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# Above-ground carbon stock in a forest subjected to decadal frequent fires in western Tanzania

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**Abstract**

Gradual increase in atmospheric temperature due to elevated levels of greenhouse gases has become a global agenda. Of these gases, carbon dioxide is the most predominant accounting for more than half of the atmospheric warming. Conveniently, forests and woodlands are important sinks of carbon through sequestration which involves carbon dioxide capture and storage. Miombo woodlands are the most widespread savanna vegetation in the Sub-Saharan Africa, and like other vegetation they are likely to have a marked degree of carbon sequestration. However, these ecosystems are normally threatened by many disturbances, including outbreaks of uncontrolled and destructive fires. Yet, it has been reported that wildfires have both positive and negative influence on carbon sequestration in forests and woodlands. The aim of the present study was to determine tree carbon in Ilunde forest after consecutive exposure to frequent fires for 10 years. A fire suppressed forest of Kitwe was used as a control. Fire frequency of Ilunde forest was obtained from published Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery from the year 2001 to 2012. Tree carbon stock was estimated using biomass allometric models so far developed for miombo woodlands.The level of difference in carbon density between the two forests was determined using t-test. Tree carbon stock was significantly high in Kitwe forest than in Ilunde ($P < 0.05$). The effects of wildfires are variable depending on the nature of ecosystems and the existing circumstances. Since fire is crucial in miombo woodlands, then prescribed burning could be prioritized to sustain sinks of carbon.

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## Introduction

The western part of Tanzania is dominated by miombo woodlands. Miombo is a word which is used by ecologists to describe woodland ecosystems dominated by trees of the genera *Brachystegia*, *Julbernadia* and *Isoberlinia* of the family Leguminosae, subfamily Caesalpinioideae (Desanker *et al*., 1995). Like other vegetation, miombo woodlands are very useful in environmental conservation specifically carbon sequestration (Ministry of Natural Resources and Tourism (MNRT), 1989). Carbon sequestration is the process of removing carbon from the atmosphere and depositing it in a reservoir such woodlands and forests, and soils (Magdoff *et al*., 1996). Miombo woodlands have carbon densities ranging between 15 and 100 t C $ha^{-1}$ in woody biomass (Frost, 1996). In Mozambique, Grace *et al*. (2007) reported carbon storage of 26 t $ha^{-1}$ in standing biomass of miombo woodlands. The Eastern Arc miombo woodlands of Tanzania have been reported to have carbon storage potential between 25 and 80 t C $ha^{-1}$ (Shirima, 2009). Furthermore, Munishi *et al*. (2010) reported carbon stock averaging 19.2 t C $ha^{-1}$ in miombo woodlands of the southern highlands of Mbeya Region.

Despite the usefulness of miombo woodlands, their survival is mainly threatened by disturbances such as fire, deforestation, charcoal extraction and agriculture (Chidumayo and Gumbo, 2010). Of these factors, fire is the major determinant of carbon stock (Chidumayo, 2002). Fire frequency is the component of fire regime which influences many ecological processes (Sugihara *et al*., 2006). Miombo woodlands account for more than half of the global area burned annually (Mouillot and Field, 2005) with a frequency of 2 to 4 years (Mouillot *et al*., 2005). This burning leads to more release of carbon into the atmosphere than the amount used by vegetation during photosynthesis (Brown, 2002). For example, wildfires emit 2–3 Petagram (Pg) (1 Pg = 984206527.6111 tonne) of carbon dioxide to the atmosphere from 3–4 million $km^2$ of the globe each year (Giglio *et al*., 2006).

Basically the western part of Tanzania is among the highly ranked national-wise in terms of high fire frequencies in the period between 2000 and 2010 (National Aeronautics and Space Administration (NASA), 2010). Yet, varied findings on how fires influence carbon stock in forests and woodlands have been reported.

