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DO INHERENT AND INDUCED MIOMBO TREE TRUNK MACRO-STRUCTURAL CHARACTERISTICS INFLUENCE REGENERATION AFTER CUTTING FOR CHARCOAL PRODUCTION?

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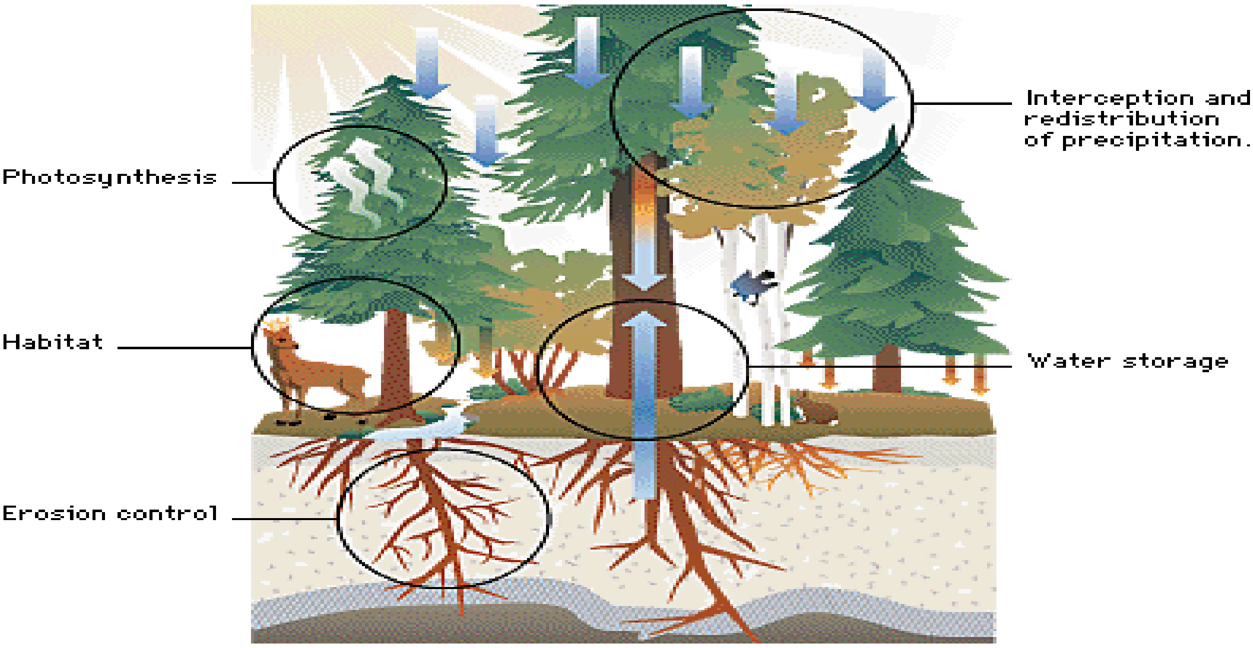
Abstract

This study assessed the influence of tree trunk macro-structural characteristics on species' potential for regeneration after cutting for charcoal production. The main objective of the study was to determine regeneration responses of species harvested for charcoal production. Diametre of the stump, bark thickness, cambium and heart wood thickness, rough and smooth bole textural groups and others were examined. Such information was necessary for regulating harvesting systems and influencing policy adjustments regarding the harvesting strategies for trees used in charcoal production. Ten transects 100 metres long each were placed parallel to each other at a minimum interval of 30 metres apart in areas where trees had been cut for charcoal in the last four years (2013 – 2017). Along each transect, five 20 m x 20 m plots were set and all tree stumps inside the plot identified and examined. The major objectives were to determine the influence of structural characteristics on the species' potential to regenerate. Bark thickness for instance, was considered to be an important stem charesctristic as it protects the living stem tissue particulalry against wildfire. Results obtained showed that the hypotheis initially advanced that in addition to soil moisture and nutrients, macro-structural components of each tree species influenced regeneration was false. It was initially thought that larger proportions of tree trunk macro-structural characteristics would yield higher and faster regeneration and vice versa but this was found to be false. All species with varying macro-structural characteristics successfully regenerated. The results were therefore, inconclusive and further research is required to be conducted in different agro-ecological zones to investigate other factors that may be critical in influencing regeneration. Factors such as root structure and root depth, soil structure and moisture retention capacity, level of accumulation of chemical compounds such as resins, phenols, and terpenes between species and age groups or stem size require detailed investigation. With regard to the survival of saplings after regeneration, it was recommended that formulation and implementation of a community-based fire management plan would enhance the survival of saplings. Good fire management practices together with soil moisture and fertility promote the ecological forest restoration of miombo woodlands.

Key words: *Stump height, fire, factors, soil moisture, soil fertility, sapling*

1. Introduction

Trees and forests provide habitat for many species of plants and animals and perform many ecological functions that benefit humans. The most important being photosynthesis (CO_2 + H_2O - Solar Energy in presence of chlorophyll- CH_2O + O_2 + H_2O) which is the chemical process in the leaves that uses sunlight and carbon dioxide to produce energy-supplying sugars for the tree or plant, in the process the foliage of the plants and trees give off pure oxygen (O_2) for breathing to humans and other animals (Figure 1a,b). Trees also prevent soil erosion, the wearing away of soil by wind and rain. In bare landscapes with little or no vegetation, for example, heavy rains fall uniformly over large areas and can wash away soil into rivers and streams and cause landslides and flooding (Encyclopaedia Britannica, 2010). This may lead to ecosystems that are deprived of both water and top soil. In areas with sufficient tree cover, tree canopy (treetops) intercepts and gradually re-distributes precipitation that would otherwise cause flooding and erosion. Some of the precipitation flows down the bark of the trunks as stem flow into the ground, while the rest percolates through the branches and foliage as through fall. This slower and non-uniform distribution of the rain ensures that soil and water will not be immediately carried away. The leaves which form a carpet of litter also helps to stop the impact of raindrops from dislodging soil particles which would otherwise be carried away by running water. In addition, the roots of the trees and other vegetation hold the soil in place and prevent flooding and clouding of streams and rivers. Trees also increase the ability of the land to capture and store valuable water. The canopy is especially efficient at capturing water from fog, condensed, cloudlike water vapour which it distributes, like precipitation, into the vegetation and soil (Encarta, 2009). Water stored in tree roots, trunks, stems, and foliage, as well as the soil of the forest floor, enables forests to maintain an even flow of water in rivers and streams in times of heavy precipitation or drought (Trouet, *et al.*, 2006).



