

Full Length Research Paper

# The regeneration dynamics of Miombo tree species in Sub-Saharan Africa

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Accepted 19 May, 2019

Miombo woodlands support livelihoods of more than 100 million rural and urban dwellers by providing them with a wide range of products and services. Concurrently, Miombo shelters more than 10000 plants and animal species majority of which are endemic. However, overexploitation of Miombo through trees cutting for charcoal, firewood, tobacco curing, farmlands expansion, and wildfires have led to deforestation and forest degradation accompanied by multiple negative effects on human livelihoods. Regeneration as a survival strategy after disturbance is an important plant functional trait for its sustainability. This paper reviewed the regeneration dynamics of Miombo tree species. The aim was to explore regeneration methods, factors affecting regeneration in Miombo ecosystem and proposes the most promising disturbance-dependent regeneration method. Information for this study was obtained by the synthesis of academic articles obtained through standard literature search performed using multiple electronic databases. Studies in Sub-Saharan Africa have demonstrated the vital role of natural regeneration in the sustainable and post-disturbance management of Miombo woodlands. Conclusively, Miombo regenerates sexually through seedlings and vegetatively propagated through root suckers and coppicing. However, vegetative propagation is highly recommended as it offers maximum regeneration with fast growth rate contributing to the rapid recovery of disturbed Miombo woodland ecosystem.

**Keywords:** Miombo woodlands, regeneration methods, disturbance, Sub-Saharan Africa, root suckers, stump coppices.

## INTRODUCTION

The term “Miombo” is a colloquial term describing the vegetation unit dominated by *Brachystegia*, *Julbernardia*, and *Isoberlinia*, three closely related genera from the legume family Fabaceae, subfamily Caesalpinioideae (Campbell *et al.*, 2007; Gumbo and Clendenning, 2018).

Miombo is an extended tropical seasonal woodland (Brenden, 2015; Pienaar *et al.*, 2015), savanna (Tarimo *et al.*, 2015) and dry forest (Chiteculo and Surovy, 2018; Zimba *et al.*, 2018) covering about 10% of the African landmass (2.5 to 4 million square km) (Malimbwi *et al.*, 2005; Malmer, 2007). The forest is distributed in Southern and Central Africa and is the dominant forest component in countries such as Tanzania, Angola, Zambia, Malawi, Mozambique and Zimbabwe (Abdallah

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and Monela, 2007; Dewees *et al.*, 2010) of which is known as Miombo ecoregion. Miombo woodland supports the livelihoods of more than 100 million rural and urban dwellers by providing a wide range of products such as firewood, charcoal, timber, forage and ecological services such as flood control, microclimate regulation, soil conservation and water catchment (Shackleton and Clarke, 2007; Syampungani *et al.*, 2009; Kalema and Witkowski, 2012; Mugasha *et al.*, 2013; Gumbo and Clendenning, 2018; Gumbo *et al.*, 2018; Teketay *et al.*, 2018; Zimba *et al.*, 2018). However, overexploitation of Miombo has led to degradation accompanied by multiple negative effects on human livelihoods (Hafner *et al.*, 2018). Miombo woodlands provide between 70-90% of all energy consumed in southern Africa in the form of fuelwood or charcoal (Woollen *et al.*, 2016; Milliken *et al.*, 2018). For example in Tanzania Miombo woodland is chief source of energy as it supplies about 90% of all energy consumed (Luoga *et al.*, 2000; Clemens *et al.*, 2018), therefore, supporting livelihoods of estimated 87% of urban and rural population (Lupala *et al.*, 2015; Mataruse *et al.*, 2018). Miombo also contributes to health services through the use of medicinal plant and products, in some cases, contributing up to 80% to rural health, including helping in coping with effects of diabetes, malaria and several other diseases (Msuya and Kideghesho, 2009; Syampungani *et al.*, 2009). Therefore, the livelihood of people in both urban and rural area depends on a stable population of these woodland species which recruits regularly over time (Worku *et al.*, 2012). The study by Kiruki *et al.* (2017) showed that different uses of Miombo have varying effect on its structure, composition and diversity thus need to balance the economic and livelihood needs of the local people with environmental sustainability of the woodland system, as degradation of Miombo will provide feedback directly on the livelihood options of the inhabitants. In order to safeguard sustained use and good management of Miombo woodlands, information on composition, diversity, structure, and regeneration characteristics are of great importance for their ecological sustainability.

The Miombo woodlands are known to have high resilient to disturbances due to their ability to regenerate (Syampungani *et al.*, 2016; Sangeda and Maleko, 2018). Miombo has been recorded to regenerate from disturbances caused by harvesting fuelwood production (Luoga *et al.*, 2000; Malimbwi and Zahabu, 2009; Clemens *et al.*, 2018), wildfires (Mapaure, 2001, 2014b; Zolho, 2005), shifting cultivation (Schwartz and Caro, 2003), animal disturbance during grazing (Daskin *et al.*, 2016), and other natural disturbances. Regeneration of Miombo involves the replacement of the old matured and disturbed individuals by new individuals of the next generation through vegetative reproduction and seedling emergence, whereby the survival of each individual has

ability to influence plant population and community dynamic (Keeley *et al.*, 2015; Larson and Funk, 2016).