In the United States of America, a study conducted on oaks of the Black Rock Forest showed that more carbon was stored in unburnt plots than in burned plots (Peñafort, 2001). In miombo woodland of Mozambique and Zimbabwe 2 Mg of C $ha^{-1}$ were reported in woody plants that were subjected to high fire intensity, while under low fire intensity the stock of carbon was 65 Mg $ha^{-1}$ (Ryan and Williams, 2011). Furthermore, in Indonesia biomass loss of 14, 889,411.07 tonnes by wildfires emitted 7,150,234.98 megagram (Mg) of carbon (Murdiyarso *et al*., 2002). On the other hand, in Australia intense frequent fires increased carbon storage in forest plantations through enhancement of regeneration by sprouting, seeding and prevention of competition with the ground flora (Forestry Tasmania, 2010). Also, forest fires are known to increase soil nitrogen, microbial biomass and temperature thereby promoting the growth of plants (Kimmins, 1996; DeLuca and Zouhar, 2000). Some miombo species are well adapted to frequent fires, hence likely to have enhanced carbon sequestration.

This is because some plant species in miombo woodlands have protected meristems, below-ground reproductive organs and seeds that can survive fire in which heat/or smoke triggers maturation and germination by breaking the hard-seed coat dormancy (Bond and Midgley, 2003). Despite these findings, there is limited information on the impacts of frequent disturbances from annual bushfires which is needed to develop relevant management actions (Williams *et al*., 2008). It follows therefore that the aim of the present study was to determine tree carbon in Ilunde forest after consecutive exposure to frequent fires for 10 years.

## Material and methods

*The Study area*

The present study was confined to frequently burnt miombo woodland of Ilunde, which is located between latitudes 5° 00 and 6° 00 S, and longitudes 30° 00 and 31° 00 E. On the other hand, fire suppressed miombo woodland of Kitwe located between latitudes 4° 54' and 4° 55' S, and longitudes 29° 36' and 29° 37' E was used as a control (Figures 1 and 2). Kitwe forest has been protected from fires by the collaborative initiatives of the United Republic of Tanzania (URT), Hardwood Forest Fund and United States Agency for International Development (USAID) for about ten years ago.

*Sampling of trees*

In each of the two forests namely; Ilunde and Kitwe, 30 circular concentric plots were established. Systematic random sampling was used and this was to ensure that the population is evenly sampled. The sampling intensities for Ilunde and Kitwe forests were 0.03% and 2.4%, respectively. Financial status, time limitation and purpose of the forest inventory may necessitate the sampling intensity to be as low as 0.01% (Malimbwi and Mugasha, 2002; Malimbwi *et al*., 2005). In each forest, the distance between the concentric plots was 100 m. Radius with 15 m was used to sample trees with DBH ≥ 20cm, radius with 10 m was used to sample trees with DBH ≥ 10 cm but less than 20 cm and radius with 5 m was used to sample trees with DBH ≥ 5 cm but less than 10 cm (Vesa *et al*., 2010).

In the present study, a tree is defined as a woody species with diameter at breast height (DBH) of ≥ 5 cm as adopted from studies that were carried out in miombo woodlands of the Eastern Arc Mountains by Chamshama *et al.* (2004); Zahabu (2008), and in Mozambique by Ryan and Williams (2011). DBH of trees were measured using diameter calipers.

*Estimation of carbon stock*

The above-ground biomass of all live trees was calculated from the following biomass allometric model developed for plant species in miombo woodlands:

$\ln W = -1.002937 + 1.382159 \times \ln DBH + 0.640364 \times \ln H$ (Stromgaard, 1986)

Where:

Ln = natural logarithm

W = biomass (kg/tree)

DBH = diameter at breast height (m)

H = total tree height (m)

The model was chosen because it was developed to be used in the Zambezian miombo woodlands within the DBH range of 5 cm and above. (http://en.wikipedia.org/wiki/Central_Zambezian_Miombo_woodlands).

Tree biomass was assumed to be 50% carbon (Munishi and Shear, 2004), which was estimated as carbon sequestered in tonnes/hectare.

*Fire frequency in Ilunde forest*

Wildfire frequencies accumulated for about ten years in Ilunde forest are presented in Figure 3. The average number of wildfires per annum was 35 (Mganga and Lyaruu, 2016).

