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Full Length Research Paper

Age and growth rate determination using growth rings of selected miombo woodland species in charcoal and, slash and burn regrowth stands in Zambia

Stephen Syampungani[1]*, Coert Geledenhuys[2] and Paxie W. Chirwa[3]

[1]Copperbelt University, School of Natural Resources, P. O. Box 21692, Kitwe, Zambia.
[2]Department of Forest and Wood Science, University of Stellenbosch, P/Bag X1, 7602 Matieland, South Africa.
[3]University of Pretoria, Forestry Chair, Postgraduate Studies, Lynwood Rd, Pretoria 0002, South Africa.

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The field of dendrochronology has not been widely applied in tropical species because many scientists generally perceive that such species rarely produce distinct growth rings. This study was undertaken to determine if the key Miombo species produce distinct growth rings and to determine the relationship between the number of growth rings and age of the tree and stem diameter. The results showed a high correlation between number of growth rings and stand age for both charcoal ($P < 0.001$, $r = 0.9246$) and slash and burn ($P < 0.001$, $r = 0.9019$) regrowth stands. Additionally, the study has revealed high mean annual ring width values ranging from 4.4 to 5.6 mm in both charcoal and slash and burn regrowth stands. The pattern of ring development per year and the mean annual ring width values provide a basis for the use of ring counts in determining the age of Miombo regrowth stands and predicting the merchantable age for key Miombo woodland species. The results can therefore be used in planning the cutting cycles in Miombo woodlands. However, the phenomenon of missing growth rings suggests that the influence of environment in the use of growth rings in age determination need to be considered in areas that experience droughts.

Key words: Growth rates, growth rings, slope, diameter at breast height and cutting rotations.

INTRODUCTION

Can growth rings of trees in Miombo woodlands in the tropics be used to determine their age and hence growth rates? Many people would say that is not possible because many scientists generally perceive that tropical species rarely produce anatomically distinct growth rings each year (Celander, 1983; Lilly, 1977) as the tropics do not show a strong seasonality in temperature and day length. However, some tree stems especially in regrowth stands, do show relatively distinct rings. Dendrochronology or tree-dating has been widely applied to climatic, ecological and forestry problems in the temperate latitudes where strong seasonality in temperature and day length induce dormancy and annual growth ring formation in many trees (Stahle et al.,1999). Tree-dating has been applied in few studies namely *Podocarpus falcatus* (McNaughton and Tyson, 1979) and *Pterocarpus angolensis* (van Daalen et al., 1992) in Southern African species.

The absence of clearly identifiable annual growth rings in tropical species to determine the age and growth rate of trees, when compared with clear rings in many temperate tree species, has made it difficult for forest managers to effectively determine cutting rotations and sound management of these forests. This also applies to Miombo woodland species (Grundy, 1995; Geldenhuys, 2005). However, the distinct seasonality of precipitation in many tropical climates does induce annual rhythms in the physiology of many tropical species, which may result in the production of annual growth rings (Borchert, 1991).

*Corresponding author. E-mail: syampungani@cbu.ac.zm, ssyampungani@yahoo.com.

Additionally, annual growth rings have, in the past, been used by forest managers in determining the age of Miombo woodland in Zambia (Fanshawe, 1956) and recently, research has shown that some tropical and sub-tropical species are capable of producing growth rings which correlate with age (Fahn et al., 1981; Jacoby, 1989; Gourlay and Barnes, 1994; Grundy, 1995; Stahle et al., 1999; Geldenhuys, 2005; Grundy, 2006). The studies of Grundy (1995) and Stahle et al. (1999) were specific to Miombo woodland. Each of these studies had some limitations. Grundy's observation was based on a four-year study period on stems of unknown manage-ment history. Stahle et al. (1999) observed evidence of phenology, ring anatomy, cross dating and the correlation between the growth rings in *P. angolensis* and seasonal climatic data. They left out evidence of the relationship between the number of growth rings and the age of the study site and the relationship between the growth rings and the diameter of these species. Furthermore, our study also dealt with correlating tree rings with different management (slash and burn agriculture and charcoal production). Whilst their findings are promising, it must be recognized that they need to be supplemented with studies of other key species of Miombo in order to add to the existing body of knowledge on use of growth rings in determining growth rates and the age of the Miombo woodland.