Miombo woodlands have experienced a long history of human influence in meeting their demands for survival (Chidumayo, 2017). Regeneration as a survival strategy of individuals after disturbance (Syampungani *et al.*, 2017) is an important plant functional trait in many ecosystems (Johnstone *et al.*, 2016), in that regard, several reviews have been done to explain regeneration in different ecosystems and plant species (Cole *et al.*, 2015; Keeley *et al.*, 2015; Johnstone *et al.*, 2016; Larson and Funk, 2016; Seidl *et al.*, 2016; O'Leary *et al.*, 2017). However, there is no comprehensive review that covers the regeneration dynamics of Miombo trees in Sub-Saharan Africa and Tanzania in particular. Furthermore, most of the information on regeneration is scattered and not yet compiled. The aim of this paper is to explore the literature on the impact of different human disturbances on regeneration of Miombo woodlands. Specifically, the paper aims to understand methods for regeneration, factors affecting regeneration in ecosystem and finally proposing the most promising disturbance-dependent regeneration methods.

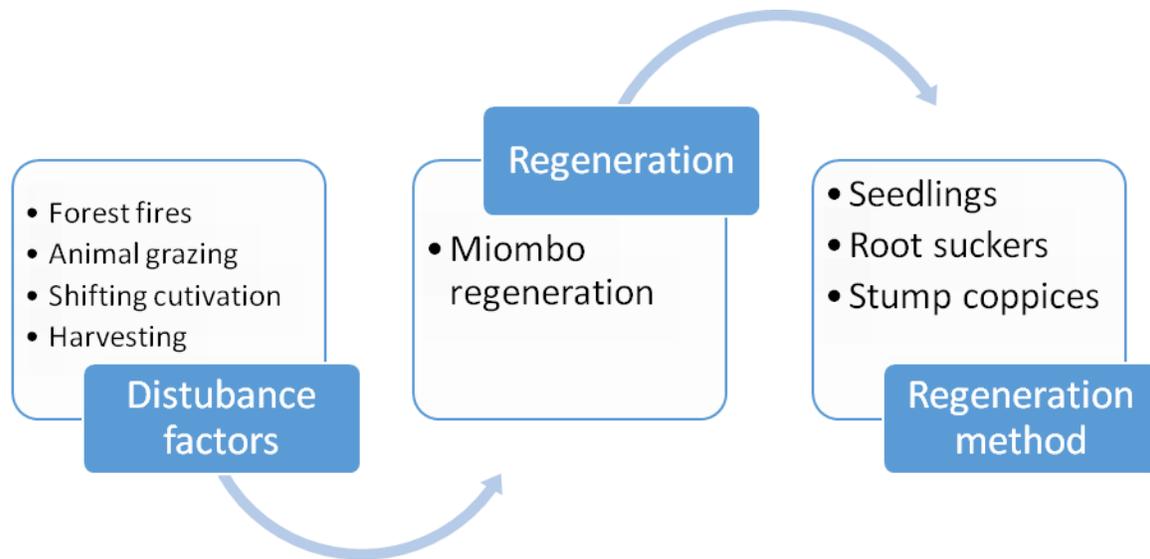
### **The conceptual framework of the study**

The sustainability of Miombo trees in correspondence to today's intensified disturbances to Miombo woodlands in meeting human demands requires clear understanding on dynamics, magnitude and the impact of these disturbances together with the knowledge of factors affecting its resilience. In this paper, we propose a conceptual framework for understanding Miombo regeneration methods in relation to disturbance factors (Figure 1). In so doing, it answers the following analytical questions: How do Miombo woodlands regenerate? What type of disturbances that triggers or hinders Miombo regeneration? What are the other factors affecting regeneration in Miombo trees?