*Statistical analysis*

The effect of fire frequency carbon sequestration was assessed by comparing the stock of tree carbon in the two forests using paired t-test (Motulsky, 1998), as recommended by Pardini *et al.* (2004); Zhao *et al.* (2012).

## Results and discussion

In the present study, the mean tree carbon stock of 6.06 ± 0.42 t ha$^{-}$ and 14.08 ± 0.99 t ha$^{-}$ was recorded in Ilunde and Kitwe forests respectively (Figure 4). Tree carbon stock was significantly higher in the control (Kitwe) than in Ilunde forest ($P < 0.05$, $t = 10.3$, $DF = 102$). Enormous biomass in Kitwe forest possibly resulted from enhanced sprouting of saplings into trees after fire suppression. According to Knox and Clarke (2005), some resprouting species store extra energy in their roots to aid recovery and re-growths after disturbance. However, in the present study the values of forest carbon are lower than that have been reported in other miombo woodlands, for example, by Grace *et al.* (2007), Shirima (2009) and Munishi *et al.* (2010).

The difference in the stock of forest carbon could be attributed to high degree of disturbance particularly wildfires and illegal tree cutting in the study area. Also, it is likely that only little time had passed since fire suppression in Kitwe forest to allow massive woody carbon accumulation. According to Kalaba (2012), twenty years or more are required for disturbed miombo woodlands to fully recover and accumulate carbon in exact the same way as mature and/or undisturbed woodlands when other factors remain constant. Conversely, the values of forest carbon that were recorded in the present study are higher than that was recorded by Malimbwi *et al*. (1994).

**Appendix 1.** Tree DBH and Total Height in Ilunde Forest.

| Species | Average DBH (cm) | Average total height (m) |
|---|---|---|
| *Stereospermum kunthianum* | 8.22 | 4.7 |
| *Burkea africana* | 9.24 | 4.8 |
| *Julbernadia globiflora* | 8.70 | 4.6 |
| *Markhamia obtusifolia* | 12.21 | 5.8 |
| *Combretum adenogonum* | 6.05 | 3.5 |
| *Terminalia kaiserana* | 5.89 | 3 |
| *Swartzia madagascariensis* | 15.02 | 8 |
| *Chrysophyllum bangweolense* | 11.10 | 6.3 |
| *Annona senegalensis* | 8.44 | 3.9 |
| *Hexalobus monopetalus* | 6.21 | 3.6 |
| *Pterocarpus angolensis* | 21.91 | 10.5 |
| *Brachystegia boehmii* | 9.50 | 4.7 |
| *Flueggea virosa* | 8.04 | 4 |
| *Combretum collinum* | 10.06 | 5.1 |
| *Celtis philipensis* | 8.60 | 8.2 |
| *Pterocarpus tinctorius* | 15.58 | 8.4 |
| *Diplorhynchus condylocarpon* | 9.81 | 4.8 |
| *Hymenocardia acida* | 8.68 | 4.6 |
| *Pseudolachnostylis maprouneifolia* | 9.78 | 5 |
| *Maprounea africana* | 6.98 | 3.6 |
| *Pericopsis angolensis* | 33.05 | 10.5 |
| *Strychnos pungens* | 11.89 | 5.2 |
| *Strychnos cocculoides* | 10.88 | 5.9 |
| *Monotes africanus* | 11.39 | 5.1 |
| *Brachystegia spiciformis* | 11.70 | 6 |
| *Combretum molle* | 15.54 | 6.8 |
| *Multidentia crassa* | 12.44 | 5.9 |
| *Margaritaria discoidea* | 13.95 | 6.7 |
| *Strychnos madagascariensis* | 14.09 | 6.5 |
| *Securidaca longipedunculata* | 11.78 | 6.7 |
| *Dalbergia nitidula* | 10.51 | 3.9 |
| *Vitex mombassae* | 12.74 | 6.9 |
| *Ochna mossambicensis* | 12.02 | 5 |
| *Combretum pisonioides* | 17.98 | 7.2 |
| *Lonchocarpus bussei* | 11.21 | 5 |
| *Boscia salicifolia* | 23.81 | 10.6 |
| *Tamarindus indica* | 33.12 | 12.5 |
| *Strychnos potatorum* | 25.80 | 7.3 |
| *Albizia harveyi* | 26.11 | 8.5 |

Besides, some studies have reported on the presence of dominant tree species of old-growth on young generation in less than 10 years-old following disturbance (Kappelle *et al*., 1996; Syampungani, 2009). Then old-growths in a fire suppressed forest of Kitwe (the control) may have significant contribution on the stock of forest carbon as opposed to what was happening in Ilunde forest where there were frequent fires.

