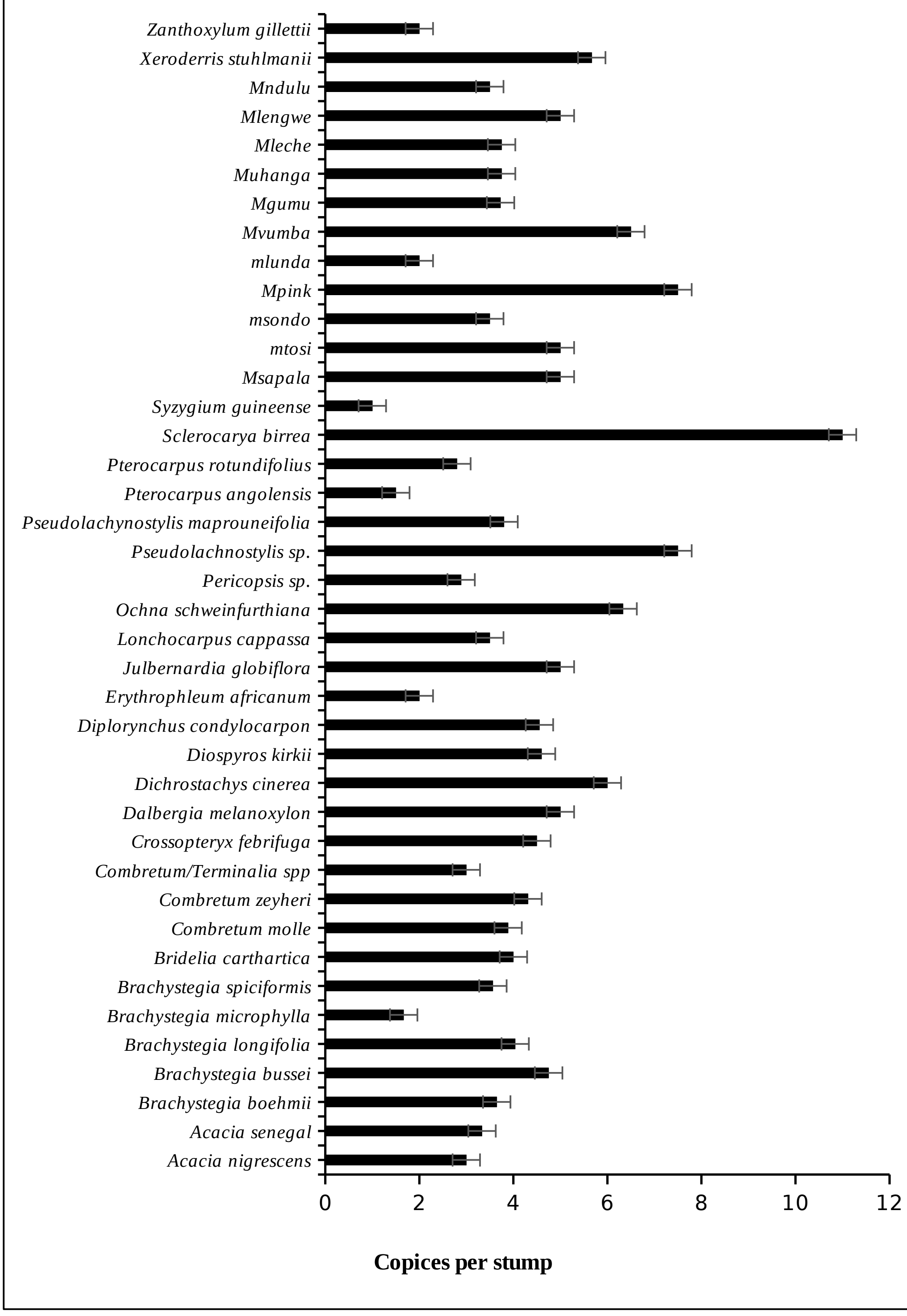
Observation __ __ __ __ __ __ ___ __ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ __

Forms of regeneration (1) Coppice (2) Saplings (3) Suckers

Co-ordinates: Easting _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ Northing _ _ _ _ _ _ _ _ _ _ _ _ _ _

Number	**Species name**	**Form of regeneration**	**DBH (cm)**	**H(m)**	**Remarks**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Appendix 3: The copping effectiveness of recorded trees species in the study sites



Appendix 4: List of tree species with their respective form of regeneration as recorded in Kilosa charcoal production areas