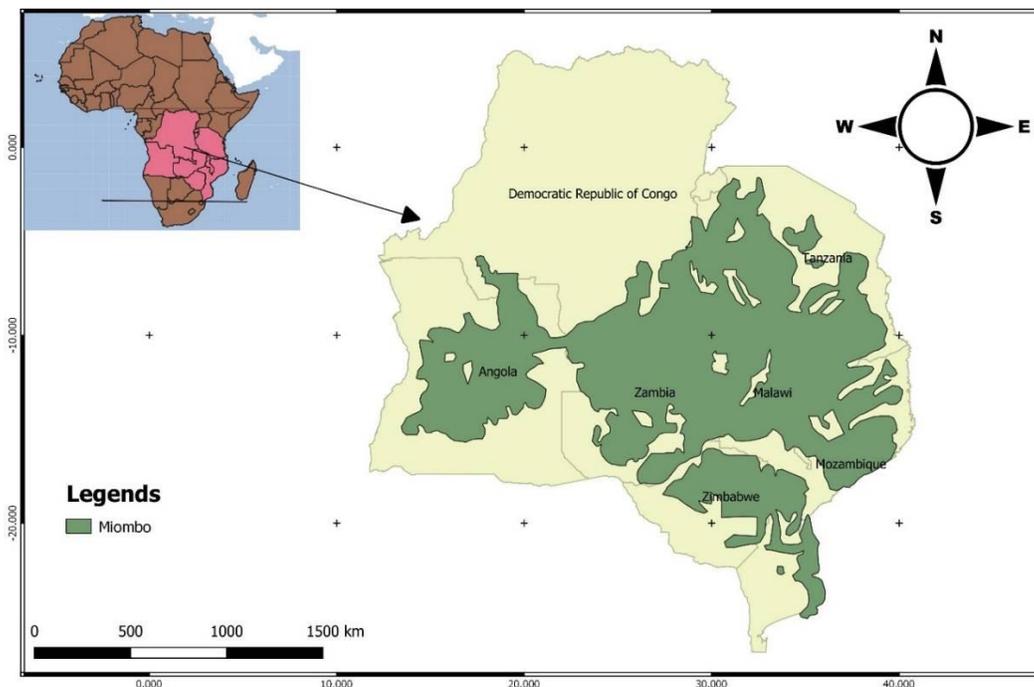
## **METHODOLOGY**

### **Study area description**

The study areas examined for this paper are the main countries found in Miombo eco-region. Miombo eco-region makes the world's largest proportion of dry forest ecosystems and comprises about 70 to 80% of the forested area in Africa (Bodart *et al.*, 2013). Miombo covers over 3.6 million square kilometers in Central and Southern Africa, extending from the west coast in Angola to the east coast in Mozambique and Tanzania and therefore making the dominant vegetation type in Sub-Saharan countries (Figure 2).



**Figure 1.** A conceptual framework of the relationship between regeneration methods and factors affecting regeneration in Miombo ecosystem.



**Figure 2.** Distribution of Miombo Woodlands in Africa (Modified from White, (1983). The mapped area is the Miombo woodlands dominated region. It is now largely a mixture of Miombo degraded woodland, smallholder cropland and other forest types are not distinguished in the data).

### Climate and types of Miombo woodlands

Miombo woodlands are characterized by low soil nutrients content, well drained and low organic matter (Campbell *et al.*, 2007). Miombo trees are found from

coast to about 2500m above sea level with annual rainfall ranging between 500 and 1400 mm in the unimodal pattern, dry season last in the range of 3 to 7 months. The annual mean temperature of Miombo ranges between 15 and 30°C (Frost, 1996) as cited by Shirima

*et al.*, (2015). Based on the amount of rainfall, Miombo vegetation is commonly classified as dry and wet Miombo (Chidumayo and Gumbo, 2010; Shirima *et al.*, 2015). The amount of moisture in Miombo gives floristic distinction (White, 1983). Dry Miombo woodlands occur in those areas receiving less than 1000 mm annual rainfall which are mostly in Zimbabwe, central Tanzania and southern areas of Mozambique, Malawi, and Zambia. While, wet Miombo woodlands receive more than 1000 mm annual rainfall and mainly located in northern Zambia, eastern Angola, central Malawi and southwestern Tanzania (Malmer, 2007).

## **METHODS**

Information for this study was obtained by analysis and synthesis of scientific articles obtained through standard literature search performed using multiple electronic databases such as Access to Global Online Research in Agriculture (AGORA), Google Scholar, SciELO, Scopus, CAB abstracts and Geoscience literature research database (GEOBASE). This review contains more than 60 peer-reviewed articles published in high profile journals on the aspect of “Miombo”, “trees” and “regeneration” of which majority came from research findings in the regeneration of Miombo and ecology of other tree species in Miombo eco-region.

## **FINDINGS AND DISCUSSION**

### **Biodiversity in Miombo Woodlands**

Miombo woodland eco-region contains a number of life forms ranging from plants, mammals, reptiles, amphibians, butterflies, birds and other species (Timberlake and Chidumayo, 2011). Table 1 shows the extent of some of these species and the levels of endemism.

Miombo vegetation is important in biodiversity conservation and source of livelihoods to both rural and urban populations. The Miombo woodlands in Africa contain about 8500 plant species, of which about 54% are endemic (White, 1983; Timberlake and Chidumayo, 2011). In addition, Miombo woodlands provide the habitat for another biota (Table 1) (Timberlake and Chidumayo, 2011). According to (Geist and Lambin, 2006; Bruschi *et al.*, 2014; Sawe *et al.*, 2014), deforestation and forest degradation in Miombo woodlands is increasing. The drivers for this degradation being charcoal production, firewood collection for subsistence use and for tobacco curing, conversion of woodlands to farmland, and seasonal forest fires (Kamusoko *et al.*, 2014). The effect of these activities is not only linked to a reduction in species abundance and richness but also the number and extent of places where species coexist (Mwakalukwa

*et al.*, 2014). A good example could be extensive exploitation of *Pterocarpus angolensis*, the common commercially timber species in the Miombo eco-region (Thunström, 2012; Jew *et al.*, 2016). The species is IUCN Red listed as near threatened in 2008 but after some years of efforts in management, *P. angolensis* has been reclassified to least concern (Barstow and Timberlake, 2018). Based on such information in the example above, it is important to understand regeneration method necessary to ensure sustainable management of Miombo species.