**Appendix 2.** Tree DBH and Total Height in Kitwe Forest.

| Species | Average DBH (cm) | Average total height (m) |
|---|---|---|
| *Julbernadia globiflora* | 11.14 | 9.8 |
| *Burkea africana* | 16.23 | 11.5 |
| *Ficus sycomorus* | 6.05 | 9.3 |
| *Zanha africana* | 6.05 | 8 |
| *Swartzia madagascariensis* | 6.85 | 9.5 |
| *Lannea schimperi* | 9.42 | 8.5 |
| *Annona senegalensis* | 7.56 | 7.6 |
| *Parinari curatellifolia* | 16.08 | 12.1 |
| *Strychnos innocua* | 8.44 | 6.9 |
| *Celtis philipensis* | 21.02 | 13.8 |
| *Stereospermum kunthianum* | 8.49 | 7.8 |
| *Psorospermurm febrifuga* | 9.24 | 6.5 |
| *Chrysophyllum bangweolense* | 7.93 | 6.4 |
| *Flueggea virosa* | 5.10 | 4 |
| *Brachystegia spiciformis* | 14.75 | 11.8 |
| *Markhamia lutea* | 6.85 | 6 |
| *Swartzia madagascariensis* | 10.99 | 11 |
| *Ozoroa insignis* | 17.48 | 12.2 |
| *Dalbergia nitidula* | 9.19 | 6.5 |
| *Pericopsis angolensis* | 13.10 | 10.6 |
| *Diplorhynchus condylocarpon* | 6.74 | 6.3 |
| *Khaya anthotheca* | 16.90 | 16.9 |
| *Afzelia quanzensis* | 24.52 | 11 |
| *Combretum molle* | 9.65 | 7.9 |
| *Ximenia caffra* | 5.73 | 4.5 |
| *Pterocarpus angolensis* | 18.45 | 12.5 |
| *Pterocarpus tinctorius* | 14.52 | 12 |
| *Pseudolachnostylis maprouneifolia* | 7.60 | 7.5 |
| *Brachystegia microphylla* | 12.86 | 10.2 |
| *Rothmannia englerana* | 6.34 | 6 |
| *Margaritaria discoidea* | 14.17 | 10.2 |
| *Podocarpus milanjianus* | 19.11 | 14 |
| *Crossopteryx febrifuga* | 21.66 | 10.9 |
| *Vitex doniana* | 12.23 | 8.3 |
| *Mangifera indica* | 21.17 | 11.6 |
| *Ficus ingens* | 27.79 | 17.2 |
| *Ficus sur* | 21.02 | 14 |
| *Grewia cornocarpa* | 37.58 | 12.5 |

According to Hoffmann *et al*. (2003) wildfires tend to reduce plant cover, change the microclimate, ultimately lowering the vegetal carbon stock. Also, it has been reported that savanna trees only recruit into mature populations once they escape the zone of grass fires (Higgins *et al*., 2000).

In the present study it was observed that a large part of Ilunde forest is changing to a bare land, which could ultimately limit organic matter accumulation (Figure 1 and Plate 1). According to McKinley *et al*. (2011), forest carbon is affected if wildfires cause large emissions and reasonable changes in vegetation type. During wildfires specifically ground level-fires, the leaf litter and grasses that contribute much to the soil organic carbon become utilized as fuel and eventually perish. Ultimately, soil organic matter redistribution by water erosion is accelerated after forest fires and contributes to degradation of soils (Novara *et al*. (2010). What is happening in Ilunde forest could be the opposite of what was suggested by Shvidenko and Goldammer (2001), that long-return intervals of fires are known to prevent the transformation of forests to shrubland and grassland.