SN	Botanical Name	Local Name	Cop*	Sap*	Suc*	DI†	IH†	KG†	KS†	MS†	NY†	UK†	UM†	Frequency
1	*Brachystegia boehmii*	Myombo	X	X	X	X	X	X	X	X	X	X	X	8
2	*Combretum zeyheri*	Mlama mweupe	X	X	X	X	X	X	X	X	X	X	X	8
3	*Diplorhynchus condylocarpon*	Mtogo	X	X	X	X	X	X	X	X	X	X	X	8
4	*Pseudolachnostylis maprouneifolia*	Msolo	X	X	X	X	X	X	X	X	X	X	X	8
5	*Combretum molle*	Mlama mweusi	X	X	X		X	X	X	X	X	X	X	7
6	*Dalbergia melanoxylon*	Mpingo	X	X		X		X	X	X	X	X	X	7
7	*Xeroderris stuhlmanii*	Mnyenye	X	X	X	X	X	X	X		X	X	X	7
8	*Brachystegia longifolia*	Mtelela	X	X	X			X	X	X	X	X	X	6
9	*Brachystegia spiciformis*	Mhani/Mtondoro	X	X	X	X		X	X		X	X	X	6
10	*Crossopteryx febrifuga*	Mkombeziko	X	X	X		X	X		X	X	X	X	6
11	*Dichrostachys cinerea*	Mkulagembe		X			X	X	X		X	X	X	6
12	*Pterocarpus angolensis*	Mninga jike	X	X	X	X	X	X			X	X	X	6
13	Unknown2	Mvumba		X	X	X	X		X	X	X	X		6
14	*Acacia polyacantha*	Mtalula	X	X		X		X		X	X	X		5
15	*Bridelia carthartica*	Msinzila	X	X	X		X		X	X		X	X	5
16	*Terminalia spp.*	Mgumu	X	X	X		X		X	X	X	X		5
17	*Acacia senegal*	Mzasa		X	X		X		X			X	X	4
18	*Annona senegalensis*	Mtopetope	X	X	X	X			X	X	X			4
19	*Brachystegia bussei*	Mgelegele	X	X		X			X		X		X	4
20	*Brachystegia microphylla*	Msani	X	X			X	X	X		X			4
21	*Erythrophleum africanum*	Mkarati	X	X	X			X			X	X	X	4
22	*Margaritaria discoidea*	Msakulankw'ale		X	X	X	X	X			X			4
23	*Sorindeia madagascariensis*	Mpilipili	X	X	X	X	X		X		X			4
24	*Strychnos spinosa*	Mtongatonga	X	X					X		X	X	X	4
25	*Vangueria infausta*	Msada	X	X	X		X	X	X			X		4
26	*Acacia nigrescens*	Mkambaa		X			X	X				X		3
27	*Euclea divinorum*	Mdaa		X					X			X	X	3
28	Unknown12	Mbiobio		X		X			X				X	3
29	Unknown8	Mndulu		X				X	X			X		3
30	*Balanites aegyptiaca*	Mkonga		X			X						X	2
31	*Cola clavata*	Muungu		X		X				X				2
32	*Diospyros kirkii*	Mkoko/Mkulwi	X	X								X	X	2
33	*Grewia bicolor*	Mkole		X						X		X		2
34	*Markhamia spp*	Mtalawanda	X	X	X					X	X			2
35	*Pericopsis sp.*	Mmanga	X	X	X				X		X			2
36	*Pseudolachnostylis sp.*	mnepa	X	X						X		X		2

(Continue down)

SN	Botanical Name	Local Name	Cop*	Sap*	Suc*	DI†	IH†	KG†	KS†	MS†	NY†	UK†	UM†	Frequency
37	*Pterocarpus rotundifolius*	Mzeza	X	X	X	X							X	2
38	*Swartzia madagascariensis*	Mlingalinga		X				X				X		2
39	*Terminalia sambesiaca*	Mkurunge/ Mpululu		X	X	X							X	2
40	*Unknown16*	Mwembeti		X					X		X			2
41	*Unknown7*	Mlengwe		X					X	X				2
42	*Vitex doniana*	Mfulu		X	X			X			X			2
43	*Acacia robusta*	Mkongowe		X							X			1
44	*Bauhinia petersiana*	Msegese		X	X					X				1
45	*Ehretia amoeana*	Mkirika		X								X		1
46	*Ficus sycomorus*	Mkuyu		X					X					1
47	*Flueggea virosa*	Mkwambekwambe		X	X					X				1
48	*Julbernardia globiflora*	Mtondoro		X								X		1
49	*Lannea schweinfurthii*	Muumbu		X						X				1
50	*Lonchocarpus cappassa*	Mfumbili		X		X								1
51	*Lonchocarpus sp.*	mkunguga		X						X				1
52	*Ochna densicoma*	msekeseke		X		X								1
53	*Pericopsis angolensis*	Mwanga		X		X								1
54	*Pterocarpus sp.*	mninga sp.	X	X	X		X							1
55	Unknown1	Msapala		X									X	1
56	Unknown10	Msondo		X						X				1
57	Unknown13	Mvuma		X		X								1
58	Unknown14	Mkaku	X	X		X								1
59	Unknown15	Mfuvungu		X							X			1
60	Unknown18	Mngolangola		X									X	1
61	Unknown19	Mbwina		X									X	1
62	Unknown20	King'enge		X								X		1
63	Unknown21	Mkololo	X	X	X							X		1
64	Unknown22	Msechelele	X	X			X							1
65	Unknown24	Mhata		X					X					1
66	Unknown5	Muhanga		X								X		1
Species Richness		66				23	21	21	28	23	28	32	26	