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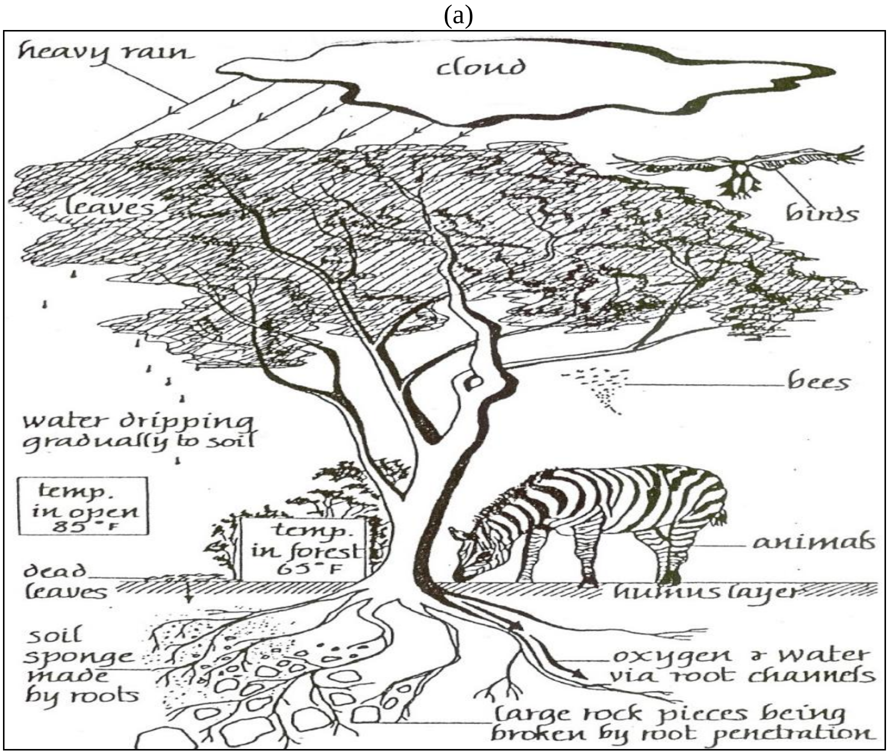

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Figure 1(a) & (b) A graphic illustration of the various and important ecological roles of trees in the environment. (Modified after: Microsoft Encarta 2009; Chomba, et al., 2014).

Trees also have many economic uses. Lumber from trees is the most widely used material in the building of homes and other structures. Many indigenous trees for instance, yield edible fruits and nuts such as; *Adansonia digitata, Anisophyllea boehmii, Azanza garckeana, Diospyros mespiliformis, Parinari curatellifolia, Strychnos cocculoides, Strychnos innocua, Syzygium guineense , Tamarindus indica, Uapaca kirkiana , Uapaca nitida , Uapaca sansibarica, and Ximenia americana* just to name some of them (Chomba et al. 2014). Trees and their fruits are also the source of many commercial waxes and oils, including olive oil and coconut oil. Tree trunks are tapped for sap, which is used in making such products as maple syrup, rubber, and turpentine. The barks of certain trees are sources of cork and spices. Many trees yield important medicines, such as quinine. The bark of the yew tree (*Taxus* spp) for instance, is the source of the drug taxol, which in 1992 was approved for treating ovarian cancer (Encyclopaedia Britannica 2010).

Chemical materials produced by trees are used in tanning leather and in the manufacture of inks, medicines, dyes, and wood alcohol. In addition, trees are used in landscaping homes, parks, and highways. In regions with extreme climates, they serve as windbreaks or as shade against the sun. In many parts of the third world particularly sub Sharan Africa; trees are an important source of energy in form of firewood or charcoal. In fact, the saying 'water is life' is incomplete without including trees which give us oxygen to breath and also influence nutrient and water cycles (Figure 1a,b).

Trees are very important in providing soil cover to protect it against soil erosion which is perhaps the most important ecological function. The wearing away of topsoil due to wind and water can lead to loss of top soil which is critical in supporting plant growth. The trunks and branches of trees provide protection from the wind, and tree roots help solidify soil in times of heavy rain. In addition, trees and forests play a critical role in the biosphere including; storing of water that act as buffers for the ecosystem during periods of drought thereby influencing the water cycles including the protection of water catchments and the buffering against extreme conditions of flood and drought; regulation of climates at both the macro and micro climatic levels including effects on temperatures, rainfall and air turbulence; maintenance of essential nutrient cycles including oxygen and carbon dioxide balance in the atmosphere; photosynthetic fixation of energy , where by energy from the sun is transferred through green plants to the ecosystem as a whole, and currently are critical in carbon sequestration among others. Of particular significance to humans however, is their role as the major source of food either directly or indirectly through consumption by herbivores and, as mentioned above, they are a primary source of consumer goods, such as building materials, textile fibres, spices, herbs, and pharmaceuticals (Figure 1a,b).

Loss of forest cover can therefore, accentuate the local negative effects of drought. In many areas, the removal of forests has also resulted in costly floods. With respect to conservation of biodiversity, trees and forests provide habitat, protection, and food for many plant and animal species. In addition, they play an important role in global climate and atmosphere regulation through leaves of trees which absorb carbon dioxide in the air there by acting as carbon sinks.

The multiple uses of trees expose them to a lot of pressure by humans and in many parts of sub –Saharan Africa, extensive areas of land have already lost forest cover with no immediate solution to reverse the trend. As human populations continue to rise and while poverty levels soar, pressure is expected to continue and measures based on science and technology are required to ameliorate the *status quo*.

In Zambia for instance, the multiple roles that trees perform in the environment within which people live and work is not clearly understood or perhaps just ignored and indiscriminate cutting of trees is wide spread. While it is widely acknowledgement that between 65% and 70% of Zambia's land area is under one form of forest cover or another, with miombo woodlands being the most extensive estimated to cover about 55% of the total land area (Kapiyo, 1996), evidence of continuing deforestation resulting in various negative factors was and is still evident. Major agents identified for tree cutting are; building poles, fire wood, fibre, fruit collection, medicine, honey collection, house hold tools and utensils, industrial uses, charcoal production and clearing for agriculture. According to Chansa (2000) clearing for agriculture is the most damaging, because it involves total removal of woody biomass of all sizes and suppression of their regeneration during cultivation in subsequent years. Charcoal production is also important because of the rising energy demands due to increasing human populations and the Forestry Department's inability to carry out its mandate. Despite the miombo tree's inherent vegetative ability to regenerate after cutting, indiscriminate cutting of trees for charcoal when combined with other factors such as late fires, plant diseases such as fungal attacks and termites if not monitored can have devastating impacts on woody cover.

1.1 Wood plant stem macro-structure

This study therefore, focused on the role macrostructural components of the tree trunk play as potential factors in influencing the ability of miombo woodland species to coppice after cutting. Such factors if confirmed can be factored into management strategies (Carrer *et al.*, 2013) which communities, government and its partners can utilize to save trees and prevent loss of soil cover and its devastating effects of soil erosion, flooding and accentuating the effects of drought among others which further increase the vulnerability of communities to the ravages of climate change. Specific objectives were to determine; species, diameter classes of tree stumps, bark thickness, size comparison between heartwood and cambium, and sprouting patterns. Bark thickness was also considered to be an important stem charesctristic as it protects the living stem tissue particulalry again wildfire. The research hypothesis was that 'Inherent and induced miombo tree trunk macro-structural characteristics influence regeneration'. Tree species with thick cork for instance are known to be fire resident and often dominate in areas subjected to late fires. In many instances, historic fire marks can be seen when a stem has been sectioned revealing internal scars of fire (Figure 2)