**Plate 1.** Bare land after fire disturbance in Ilunde forest.

**Plate 2.** Termite infestation in ilunde forest.

Another factor that could account for limited forest carbon in Ilunde forest could be burning of trees which may leave scars and dead tissues which can be secondarily infected by pathogens ultimately resulting into death of trees. Miller (2000) observed that plant mortality reflects the amount of meristematic tissues killed by heat of fire. It is, however, suggested that high fire frequency is not responsible for the death of large trees as flame heights of a burning grass layer are usually low (Bond and Van Wilgen, 1996). Thus a combination of other factors such as old age, drought and insects especially termites could also be the cause of low woody carbon stock in Ilunde forest (Plate 2).

These results of tree carbon stock in the frequently burnt forest of Ilunde and fire suppressed forest of Kitwe are in agreement with those reported by Peñafort (2001) and Ryan and Williams (2011).

*Conclusion and recommendation*

Decadal exposure of miombo woodland to frequent fires negatively affected its woody carbon stock.

On the other hand, fire suppression in miombo woodland positively contributed to its woody carbon stock. According Nssoko (2002), fire is very important in regeneration and growth of miombo woodlands. Thus, a study on the potential of carbon sequestration in forests during the early dry season fires and late dry season fires is recommended.

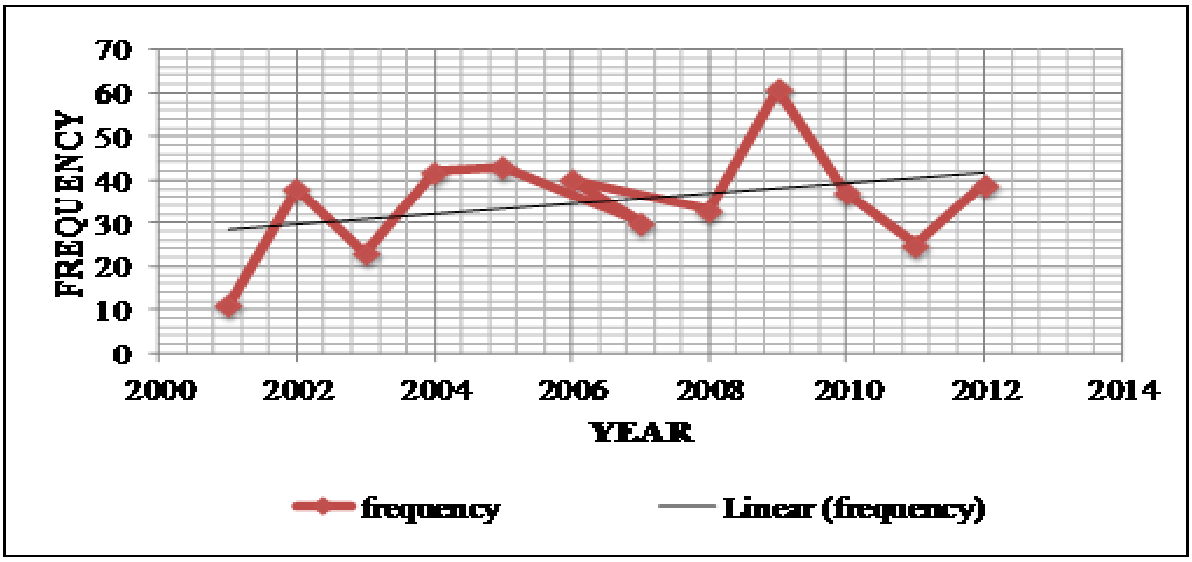


**Fig. 3.** Fire Frequency in Ilunde Forest as Detected by 16 Days 250 m MODIS Satellite Imagery from 2001 to 2012. Source: Mganga and Lyaruu, 2016.