### **Types of Miombo Regeneration**

To ensure the successive existence of tree species within different generations, biomass production, germplasm conservation, and regeneration are very important (Parveen *et al.*, 2010; Larson and Funk, 2016). Regeneration refers to the process by which mature individuals of a plant population are replaced by new individuals of the next generation through seed production, dispersal, germination, seedling emergence and survival, and vegetative reproduction, each of which has the ability to influence plant population and community dynamics (Larson and Funk, 2016). Several studies in Tanzania (Schwartz and Caro, 2003; Luoga *et al.*, 2004; Piironen *et al.*, 2008; Mtimbanjaya and Sangeda, 2018), Zambia (Chidumayo, 1992, 2019; Ferdinand *et al.*, 2011; Ribeiro *et al.*, 2015; Syampungani *et al.*, 2016; Syampungani *et al.*, 2017; Chomba, 2018), Mozambique (Zolho, 2005) and Zimbabwe (Chinuwo *et al.*, 2010) demonstrated the vital role of natural regeneration in the sustainable management of Miombo woodlands. Miombo trees have the ability to naturally regenerate after disturbance (Schwartz and Caro, 2003; Afrifa *et al.*, 2016; Syampungani *et al.*, 2016), its regeneration is much stimulated by the presence of open patches created by disturbances and death or felling of mature trees (Grubb, 1977; Mwansa, 2018). Regeneration of Miombo occurs through coppicing, root suckers and seedlings (Sangeda and Maleko, 2018) which falls under sexual (seedling) and vegetative propagation (root and stumps) (Deiller *et al.*, 2003; Chidumayo and Gumbo, 2013).

### **Sexual regeneration**

Sexual regeneration i.e. regeneration by seeds from surrounding trees or seeds present in soil (Figure 3) is often considered as the primary forest regeneration method (Deiller *et al.*, 2003; Bognounou *et al.*, 2010; Teketay *et al.*, 2018). The process involves flower pollination, fruit formation, seed dispersal, seed germination, seedling establishment, and recruitment into a tree (Chidumayo and Gumbo, 2010). Seedling establish-

**Table 1.** Numbers of species recorded from the Miombo eco-region in Sub Saharan Africa.

Groups of Biota	Number of species in the Miombo ecoregion	Number of endemic/ near endemic species
Plants	8,500	4,590
Mammals	318	35
Reptiles	938	51
Amphibians	284	83
Butterflies	130	36
Birds	200	30
Total	10,370	4,825

Adopted from Timberlake and Chidumuyo (2011).



**Figure 3.** Field photos showing regeneration through seedlings of Miombo trees in Kilosa District, Tanzania.

ment requires the presence of water, light and nutrient availability (Larson and Funk, 2016). Therefore, most of the tropical dry forests, reproductive phenology and growth of Miombo tree seedlings depends on the seasonality of precipitation (Deiller *et al.*, 2003; Josiane *et al.*, 2015) and other abiotic drivers such as atmospheric carbon dioxide, fire, and herbivory regime (Immaculada and Yadvinder, 2016).

The established seedling location of Miombo is always determined by the method of seed dispersal including wind dispersal of which the maximum observed distance is 103 m, explosive pods with a maximum distance of 20 m and animal-dispersed for fleshy-fruited species (Chidumayo, 1987). The seed dispersed develops into seedling when it meets the necessary requirement for germination. The seedling is said to come into existence soon after the protrusion of the radicle from the seed (i.e.

the externally visible consequences of the internal processes of germination), but there is no agreement as to when the young plant ceases to be a seedling and therefore, any small plant grown from a single seed is often called a seedling, without any clear indication of the stage of development reached (Kitajima and Fenner, 2009). However, in most forest monitoring and assessment studies, a seedling recruited to a diameter at breast height (DBH) above 5 cm is regarded as a tree.

Several authors (Schupp, 1995; Zida *et al.*, 2008; Vdzquez-Yanes and Orozco-Segovia, 2010) found that seed and parent-offspring characteristics influence the survival of the seedling. Features such as seed's physical dimensions, e.g. mass, length, width, and depth influence the dispersal mechanism and the final destination where the seedling will be established (Chambers and MacMahon, 1994). For instance, a significant number of

*Brachystegia spiciformis* and *Julbernadia globiflora* seedlings mechanically expelled from the pod are found beneath the tree canopy than in the open (Grundy, 1996). This is to take advantage of the moderate moisture offered by the canopy and higher initial seed input. Seedling of Miombo shows good performance in moist and fertile environments where, post-disturbance regeneration (i.e. after logging and mature trees death) is very rapid and seedlings confer a competitive advantage by recapturing space previously occupied by the mature plant (Pausas and Keeley, 2014). Even though, seedling regeneration depends on the type of disturbance the Miombo trees are exposed to. Seedling regeneration is affected by fire (Mwansa, 2018), grazing (Mtimbanjaya and Sangeda, 2018), crops cultivation (Chinuwo *et al.*, 2010), wild animals i.e. Elephant (Mapaure, 2001, 2014a; Daskin *et al.*, 2016) and others. The seedlings regeneration from Miombo trees is hampered by the sporadic fruit production (Magingo and Dick, 2001), high levels of pre-dispersal seed predation (Chidumayo, 1987) limited seed dispersal distance (Chidumayo, 1992) and low germination ability e.g. *Brachystegia spiciformis* (Magingo and Dick, 2001; Obiri *et al.*, 2010). Very low field survival of Miombo seedlings is caused by drought stress, wildfires and seedling predation such as overgrazing and browsing (Grundy, 1996). Since Miombo seedlings are fewer (mostly single shoot per seed) and have slow growth rate, regeneration through Miombo seedlings has not been the most pragmatic and robust regeneration method in woodlands.