Note:

*Cp, Sl and Rs meaning Coppicing, Seedlings/Saplings and Root suckers respectively.

DI†, IH†, KG†, KS†, UM†, UK†, NY† and MS† meaning Dodoma Isanga, Ihombwe, Kigunga, Kisanga, UlayaMbuyuni, Ulaya kIbaoni, Nyali and Msimba Village land Forests reserves, respectively.

Appendix 5: Allometric models from different authors used in this study and their scores for four criteria used to identify the most relevant model for estimating the above-ground biomass and volume for miombo trees in Kilosa, Morogoro region, Tanzania

SN	Source†	Equation	Source Country and region	Coverage/ Locality	Species	Sample size	No of variables	Total score
1	(Chidumayo, 2014) (n=101, Spp =19, DBH = 2-39)	$B=0.0446\,x\,D^{2.765}$	Zambia, Lusaka	1	0	1	0	2
2	(Malimbwi *et al.*, 1994) (n=17, Spp=17, DBH=>5)	$B=0.06\,x\,D^{2.012}\,x\,H^{0.71}$	Tanzania, Morogoro	1	0	0	1	3
3	(Chamshama *et al.*, 2004) (n=30, Spp=20, DBH=1-50)	$B=0.0625\,x\,D^{2.553}$	Tanzania, Morogoro	1	0	0	0	2
4	(Mugasha *et al.*, 2013) (n=167, Spp=60, DBH=1.1-110)	$B=0.0763\,x\,D^{2.20468}\,H^{0.4918}$	Tanzania, Manyara, Katavi,	2	2	1	1	6
5	(Mugasha *et al.*, 2013) (n=167, Spp=60, DBH=1.1-110)	$B=0.1027\,x\,D^{2.4798}$	Lindi and Tabora	2	2	1	0	5
6	(Mwakalukwa *et al.*, 2014b) (n=72, Spp=28, DBH=5-62)	$\ln(B)=0.123+0.057\times\ln(D)+0.115\times\ln(H$	Tanzania, Iringa	2	1	0	1	4
7	(Chamshama *et al.*, 2004) (n=30, Spp=20, DBH=1-50)	$\ln(V)=0.000048+1.445\,x\ln(D)+1.7026\,x\ln$	Tanzania, Morogoro	2	0	0	1	3
8	(Mwakalukwa *et al.*, 2014b) (n=72, Spp=28, DBH=5-62)	$\ln(V)=0.075+0.040\times\ln(D)+0.076\times\ln(H$	Tanzania, Iringa	2	1	0	1	4
9	(Malimbwi *et al.*, 1994) (n=17, Spp=17, DBH=>5)	$V=0.0001\,x\,D^{2.032}\,x\,H^{0.66}$	Tanzania, Morogoro	2	0	0	1	3
10	(Mauya *et al.*, 2014) (n=158, Spp=55, DBH=1.1-110)	$V=0.00016\,x\,(D^{2}\,x\,H)^{2.4630}$	Tanzania, Manyara, Katavi,	2	2	1	1	6
11	(Mauya *et al.*, 2014) (n=158, Spp=55, DBH=1.1-110)	$V=0.00016\,x\,D^{2.4630}$	Lindi and Tabora	2	2	1	0	5

Note:

Where; B, biomass (t); V, volume (m^3); D, diameter (cm) at 1.3 m (DBH, diameter at breast height); H, total tree height (m), *ρ*, wood density (g cm^{-3}),

†The range of diameter distribution, sample size and number of species in material basis for the formation of each model is specified.

Models was scored based on: **locality;** 1 if data was from countries within miombo ecoregion and 2 if within Tanzania. **Number of parameters included;** 0 for DBH, 1 for DBH and wood density (WD) or height (Ht), 2 for models including DBH, Ht and WD. **Sample size**, 0 for <100 trees, 1 for >100 trees but <1000 trees and 2 for >1000 trees. **Number of species included**; 0 for <20 species, 1 for >20 trees but <50 and 2 for >50 tree species.