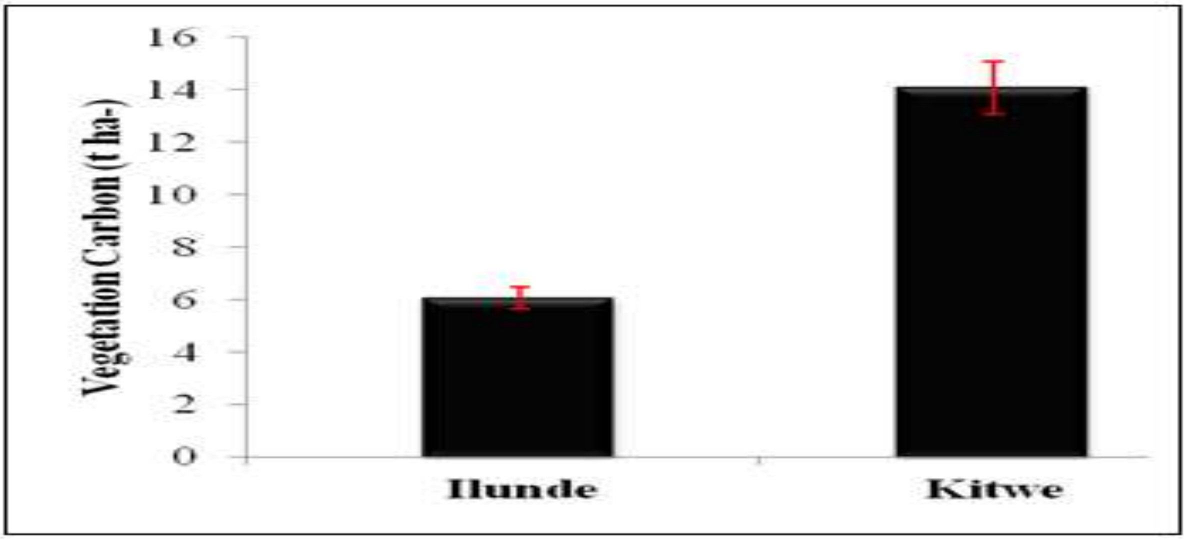


**Fig. 4.** Tree carbon stock in the study area.

Then, prescribed burning could simultaneously meet ecological requirements of certain plant species and sequester significant levels of woody carbon.

## References

**Brown S.** 2002. Measuring carbon in forests: current status and future challenges. Environmental Pollution **116,** 363-372.

**Bond WJ, Midgley JJ.** 2003. The evolutionary ecology of sprouting in woody plants. International Journal of Plant Sciences **164,** S103–S114.

**Bond W, van Wilgen BW.** 1996. Fire and plants: Population and community Biology. Chapman Hall, London, United Kingdom.

**Chamshama SAO, Mugasha AG, Zahabu E.** 2004. Stand biomass and volume estimation for miombo woodlands at Kitulanghalo, Morogoro, Tanzania. South African Forestry Journal **200,** 59–64.

**Chidumayo EN.** 2002. Changes in miombo woodland structure under different land tenure and use systems in central Zambia. Journal of Biogeography **29,** 1619-1626.

**Chidumayo EN**, **Gumbo DJ**. 2010. The dry forests and woodlands of Africa. Earthscan, London, UK.

**DeLuca TH, Zouhar KL.** 2000. Effects of selection harvest and prescribed fire on the soil nitrogen status of ponderosa pine forests. Forest Ecology and Management **138,** 263-271.

**Desanker PV**, **Frost PG**, **Frost CO**, **Justice CO**, **Scholes RJ.** (Eds.). 1997. The Miombo Network: Framework for a Terrestrial Transect Study of Land-Use and Land-Cover Change in the Miombo Ecosystems of Central Africa, IGBP Report **41,** The International Geosphere-Biosphere Programme (IGBP). Stockholm, Sweden, 109.

**Forestry Tasmania.** 2010. Fire and carbon in managed and unmanaged forests, Australia www.forestrytas.com.au/news/2010.

**Frost P.** 1996. The ecology of miombo woodlands. In: Campbell B*,* Ed. The miombo in transition: Woodlands and welfare in Africa. Bogor, Indonesia: CIFOR, 11-57 p.

**Giglio L, van der Werf GR, Randerson JT, Collatz GJ, Kasibhatla PS.** 2006. Global estimation of burned area using MODIS active fire observations. Atmospheric Chemistry and Physics **6,** 957–974.