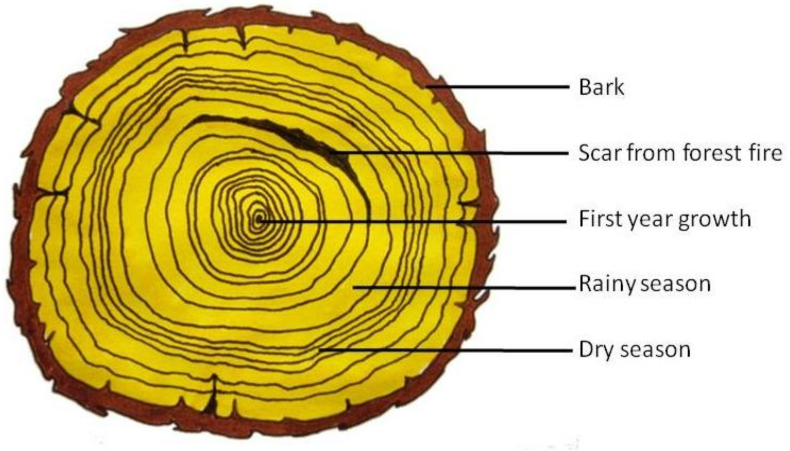
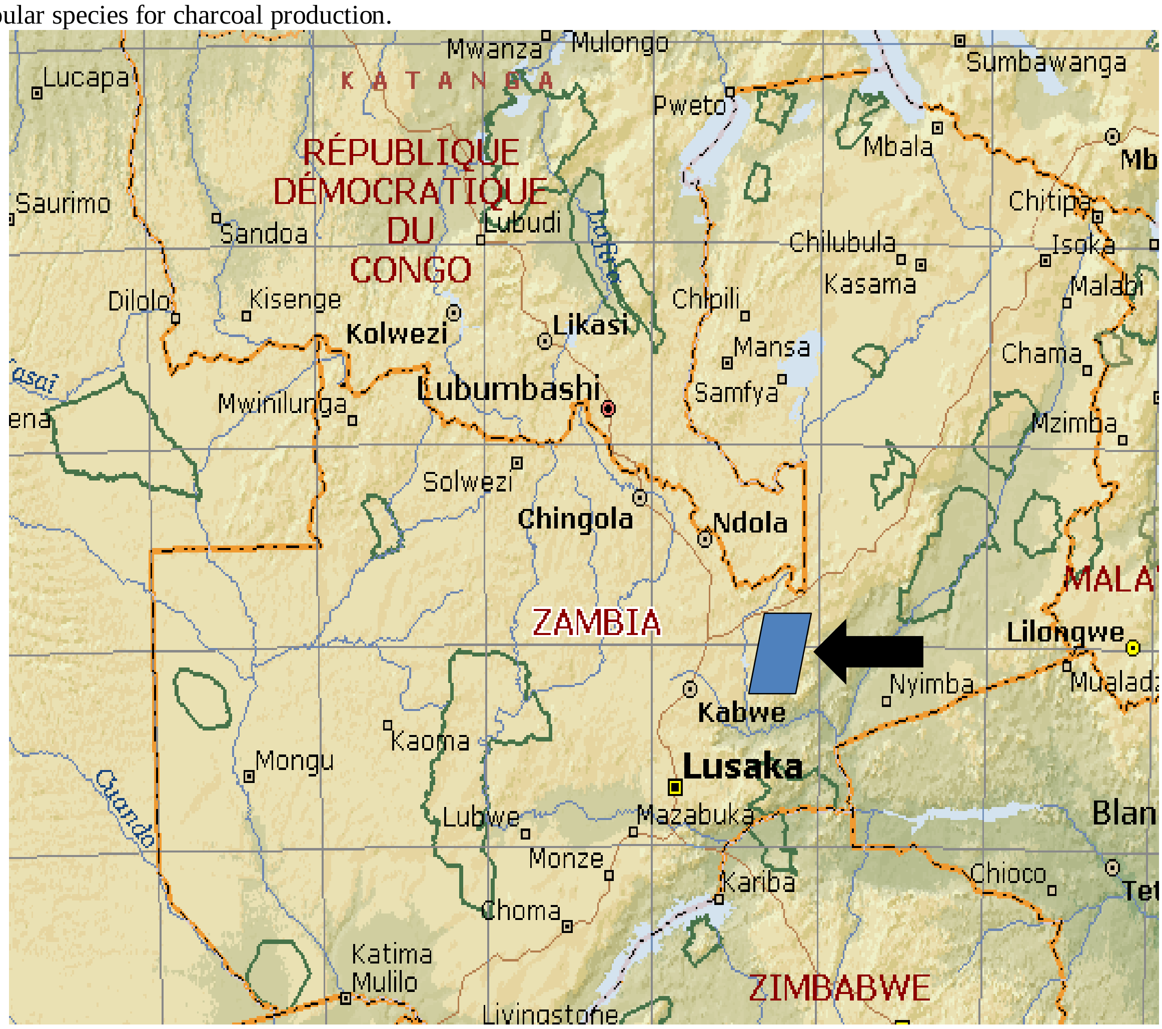


Figure 2 Historic fire marks in the sectioned stem revealing internal scars of fire (Source: http: www.google .com downloaded on 8th February 2018)

2. Materials and Methods

2.1 Location and Description of Study Area

Kapiri Mposhi is situated almost half way between Lusaka the capital city of Zambia and the Copperbelt which are the most developed parts of the country with the highest population density (Figure 3a,b) and a high demand for charcoal as source of energy mainly for cooking. As such, the area is heavily utilized for charcoal production to feed the urban areas. The vegetation of the area is typical plateau miombo woodland dominated by the genera *Brachystegia – Julbernardia* and *Isoberlinia.* Some localities form almost pure *Brachystegia spiciformis*, and in some interspaced with *Julbernardia paniculata* or *Julbernardia globiflora* or both, which are also the most popular species for charcoal production.



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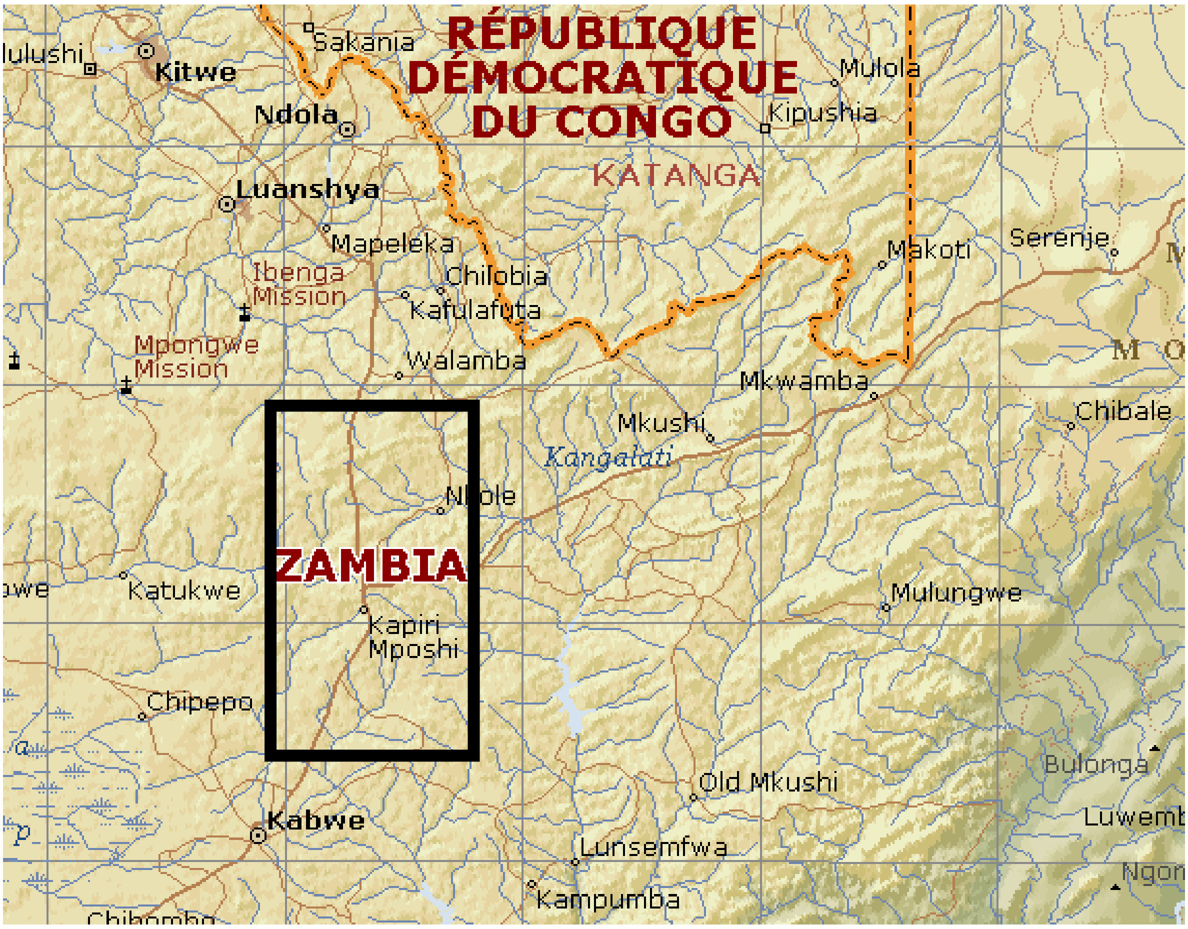