### Vegetative propagation

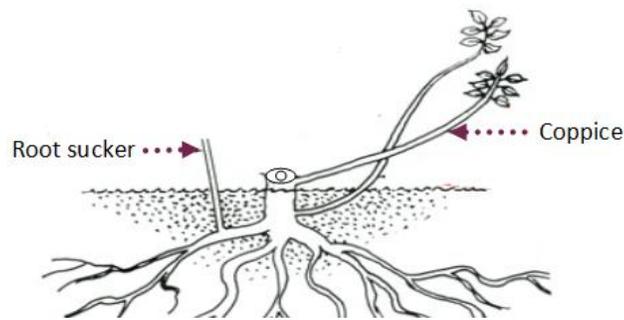
Asexual reproduction through vegetative regeneration is the most effective form of reproduction in Miombo species (Luoga *et al.*, 2004; Zolho, 2005; Chirwa *et al.*, 2015). Miombo trees are known to regenerate vegetatively through coppice and root suckers (Grundy, 1996; Luoga *et al.*, 2004; Morin *et al.*, 2010; Hanington, 2015; Sangeda and Maleko, 2018). Most of the species in Miombo woodlands have the ability to produce root suckers and possesses epicormic buds which allow coppice regeneration when the aboveground part has been removed or damaged (Teketay *et al.*, 2018). As discussed above, seed dispersal, predation, and seedling survival are limiting factors to sexual regeneration in Miombo trees, however, the ability of Miombo to regenerate through root suckers and coppices overcomes this potential barrier (Vieira *et al.*, 2006). Different names such as root sprouts/suckers or coppices have been used by researchers to name shoots originating from roots and stem coppices from those originating from stumps (Luoga *et al.*, 2004; Syampungani *et al.*, 2017; Chomba, 2018; Shackleton, 2000; 2001) as shown in Figure 4 and Figure 5. Previous

studies by Chidumayo (1988) and (2008) observed that majority of Miombo woodland trees have the ability to produce suckers. The presence of surface roots of trees under disturbances amplifies the successive formation of root suckers. However, tree cutting stimulates the emergence of the shoot (coppice) in the cut stump (Kaschula *et al.*, 2005).

Unlike regeneration by root suckers, regeneration from coppices depends on the cut size (diameter and height) of the stump (Shackleton, 2000, 2001; Kaschula *et al.*, 2005; Akouehou, 2017), cutting season and cutting angle (Grundy, 1996; Luoga *et al.*, 2002). Despite the mentioned factors, studies have revealed that the coppicing ability of Miombo trees is also species dependent (Mwavu and Witkowski, 2008; Ferdinand *et al.*, 2011).

Previous studies have shown that stump height has a strong influence on the coppicing ability of Miombo woodlands that, the shorter the stump height, the lower number of coppices and vice versa. For example, studies by Shackleton (2000) indicated that increased cutting height appears to have a positive effect on the number of coppice shoots. Frost (1996) as cited by Magingo and Dick, (2001) has shown less coppice growth for *Brachystegia spiciformis*, and *Julbernadia globiflora* when cut close to the ground (< 5 cm) than when cut at 1.3 m. Mishra *et al.*, (2003) also reported the positive relationship between stump height and coppice density of *Terminalia sericea* typical Miombo tree species. Other studies e.g. Shackleton (2001) in South Africa, Amri *et al.* (2010) in Tanzania and Ferdinand *et al.* (2011); Syampungani *et al.* (2017) in Zambia came with the same evidence on the positive effect of stump height on the regeneration of Miombo trees. The positive influence of stump height can be attributed to the availability of more reserved food and dormant buds on longer stumps together with discouraging of fungal infections because of moisture from the ground or stump decay. However, the positive ecological effect of increased cutting height must be balanced against the negative economic loss of biomass left behind as a stump. Therefore an optimal cutting height is required.

Same as in stump height, stump diameter has a positive effect on the coppicing ability of Miombo trees. For instance, the studies by Grundy (1996); Luoga *et al.* (2000); Magingo and Dick, (2001) and Lévesque *et al.* (2011) reported on the positive influence of stump diameter on re-sprouting of *B. spiciformis* and *J. globiflora*. They observed that trees with large stump diameter had a large number of coppices. Moreover, Grundy (1996) noticed a difference in initial shoot production remaining after one growing season. Larger diameter stumps had slower buds production rate but over the whole growing season, larger stumps produced more shoots than smaller stumps. Findings from Luoga *et*