**Grace J, Ryan C, Williams M.** 2007. An inventory of tree species and carbon stocks for the N'hambita pilot project. Sofala Province, Mozambique, p. 105.

**Higgins SI, Bond WJ, February EC, Bronn A, EustonBrown DIW, Enslin B, Govender N, Rademan L, O'regan S, Potgieter ALF, Scheiter S, Sowry R, Trollope L, Trollope WSW.** 2007. Effects of four decades of fire manipulation on woody vegetation structure in savanna. Ecology **88,** 1119-1125.

**Hoffmann WA**, **Solbrig OT.** 2003. The role of topkill in the differential response of savanna woody species to fire. Forest Ecology and Management **180,** 273–286.

**Kalaba F.** 2012 Carbon storage, biodiversity and species composition of miombo woodlands in recovery trajectory after charcoal production and slash and burn agriculture in Zambia's Copperbelt. Centre for Climate Change Economics and Policy, Working Paper No. 119*;* Sustainability Research Institute Paper No. **40,** 1-39.

**Kappelle M, Geuze T, Leal M, Cleef AM.** 1996. Successional age and forest structure in a Costa Rican upper montane Quercus forest. Journal of Tropical Ecology **12,** 681 – 698.

**Kimmins JP**. 1996. Importance of soil and the role of ecosystem disturbance for sustained productivity of cool temperate and boreal forests. Journal of American Soil Society **60,** 1643-1654.

**Knox KJE**, **Clarke PJ.** 2005. Nutrient availability induces contrasting allocation and starch formation in resprouting and obligate seeding shrubs. Functional Ecology **19,** 690-698.

**Magdoff FR, Tabatabai MA, Hanlon EA.** 1996. Soil Organic Matter: Analysis and Interpretation. Soil Science of America, Madison, WI.

**Malimbwi RE**, **Mugasha AG.** 2002 Reconnaissance Timber Inventory for Handeni Hill Forest Reserve in Handeni District, Tanzania. Morogoro: FOCON-SULT.

**Malimbwi RE, Solberg B, Luoga E.** 1994. Estimation of biomass and volume in miombo woodland at Kitulanghalo forest reserve, Tanzania. Journal of Tropical Forest Science **7,** 230-242.

**Malimbwi RE, Shemweta DTK, Zahabu E, Kingazi SP, Katani JZ, Silayo DA.** 2005 Inventory for Mvomero and Morogoro Districts, Tanzania. Morogoro: FOCONSULT.

**McKinley DC, Ryan MG, Birdsey RA, Giardina CP, Harmon ME, Heath LS, Houghton RA, Jackson RB, Morrison JF, Murray BC, Pataki DE, Skog KE.** 2011. A synthesis of current knowledge on forests and carbon storage in the United States. Ecological Applications **21,** 1902–1924.

**Mganga ND**, **Lyaruu HVM**. 2016. Plant species diversity in western Tanzania: Comparison between frequently burnt and fire suppressed forests. International Journal of Pure & Applied Bioscience **4(3),** 28-44.

**Miller M.** 2000. Chapter 2: Fire autecology. In: Brown JK and Smith JK (Ed.) Wildland fire in ecosystems: effects of fire on flora. USDA Forest Service General Technical Report RMRS-GTR-42 volume 2.

**Ministry of Natural Resources and Tourism**. 1989. Tanzania forestry action plan 1990/91- 2007/8. Dar es Salaam, Tanzania.

**Motulsky H**. 1998. GraphPad Software, InStat Guide to Choosing and Interpreting Statistical Tests. GraphPad Software, Inc. San Diego California United States of America. www.graphpad.com

**Mouillot F, Field CB.** 2005. Fire history and the global carbon budget: a 18 fire history reconstruction for the 20th century. Global Change Biology 11, 398–420.

**Mouillot D**, Mason NWH, Dumay O, Wilson JB. 2005. Functional regularity: a neglected aspect of functional diversity. Oecologia **142,** 353-359.