(b)

Figure 3a) General location of the study area , b) specific study site along the Lusaka - Copperbelt Highway, Zambia

2.2 Data collection techniques

Data collection techniques focused on the collection of field data (sensu Mueller – Dombois and Ellenberg, 1974) on stump height and diameter, species identification, observation of coppices as an indication of regeneration and; bark thickness and textural classes, cambium and heart wood thickness.

2.2.1 Species, Stump Diameter and Height

At each charcoal production site, all stumps were identified by the appearance of the stem or coppice buds or young saplings. Using a steel tape, height was measured in cm from ground level to the highest point on the stump. The species was identified based on the bark and recorded on a data sheet which showed locational details.

Diameter of the stump and thickness of the bark were also measured. Stump diameter was measured using a linear caliper calibrated in cm. The caliper was placed at the lowest cut side of the stump. Readings were then taken on the caliper scale. Where the stump exceeded the length of the linear caliper, two wooden planks were used. The two straight planks were placed on opposite sides of the stump and a steel tape was used to measure the distance between the two wooden planks which was equal to the diameter of the stem.

In identifying species, the bark was used as a guide based on Storrs (1995), Palgrave (2002) and Moll (2011). In fact most tree species have bark that is unique in structure and appearance and can be identified by the characteristics of their bark alone. In some species, the bark looks similar throughout the life of the plant, while in others there are dramatic changes with age, such characteristics serve to distinguish species with minor or no errors at all. All regenerating coppices were recorded as buds or shoots if they have sprouted from the bud.

2.2.2 Bark texture and Thickness of the Bark

The bark or cork cambium primarily produces a single cell type, the cork cells; of which the walls may be thick or thin. Barks also vary from the smooth, to the thick, soft, spongy bark, to rugged, fissured outer coat (Chomba, 2014) (Figure 4).

Figure 4 Rough bole texture

In this study, the roughness of the substrate was visually carried out to categorize between rough and smooth bole textures. This was further verified by running the inner side of the researcher's palm over the surface of the tree bark as earlier carried out by Chomba (2014). Rough bole texture had a prickly scaly feel on the palm while smooth bole did not. There were only two categories developed; i) rough bole, and ii) smooth bole textures and each stump examined was placed under either rough or smooth bole texture categories.

The thickness of the bark was measured using a linear caliper placed from inside out of the cut surface of the tree stump and readings were taken in cm. The bark was further subdivided between inner soft bark, or bast and the outer dermal tissue or cork. The condition of the bark was visually examined and recorded as wet or dry. Dry when it could easily be peeled off from the stem and broken, and wet when it was still attached to the stem and could not be peeled by hand except with a hard-sharp object such as a knife. The sprouting was visually examined and the number of coppices counted. The level at which the coppice was located from the cut surface was also measured in cm using a 5 m steel tape.

2.2.3 Measurements of bark, cambium and Heart wood

Measuring the dimensions of heart wood and sap wood was difficult in some instances. However, in this study, it was assumed that sapwood was lighter in colour and found on the outer part of the trunk while heart wood was darker; being dark brown, red hues, or simply darker than sapwood and located in the inner part of the trunk. With experience, the two parts were easily distinguished by colour alone (Figure 4). Sapwood being lighter and heart wood was darker in appearance. Since the number of species in most miombo woodlands which are utilized for charcoal production are limited (Syampungami et al., 2010), distinguishing cambium from heart wood by colour alone was considered to be sufficient.

Using a linear caliper, measurements were taken in cm of the heart wood from the center (pith) to the outer region where it shares the borderline with cambium. From this point another measurement for the cambium was taken to borderline with the bark (Figure 5).

Figure 5 Stem transverse section showing sapwood (lighter area) and heart wood (darker area) a) as adopted from Microsoft Encarta, 2009; http: www.google .com downloaded on 8th February 201) and b) *Brachystegia spiciformis* cut for charcoal production in the study area.

3. Results

3.1 Presence of saplings

The differences between stump height, stump diameter, bark thickness and bole texture did not have any impact on the regeneration potential of all species encountered in the study. All species successfully regenerated with a varying number of saplings (Table 1).

Table 1 Number of saplings for each species in the first and forth years of study

No.	Species Name	Mean number of saplings for each species		Percent (%) sapling mortality
		Year I (2013)	Year IV (2016)	
1	*Brachystegia spiciformis*	9	3	67
2	*Brachystegia longifolia*	7	2	71
3	*Brachystegia bohemii*	11	4	64
4	*Julbernardia panniculata*	8	3	63
5	*Julbernardia globiflora*	7	3	57
6	*Pericopsis angolensis*	9	2	78
7	*Bobgunnia (Swartzia) madagascariensis*	4	2	50
8	*Burkea africana*	7	4	43
9	*Albizia anthunesiana*	8	2	75
10	*Brachystegia spiciformis*	9	3	67

3.2 Stump diameter and height

The diameter of tree stumps varied significantly (χ^2 = 13.33, DF = 2, α= 0.05 P < 0.05) between the mean values of the three categories, small (10 – 30 cm), medium (31 – 50 cm) and large > 51 cm. The stump height however did not vary significantly (χ^2 = 3.47 DF = 9, α= 0.05 P >0.05).

3.3 Bark thickness and texture

The bark thickness visually appeared different but in fact, the difference was statistically insignificant (χ^2 = 0.32, DF = 9, α= 0.05 P >0.05), suggesting that bark thickness alone was not an important factor (Figure 6).