**Figure 4:** The position of root suckers and coppices in a regenerating Miombo tree stump.



**Figure 5.**Photos showing regeneration by coppices and root suckers in Miombo woodland of Kilosa District, Tanzania.

*al.*(2004), Sangeda and Maleko (2018) opposed the previous established positive relationship between stump diameter and coppicing ability of Miombo trees. Several other coppicing studies by Masahoro and Shin-inchi (2003); Mwavu and Witkowski (2008); Milliken *et al.* (2018) have demonstrated significant relationship in this regard, showing decreasing capacity for coppice regeneration with increasing stump diameter. According to Tripathi and Khan (1986, 1989), the lower coppicing ability of larger diameter trees may be associated with the greater bark thickness which inhibits the sprouting. Some scholars made some effort in establishing the optimum stump diameter at which trees regenerate abundantly. In Tanzania, Sangeda and Maleko (2018) also in Zambia, Ferdinand *et al.* (2011) found the stump diameter range between 20 cm and 30 cm and 15 cm to 35.5 cm respectively, provided optimum coppicing for Miombo trees harvested for different uses. Based on the above discussion on diameter size, it is noticed that vegetative reproduction is maximized by trees of average diameter

size (neither too large nor small). On the other hand, small sized and large sized trees perform poorly compared to medium aged trees with medium diameter class ranging from 15 to 35 cm DBH. Therefore, root and stump coppicing are highly recommended in the management of Miombo woodlands. This is because coppices and root suckers can offer maximum regeneration in harvested Miombo for charcoal, firewood, poles and timber production (Syampungani *et al.*, 2017; Chomba, 2018). Coppices with an already well-established root system grow rapidly compared with newly established seedlings offering a great contribution to the rapid recovery of disturbed Miombo woodland.

#### **Disturbance factors in regeneration of Miombo**

The establishment and subsequent dynamics and productivity of many Miombo species is altered by diverse disturbances (Johnstone *et al.*, 2016). Some important disturbances in ecosystems include forest fire

(Mapaure, 2001, 2014b; Zolho, 2005; Dayamba, 2010; Hollingsworth, 2015), livestock grazing (Ribeiro *et al.*, 2017; Mtimbanjaya and Sangeda, 2018), crop cultivation (Chinuwo *et al.*, 2010), tree harvesting (Lowore, 1999; Monela *et al.*, 1999; Schwartz and Caro, 2003), and wild animals (Mapaure, 2014a; Daskin *et al.*, 2016 and Seidl *et al.*, 2016). All these different disturbances play significant ecological roles in regeneration of Miombo. The following are various types of disturbances that lead to regeneration of Miombo woodlands.

### **Role of forest fires in regeneration of Miombo**

Humans have a large impact on the dynamics of many ecosystems by altering fire regime (Hoffmann, 1998; Cochrane *et al.*, 2009; Hantson *et al.*, 2015). The history of forest fires dates back more than 1.5 million years ago when human being first discovered and managed fire (Wilgen, 2009; Gowlett, 2016). Since then, fire has played a vital role in shaping the environment (Morton *et al.*, 2010). In the presence of oxygen, trees provide the fuel necessary for combustion. Despite the advantages gained by human from fire discovery, forest fire has become the major global forest disturbance. The forest fire ignition can be human-induced or a result of environmental causes like lightning (Ganteaume and Jappiot, 2013; Ganteaume *et al.*, 2013). African savannas account for more than half of the annual global burned area. Miombo woodlands, a type of savanna, are the dominant vegetation cover in southern Africa making the major fire affected area (Ryan and Williams, 2011). Miombo woodland experiences human-induced fire in the preparation of land for cultivation, clear bush and undergrowth to improve visibility around settlements and footpaths, keeping away dangerous animals, clear roadside areas before or after grass slashing in road maintenance operations, management of grazing land for both livestock and wildlife, charcoal burning, honey collection and hunting (Chidumayo, 2013; Tarimo *et al.*, 2015; Ribeiro *et al.*, 2017). The effects of fire on vegetation, soil and the atmosphere are strongly associated with fire characteristics (density, frequency, severity, intensity, seasonality, size distribution, etc.), which are commonly grouped under the general term of fire regimes (Chuvieco *et al.*, 2008; Hantson *et al.*, 2015). The impacts of wildfires largely depend on the fire's characteristics (e.g. size, heat released, duration and intensity). Larger fires are the result of more extreme conditions (high fuel availability, low humidity, high temperatures, and high wind speed) and they are therefore often more intense and have greater impacts than smaller fires, for the same total area burned (Hantson *et al.*, 2015).

Regeneration in Miombo is much affected by fire. For example, Ribeiro *et al.*, (2017) mentioned that late dry-

season fires are of sufficiently high intensity to kill the natural regeneration of main tree species such as *Brachystegia* and *Julbernadia* species. Unlike the late fire, early burning allows regeneration due to the low-intensity fires resulted from high moisture (grass). The decrease in fire frequency of which in Miombo has been considered to be a return interval of 2-4 years will allow small trees to grow above the threshold where they are killed by fire (Tarimo *et al.*, 2015). The study by Hoffmann (1998) mentioned that for a species to reproduce successfully sexually in fire frequent area, seedlings must establish and grow to fire-tolerant size within the short period of time between burns. In addition, trees must develop the mechanism for protecting their seed from burning. However, most literature showed that no seedling was regenerating in a period of one year after fire occurrence. For example, Ryan and Williams, (2011) complement as they found that no seedlings were found growing in one year period for the burned despite the fire intensity. Luoga *et al.* (2004) reported that fire is partly responsible for the shoot die-back exhibited by many savanna tree species. Many Miombo studies conclude that vegetative propagation is usually successive post burn regeneration method (Dayamba, 2010; Simon and Pennington, 2012; Alvarado *et al.*, 2014; Hantson *et al.*, 2015; Hollingsworth, 2015). This is because vegetative offspring tend to be larger than seedlings of similar age and have a greater capacity to survive environmental stress (Cochrane *et al.*, 2009). Post-fire regeneration of trees is related to its top-killing effect (i.e. death of the aerial biomass), which activate dormant buds to produce more root suckers or sprouts (Hoffmann, 1998; Zida *et al.*, 2008). These findings suggest that Miombo regeneration is negatively affected by high-intensity fire especially if it happens in the late dry season.