**Munishi PKT.** 2001. The Eastern Arc Mountains of Tanzania: Their role in Biodiversity, Water resource conservation and net contribution to atmospheric carbon. Unpublished PhD Thesis. College of Natural Resources, NC State University, United States of America.

**Munishi PKT, Shear T.** 2004. Carbon storage of two Afromontane rain forests in the Eastern Arc Mountains of Tanzania. Journal of Tropical Forest Science **6,** 78-93.

**Munishi PKT**, **Mringi S**, **Shirima DD**, **Linda SK**. 2010. The role of the Miombo Woodlands of the Southern Highlands of Tanzania as carbon sinks. Journal of Ecology and the Natural Environment **2(12),** 261-269.

**Murdiyarso D**, **Widodo M**, **Suyamto D**. 2002 Fire risks in forest carbon projects in Indonesia. Science in China Series C Life Sciences **45,** 65-74.

**National Aeronautics and Space Administration (NASA)**. 2010. Active fires from FAO's global fire information management system http://rapidfire.sci.gsfc.nasa.gov/

**Novara A, Gristina L, Bodì MB, Cerdà A.** 2010. The impact of fire on redistribution of soil organic matter on a Mediterranean hillslope under maquia vegetation type. Land Degradation and Development **4,** 530 – 536.

**Nssoko E**. 2002. Fire in Miombo woodlands: A case of Bukombe District, Shinyanga - Tanzania. Presented at Communities in flames: An international conference on community involvement in fire management, 25 - 28 July 2001, Balikpapan, Indonesia.

**Pardini R.** 2004. Effects of forest fragmentation on small mammals in an Atlantic Forest landscape. Biodiversity and Conservation1 **3,** 2567–2586.

**Peñafort T.** 2001. What effects do forest fires have on the storage of carbon? National Aeronautics and Space Administration. Goddard Institute for Space Studies. Space Flight Center
http://www.giss.nasa.gov

**Ryan CM**, **Williams M**. 2011. How does fire intensity and frequency affect miombo woodland tree populations and biomass? Ecological Applications **21,** 48-60.

**Shirima DD**. 2009. Structure, composition, diversity and carbon storage in miombo woodland: an estimate for the Eastern Arc Mountains of Tanzania. Unpublished Master of Science Dissertation, Sokoine University of Agriculture, Morogoro, Tanzania. P. 76.

**Shvidenko A, Goldammer JG.** 2001. Fire Situation in Russia. International Forest Fire News **24,** 41-59.

**Stromgaard P**. 1986. Biomass estimation equations reviewed – the example from Zambian miombo. Agroforestry Systems **4,** 375-379.

**Sugihara NG, van Wagtendonk JW, Fites-Kaufman J.** 2006. Fire as an ecological process. In: Sugihara NG, van Wagtendonk JW, Shaffer KE, Fites-Kaufman J and Thode AE (Ed) Fire in California's ecosystem. Berkeley and Los Angeles, California: University of California Press.

**Syampungani S.** 2009. Vegetation Change Analysis and Ecological Recovery of the Copperbelt Miombo Woodland of Zambia. University of Stellenbosch, Stellenbosch.

**Vesa L, Malimbwi RE, Tomppo E, Zahabu E, Maliondo S, Chamuya N, Nssoko E, Otieno J, Miceli C, Daisgaard S.** 2010. National Forestry Resources Monitoring and Assessment of Tanzania. FAO-Finland Forestry Program, Forestry Department, FAO.

**Williams M, Ryan CM, Rees RM, Sambane E, Fernando J, Grace J.** 2008. Carbon sequestration and biodiversity of re-growing miombo woodlands in Mozambique. Forest Ecology and Management **254,** 145-155.

**Zahabu E.** 2008. Sinks and sources: a strategy to involve forest communities in Tanzania in global climate policy. Unpublished PhD Dissertation, University of Twente, Netherlands.

**Zhao H, Tong DQ, Lin Q, Lu X, Wang G.** 2012. Effect of fires on soil organic carbon pool and mineralization in a Northeastern China wetland. Publications, Agencies and Staff of the U.S. Department of Commerce. Paper 424.