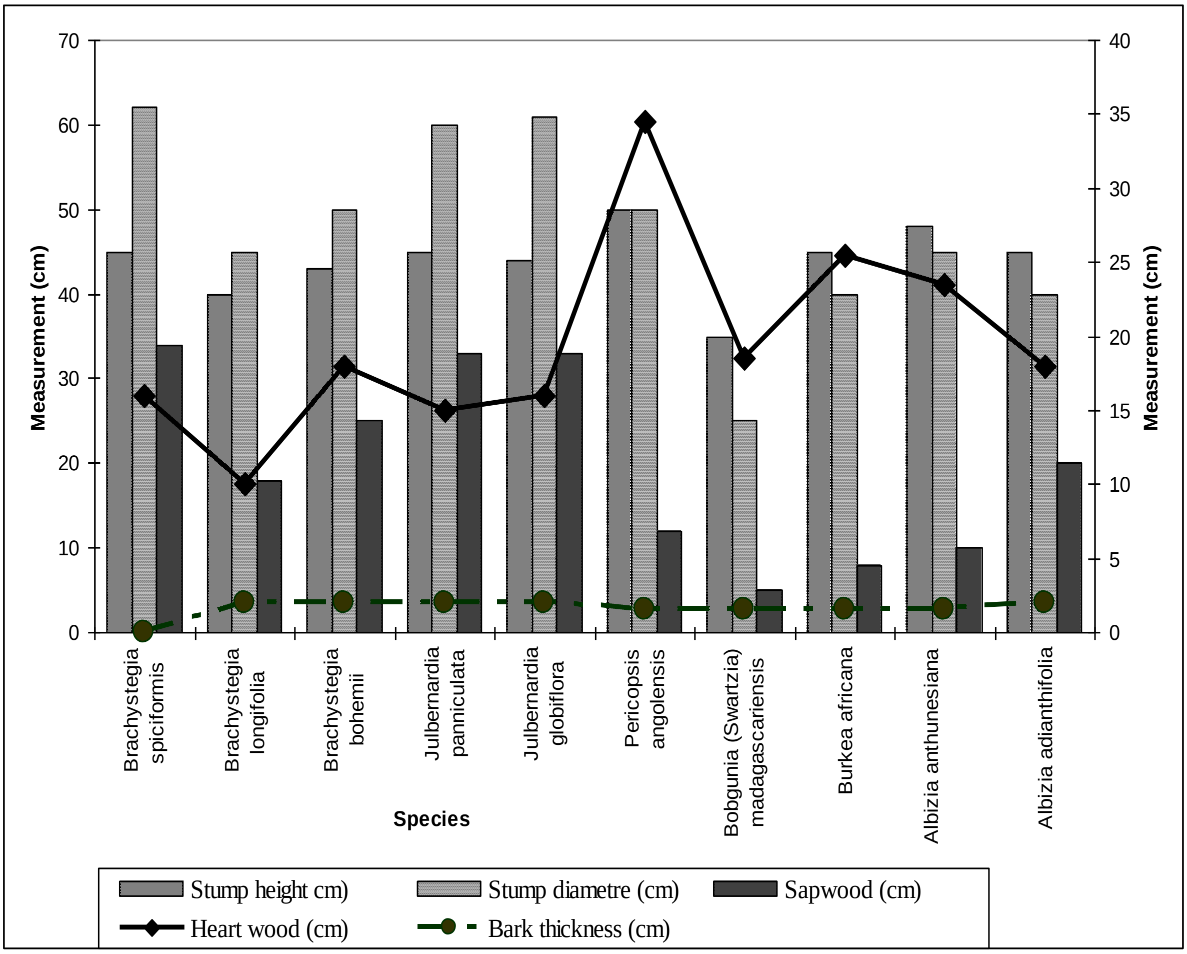


Figure 6 Species comparisons of bark thickness, stump height and diameter as probable factors influencing regeneration

3.4 Proportional size of Sapwood and Heartwood

The dendrogram with average linkage and Euclidean distance showed three subgroups with one outlier (Figure 6 and 7; Table1). Despite these differences in dimensions, they all regenerated producing saplings that did not vary significantly in number ($p > 0.05$) (see Table 1).

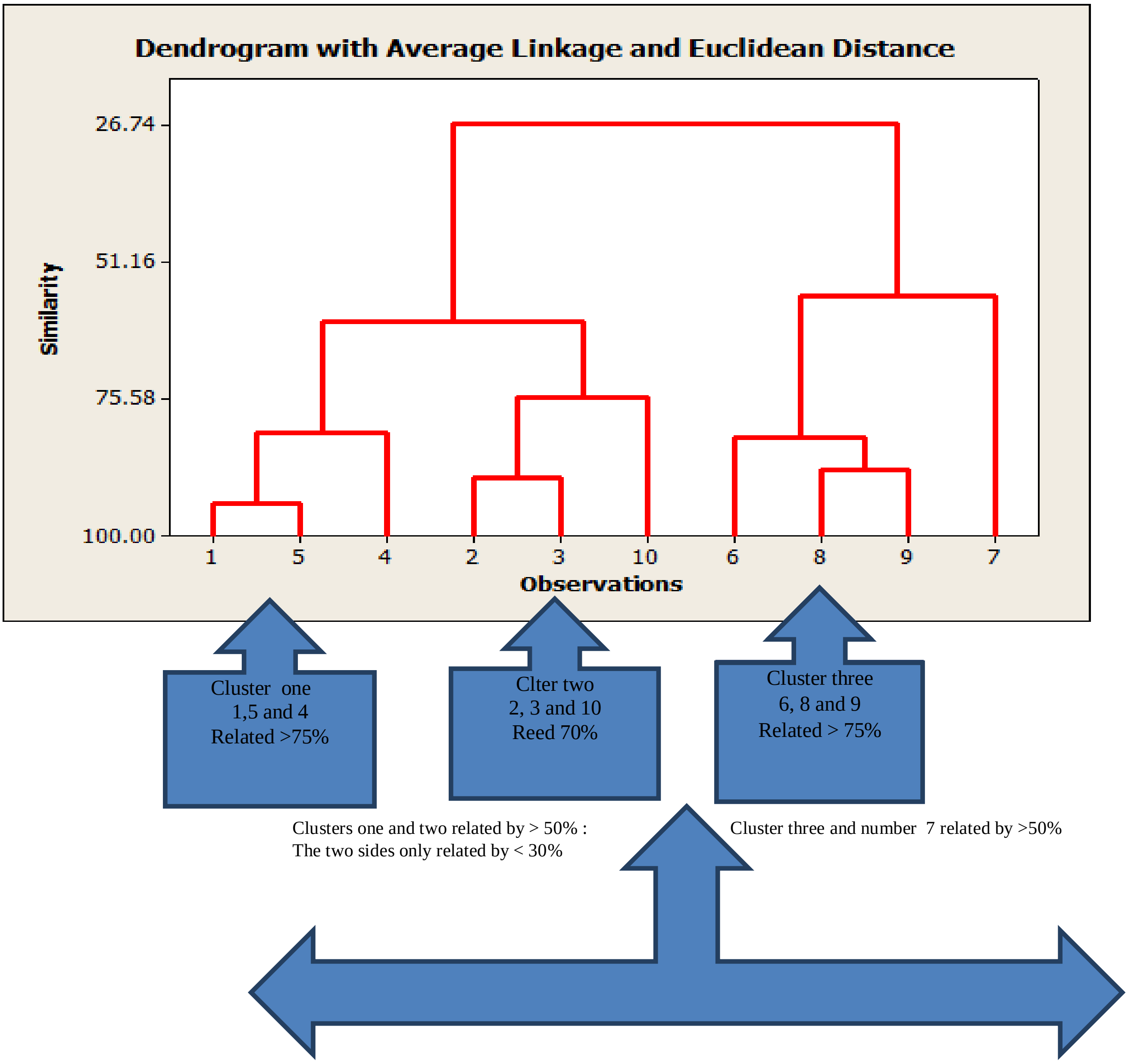


Figure 7 dendrogram with average linkage and Euclidean distance showed three subgroups formulated on the basis of the mean size of Sapwood and Heartwood

4. Discussion

At the beginning of the study it was assumed that since different macro-structural components of a tree trunk have different functions to the growth and survival of a plant, any difference in size or proportion between species would yield visual and measurable differences in regeneration (Figure 8). For example, thickness of the bark (cork) and texture can protect the plant from fire, termites and other environmental factors. Like the skin of an animal the bark protects the inner parts (Figure 9). For example, Chidumayo (1997) indicated that fire was the main agent responsible for killing saplings. After the trees have been cut as feed lot for charcoal production, grass growth takes over the sites which becomes fuel for surface fires that kill saplings. This could explain the more than 50% sapling mortality recorded in this study. In this study however, all species irrespective of differences in stump height, stump diameter, bark thickness and bole texture differences successfully regenerated, producing varying numbers of saplings *per* stump.