### **Role of herbivores grazing in regeneration of Miombo**

Herbivores include animals which feed on plants. Miombo woodlands are famous for the diversity and abundance of large mammalian herbivores that they support ranging from wild animals such as elephant, antelope, zebra and livestock such as cattle, sheep, and goats (Piiroinen *et al.*, 2008; Timberlake and Chidumayo, 2011). Herbivores in Miombo woodlands include browsers and grazers which feed on leaves, stems, seed and backs of trees (Piiroinen *et al.*, 2008; Mtimbanjaya and Sangeda, 2018). Herbivores may influence vegetation both directly through consumption of plant tissues and indirectly via their effects on nutrient cycling and soil disturbance (Maron and Crone, 2006). Herbivores are specifically important to seedling regeneration through enhancing both colonization process by long-distance dispersal of seeds (Zida *et al.*, 2008) and seed germination through gut action (Dayamba, 2010). Furthermore, disturbance from

herbivores such as elephant and cattle provides the necessary disturbance for coppicing regeneration (Mapaure, 2001, 2014a; Daskin *et al.*, 2016). The effect of grazing by livestock on trees regeneration and subsequent growth is generally related to spatial and temporal variations in grazing intensity, stocking rate and feeding behavior (Zida *et al.*, 2008). Attack from herbivore to seedlings negatively affects growth in height and stem resulting in the creation of imbalanced shoot-root ratio and further severe attacks can even kill seedlings (Gill and Beardall, 2004). Feeding on tree seedlings, shrubs and climbers, tend to reduce stem densities, limit height growth and reduce foliage density (Ribeiro *et al.*, 2017), as a result creating a more open understory which stimulates regeneration (Harmer, 2001).

Despite the positive influence of herbivores on the regeneration of Miombo, presence of herbivores in Miombo forest tends to hinder successive growth of the saplings (a young tree < 5cm DBH). For instance, Mtimbanjaya and Sangeda (2018) found that grazing pressure negatively affects growth rate of coppices and root sprouts. They observed some root sprouts, coppices and even plant stem branches damaged after grazing cattle. This is also in line with the study by Piironen *et al.* (2008) who found no effects of animal exclusion on the regeneration of saplings. These findings lead to the general consensus that, high intensity of herbivores has a negative effect on the growth of the saplings and therefore reducing the intensity of grazing can improve the growth of saplings and therefore promoting Miombo regeneration.

### **Role of shifting cultivation in regeneration of Miombo**

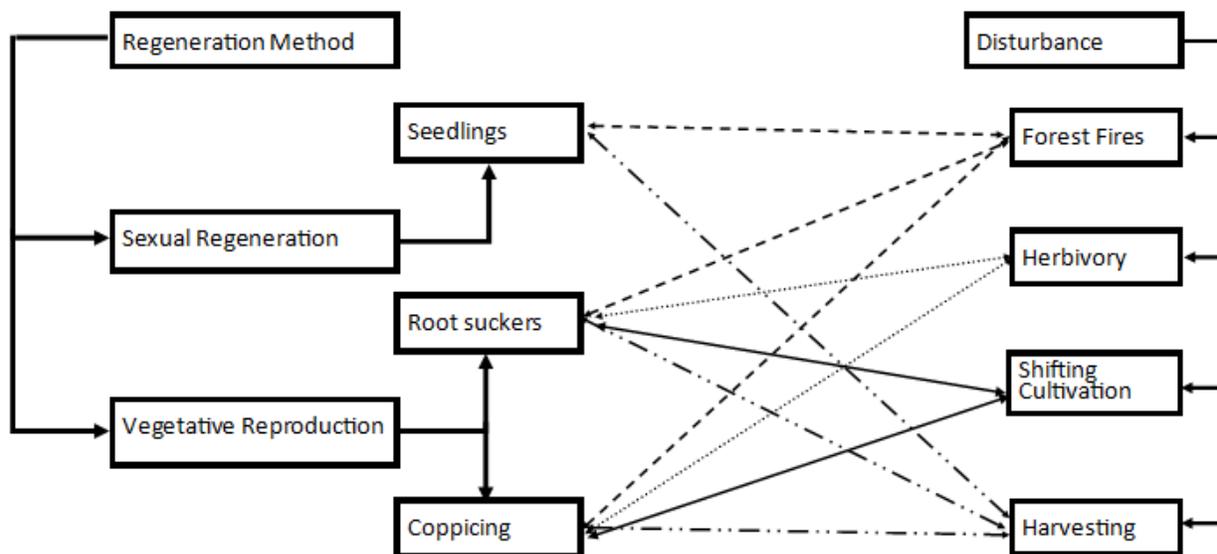
Shifting cultivation influences deforestation of woodlands through the land clearance for farming and crop induced tree cutting (Campbell *et al.*, 2007; Chidumayo, 2018). This practice involves complete removal of the surface vegetation using a mixture of cutting and fire, followed by a period of manual cultivation before eventually shifting to a new patch of land once soil fertility is depleted and allow the abandoned field to regenerate (McNicol *et al.*, 2015). Some studies e.g. Lawrence *et al.* (2016) and Gonçalves *et al.* (2017) conducted to assess the floristic diversity and the species composition during post-cultivation regeneration, found lower species composition and abundance. For example, Gonçalves *et al.* (2017) found that the Shannon Diversity Index ( $H'$ ) was highest in mature pre-cultivated forests and lowest in young fallows. The findings of which suggest low regeneration ability in a cultivated area. Pre-cultivation preparation involves tree cutting, extraction of stumps and even burning the remaining tree slashes (Mangora, 2012). However, during cultivation, weeding and other farm