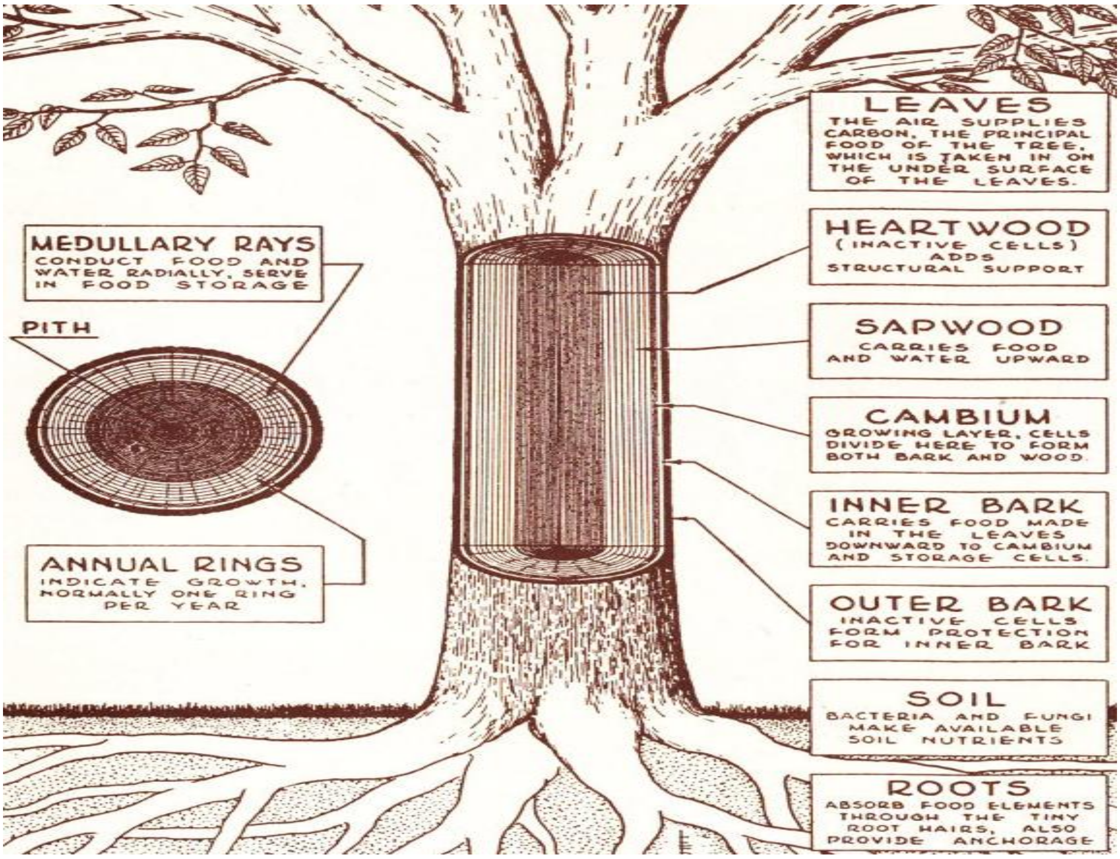


Figure 8 Tree macro-structural components and their functions (Modified after Iberrson, *et al.*, 2016)

4.1 Role of the Bark

The cork contained in the outer bark is the tree's protection from the outside world. It varies so widely in colour, texture, and thickness, and is one of the most important means of identifying species of trees as was the case in thus study. It comprises dead tissue that protects the inner tissues from drying out, from mechanical injury and from insects. It is continually renewed from within, helps keep out moisture in the rain, and prevents the tree from losing moisture when the air is dry. It insulates against cold and heat and wards off insect enemies. The inner bark**,** or "phloem", conducts sugars produced by photosynthesis to the roots and other non-photosynthetic parts of the tree and is indeed synonymous to a pipeline through which food is passed to the rest of the tree. It lives for only a short time, then dies and turns to cork to become part of the protective outer bark (Iberrson *et al,* 2016).

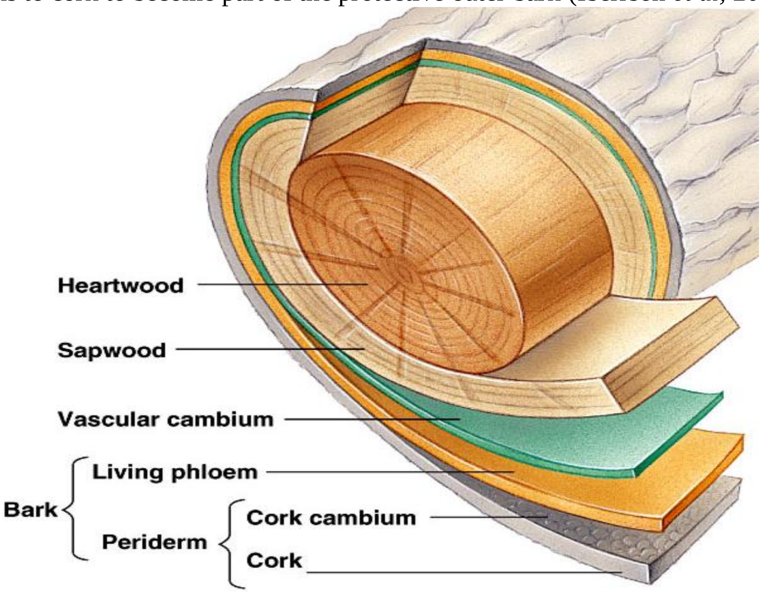


Figure 9 Importance of the bark in protecting the inner parts of the stem. The figure shows successive tree trunk concentric layers (Modified after Microsoft Encarta 2009; http: www.google .com , Pearson Education Inc. Publishing and Benjamin Cummings downloaded on 8th February 2018)

The bark therefore, in general terms, is important in woody plants, because it is tissue external to the vascular cambium (the growth layer of the vascular cylinder). The term bark is also employed more popularly to refer to all tissues outside the wood and which is also inevitable in gaseous exchange because it allows the movement of carbon dioxide and oxygen to and from the inner tissue (Enclopaedia Britanninca, 2010). It is mostly dead tissue and is the product of the cork cambium (phellogen). Layered outer bark, containing cork and old, dead phloem, is known as rhytidome. The dead cork cells are lined with suberin, a fatty substance that makes them highly impermeable to gases and water. Gas exchange between the inner tissues of bark-covered roots and stems and their surroundings takes place through spongy areas (lenticels) in the cork. In the Miombo woodlands of Zambia where hot fires are common, the thickness' and structure of the bark imparts protection from fire and insects. In dendrochronology, scientists are able to detect events such as hot fires as these are easily identified when the stem is cut. In instances where the bark is destroyed by fire, a mark would remain even as the tree recovers and continues to grow (see Figure 2).

Bark however, is usually thinner than the woody part of the stem or root. Both inner bark (secondary phloem) and wood (secondary xylem) are generated by the vascular cambium layer of cells pushed toward the outside where the oldest layers may slough off, and wood toward the inside where it accumulates as dead tissue. As already intimated, it offers physical protection to the plant and also serves as a transport system from leaves to the roots. Once a tree has been cut, the transportation is curtailed. Depending on the thickness and chemical constituent such as tannin and moisture as well as environmental factors may cause a stump to either dry slowly or quickly.

Trees with thicker outer and more fibrous inner bark such as *Brachystegia bohemii*, would be expected to respond better to re-sprouting than those with less soft and shorter fibre. This could be explained by the nature of their tissue which conducts foods made in the leaves to all other parts of the plant. Phloem in particular, is composed of various specialized cells called sieve tubes, companion cells, phloem fibres, and phloem parenchyma cells. Primary phloem is formed by the apical meristems (zones of new cell production) of root and shoot tips; it may be either protophloem, the cells of which are matured before elongation (during growth) of the area in which it lies, or metaphloem, the cells of which mature after elongation. Sieve tubes of protophloem are unable to stretch with the elongating tissues and are torn and destroyed as the plant ages. The other cell types in the phloem may be converted to fibres. The later maturing metaphloem is not destroyed and may function during the rest of the plant's life in plants such as palms but is replaced by secondary phloem in plants that have a cambium.

Sieve tubes, therefore, which are columns of sieve-tube cells having perforated, sieve-like areas in their lateral or end walls, provide the channels in which food substances travel. Phloem parenchyma cells, called transfer cells and border parenchyma cells, are located near the finest branches and terminations of sieve tubes in leaf veinlets, where they also function in the transport of foods. While phloem fibres are flexible long cells that make up the soft fibres popular in weaving and basketry in many rural parts of the country. In fact, firewood collectors than carry firewood on their heads need soft fibre to tie wood poles into a bundle of firewood. Whether the flexibility of the fibre imparts a comparative advantage in the miombo regeneration was not examined.

With these critical functions of the bark, it was expected that the difference in thickness and structure would influence the regeneration potential of a species. Thicker barked species were expected to re-generate much quicker producing more saplings, but this was not the case in this study, and the reason cannot be explained by the current study results.

4.2 Role of cambium

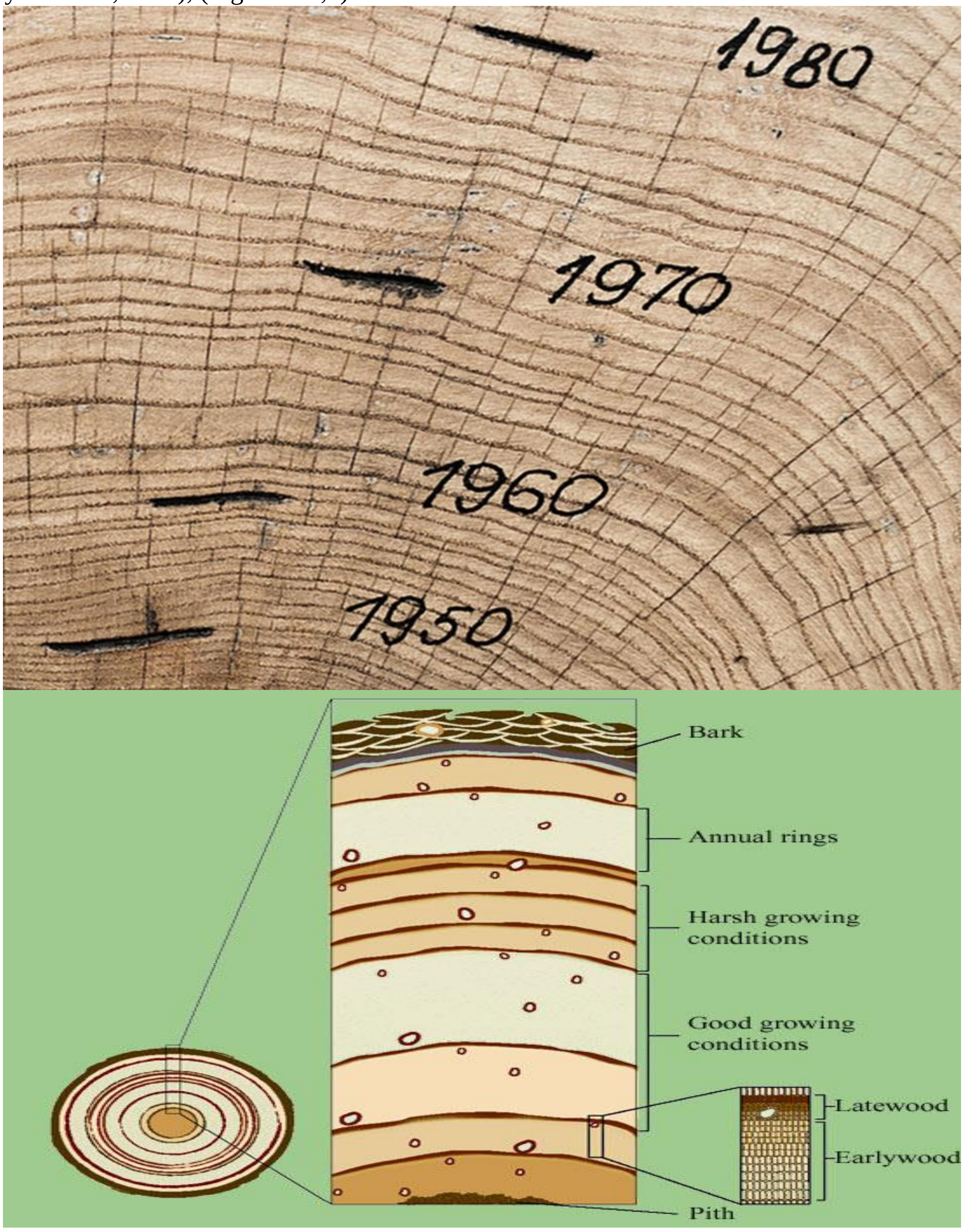
The cambium cell layer produces secondary xylem and secondary phloem. It is the growing part of the trunk. It annually produces new bark and new wood in response to hormones that pass down through the phloem with food from the leaves. These hormones, called "auxins", stimulate growth in cells (Encyclopaedia Britannica 2010). Auxins are produced by leaf buds at the ends of branches as soon as they start growing. The sapwood consists of xylem tissue through which water and minerals move from the soil to the leaves and other living parts of the tree. It is the tree's pipeline for water moving up to the leaves. Sapwood is new wood, and as newer rings of sapwood are laid down, inner cells lose their vitality and turn to heartwood. Heartwood, is therefore, composed entirely of dead cells, the supporting column of the tree. It is undoubtedly the central, supporting pillar of the tree. Although dead, it will not decay or lose strength while the outer layers are intact.

With regard to the difference in size between cambium and heart wood, again, this was expected to show numerical differences in saplings. I expected trees with larger cambium to have a higher regeneration potential than those with a narrower band of cambium.