management activities are always administered to reduce competition to the target crop. Regeneration of Miombo tends to differ depending on the fallow period as more time is elapsed with cultivation in the area, more trees are removed (Wallenfang *et al.*, 2015).

Regeneration in post-cultivated land is very important in the management of forest as it reduces the deforested area. Through literature, it is evidently confirmed that Miombo can regenerate well in a cultivated area. However, researchers found that post cultivation regeneration of Miombo can be achieved well vegetatively through the use of coppices. The study by Chidumayo (2018), who explored the long term effect of crop cultivation on regeneration of Miombo trees found the main regeneration method used in this case was coppicing. Furthermore, Chinuwo *et al.* (2010) compared the regeneration method used in a post-cultivated land to that of normal forest and found the absence of tree seedlings in post cultivated land. The absence of seedlings suggests that regeneration in post cultivated area is through coppicing. Cutting of trees during preparation acts as the catalyst for shoot coppicing, disturbance of roots by manual cultivation also causes root coppicing and therefore abandoning of the farms in Miombo eco-region for some years allows trees growth and recovery to its original form.

### **Role of tree harvesting in regeneration of Miombo**

Miombo tree species comprised of vast uses in sustaining livelihood of the communities. They are cut for timber, poles, firewood, charcoal production (Malimbwi *et al.*, 2005) as well as specific crop such as tobacco also influences trees harvesting (Lecours *et al.*, 2012; Mandondo *et al.*, 2014; Mataruse *et al.*, 2018). Harvesting in Miombo is usually done as selective or total felling. However, the majority of trees are selectively harvested (Hosier, 1993; Schwartz and Caro, 2003; Kiruki *et al.*, 2017). Some scholars e.g. Schwartz and Caro, (2003) researched on the effect of selective harvesting on regeneration of Miombo woodlands and it was found that this method had no significant influence on the regeneration method. Which means, trees harvest selectively can regenerate from either sexual or vegetative means (Lowore, 1999). Furthermore, Backéus *et al.* (2006) mentioned that regeneration in selectively harvested stand was good with the use of root suckers and coppices while the use of seedlings was not prominent as much of mature trees were harvested for timber. However, in some species despite large trees being harvested for different uses, regeneration by using seedlings can be good as individuals below logging size have a good seed set (Kammesheidt, 1999) for example the case of *Pterocarpus angolensis* (Schwartz and Caro, 2003). Regeneration through coppicing can provide effective



**Figure 6:** Relationship between regeneration method and disturbance in Miombo woodlands. (Authors analysis from literature).

production in clear-felled area compared to the selectively harvested area (Monela *et al.*, 1999). Through this analysis, it is obvious that there are some relationships between regeneration method and the form of disturbance in Miombo woodlands as shown in Figure 6.

## CONCLUSION

Based on above synthesis, it can be concluded that regeneration of Miombo occurs through coppicing, root suckers and seedlings which fall under sexual (seedling) and asexual which is through vegetative propagation (root suckers and coppices from stumps). However, natural vegetative propagation is the most feasible in the sustainable management of Miombo because they have robust regeneration in harvested areas for charcoal, firewood, poles and timber production. Root suckers and coppices grow rapidly compared with seedlings offering great and rapid recovery of disturbed Miombo ecosystems. Unlike regeneration by root suckers, regeneration from coppices depends on the cut size (diameter and height) of the stump, cutting season and cutting angle. In addition, various studies are in agreement that the coppicing ability of Miombo trees is also species dependent. Furthermore, the establishment and subsequent dynamics and productivity of many Miombo species is altered by diverse disturbances which have both negative and positive effects on regeneration including forest fires, animal grazing, and browsing, shifting cultivation and tree cut for various uses.

## ACKNOWLEDGMENT

The authors are pleased to acknowledge two related organizations; Tanzania Forest Conservation Group (TFCG) and MJUMITA for funding ongoing research work through their project “Transforming Tanzania’s Charcoal Sector-TTCS”. Special thanks to Theron Morgan-Brown, Project Technical Adviser and Charles Meshark, Executive Director for their technical inputs and Charles Leonard, Project Manager for logistical support.

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