Away from the bark is the inner bark layer, called the phloem, which consists of a thin layer of living cells. These cells act together to transport food in the form of sugars, which are made in the tree's leaves, through the trunk and stems to other parts of the tree. Phloem cells have thin walls, and their living contents are so interconnected that the sugar solutions can pass easily and rapidly from one end of the plant to the other. As old layers of outer bark are sloughed off, new ones are constantly being added from the inside, where new phloem is always being created. It is therefore evident that when a tree is cut the transportation function is curtailed and during the period of active growth it is expected to have an influence on the rate of regeneration (Gliniars 2010).

Structurally, lateral meristems, called cambia, run the length of the stems and roots of vascular plants and produce secondary tissues, which develop after a plant organ or part of a plant organ has ceased to elongate. Secondary growth is essentially an increase in girth. The vascular cambium produces secondary xylem and secondary phloem, and the cork cambium (phellogen) produces cork cells, from which the outer bark develops.

Most of a tree trunk is occupied by the wood, or xylem layer, which consists almost entirely of dead cells. The living xylem cells, however, act as the tree's plumbing system by transporting water and dissolved food through the trunk and stems. A layer of cells called the *cambium* separates the living xylem cells from the phloem. As the tree grows and develops, the cambium forms new phloem and xylem cells. The layers of xylem cells form rings; and in fact these rings can be counted to determine the age of the tree in areas with distinct growing seasons (Therrell 2007; Verheyden et al., 2004), (Figure 10a,b).



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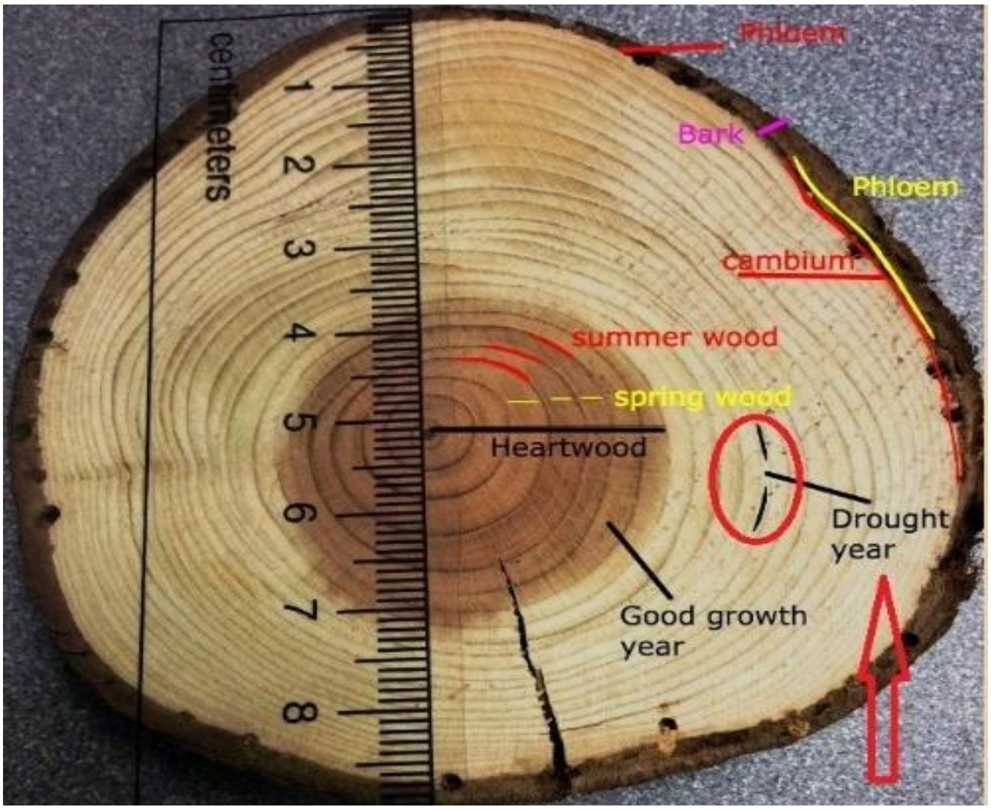

(b)

Figure 10 Use of rings to determine the age of the tree in areas with distinct growing seasons as shown in (a), and their use in paleoclimatology in (b). (Modified after - http: www.google .com downloaded on 8th February 2018)

In young trees the center of the woody column, inside the xylem, consists of soft thin-walled cells called the pith. The pith serves as a storage tissue for sugars and later as a reservoir for wastes. In older trees the pith is crushed by the xylem's woody tissue, and wastes are simply deposited in the wood cells near the center of the trunk. As a result, in some trees the cells within the pith become dark in color and form what is often called the heartwood. The lighter cells around them make up the sapwood. The importance of cambium in promoting regeneration was again not proven as expected.

With regard to heart wood, it is obvious that all trees need mechanical support. This could be a factor that may limit tree height. As the tree grows taller mechanical strength is required. Even the largest known trees remain well below the height–diameter ratio that would cause toppling with minimal wind sway. As height increases diameter should also increase in order to keep them from toppling over (Encyclopaedia Britannica, 2010). The taller thicker trees are the ones charcoal producers require because they yield more and large logs to form a kiln and the in process mature forest stands become the prime targets for charcoal producers. The desire for large stems could also explain the reason why kilns are longer (about 12 m) than their height (about 2m). If they were made higher than 2m manual piling of large logs would be a physical constraint.

Contrary to the earlier expectation that older trees with larger heart wood would have less regeneration and perhaps produce fewer saplings because heartwood is predominantly a preserve of dead cells, was not proved in this research. All trees irrespective of heart wood size regenerated. The lack of relationship cannot also be explained by the results of this study.

Earlier research findings on regeneration of miombo in Zambia by Chidumayo (1987, 1997) examined the influence of season and soil conditions and not tree trunk macro-structures. He showed that the slow re-sprouting between warm and cold season, was attributed to low temperatures during the period May-July when buds seem to become quiescent, suddenly flushing out when temperatures start to rise sometime in August, when most deciduous species put on new leaves as well.

It could therefore, for now, appear that the main factors that would require further detailed investigation are;

i) the number of height growth units (the node plus its subtending internode) produced during each growing season and elongation of the internodes,
ii) water availability,
iii) soil quality,
iv) climatic variation,
v) as well as to the time of year.

These could be responsible for the variation in the rate of sprouting between seasons and tree trunk macro-structures.

While an attempt has been made to explain the observed variations between seasons, the other insignificant variations observed between species (see Figure 6) may not easily be explained but can be attributed to genetic factors and the role of hormonal induced growth, but this cannot also be validated by the results of this study.

4.3 Conclusion

At the beginning of the study, it was conceptually assumed, that in addition to soil moisture and nutrients, macro-structural components of each tree species would influence regeneration. Implying therefore, that larger proportions of these structural components would yield higher and faster regeneration and vice versa. This has not been proven in this study. No temporal and numerical differences for instance, between species, stump height and diameter, bark thickness, and size of heart wood and cambium were established. This study is therefore inconclusive and further research is required to investigate other factors that may be critical in influencing regeneration in addition to the known ones.

4.4 Recommendation

The macro structural components originally assumed to influence regeneration have not been proven. In light of this dichotomy, it is critical in the next study following from this outcome to consider other factors such as; root structure and root depth, soil structure and moisture retention capacity, the level of accumulation of chemical compounds such as resins, phenols, and terpenes between species and age groups or stem size.

With respect to post harvest management, this study shows the impact of fire on the survival rate of saplings. Formulation and implementation of a community-based fire management plan would enhance the survival of saplings and together with soil moisture and fertility promote the ecological forest restoration of miombo woodlands.

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