Most investigations of growth rate using growth rings have been based on either coring (Stahle et al., 1999), or whole discs (Gourlay, 1995), or a combination of the two, or by damaging the cambium (Grundy, 1995, 2006) and then cutting the cross section of the stems at heights of either 1.3 or 1.4 m from the ground to allow for counting of the growth rings. However, Chidumayo (1988) used diameter increment data collected over a long period of time to determine the influence of early burning and complete protection on the growth rate of some Miombo species. Apart from being limited to the influence of fires, Chidumayo (1988) based his observation 1.3 m from the ground. Additionally, the study did not involve any study of growth rings. Each of these methods has some limitations. For example, increment core sampling in species with dense wood is difficult, and the operator may miss or fail to reach the pith. And therefore, this could result in inaccuracies in determining the growth rings. Additionally, most seedlings in miombo tend to take time to reach the height of either 1.3 or 1.4 m from the ground at which samples were taken, and therefore such techniques could result in underestimating the age of the trees.

In this study, the research objectives were: (i) To determine the relationship between the numbers of growth rings in selected key Miombo species and the age of the chosen sites. (ii) To determine the relationship between growth rings and the diameter of the chosen species. (iii) To determine the reliability of growth rings in age determination. The key questions were: (i) What are the largest diameters for each selected species in each disturbance and age categories? (ii) What is the number of growth rings in each stem diameter? (iii) What number of growth rings does each species show in each age category? The species of focus were *Brachystegia floribunda, Isoberlinia angolensis* and *Julbernadia paniculata.*

MATERIALS AND METHODS

Study area

Two different sites in Masaiti District 13° 25' 00"S to 13° 45' 00"S, and 28° 25' 00"E to 28° 40' 00"E) were selected for the study: Mwaitwa and Kaloko-Luansobe (Figure 1). The sites were selected because they were of known management history that made it easier to relate the number of growth rings with age and therefore determine the growth rates of species.

The climate of the area is characterized by an alternation of dry and wet seasons. Based on temperature and rainfall, three distinct seasons are recognized in the area: hot dry season (August - October); hot wet season (November - April); and cool dry season (May - July). The average annual rainfall is 1250 mm (MTENR, 2003). The temperatures range from 16 to about 27°C in the cold-dry season and from 27 to 38°C in the hot dry and warm rainy seasons (MTENR, 2003). The lowest temperatures usually occur in June/July while the highest temperatures occur in October.

Methods

Sampling design

The data were collected in areas of known age after previously being under different land use types namely, slash and burn agriculture or charcoal production, and also from natural mature forests. In each land use category, sites were selected with the following ages: 7, 8, 10, 16, 17, and 20 years since disturbance cessation. In each site, six plots were randomly selected. The Global Positioning System was used to locate plots in the field. Within each stand, the stems with the largest diameters of the key species were selected for study (Figure 2). The assumption was that the largest stems of a species were the oldest in each stand and therefore would be more reliable in determining the relationship between stand age and number of growth rings. The three selected key species, *B. floribunda*, *I. angolensis* and *J. paniculata,* were abundant in both the former charcoal production and slash and burn agricultural sites. The selected stems were located by measuring distances from the tree to the centre of the plot and the following recorded for each stem: diameter at breast height (DBH) and diameter at the point where the disc was cut.

Collection of stem sections

Attempts were made to minimize errors mentioned under the introduction section during data collection. Firstly, the stems selected for study were cut at 10 to 20 cm height from the ground level or stump, in case of a shoot, in order to capture the maximum number of growth rings. Secondly, the discs were cut using a sharp silky saw that made the final surface smooth with clear ring boundaries. From each stem, one disc was cut for study. A number of cut sections for each species were selected for study. Table 1 shows the number of sections which were selected for each species under each disturbance and age category. Each disc had three points marked at known distances from each other before taking the photograph using a Canon PowerShot A620 digital camera.

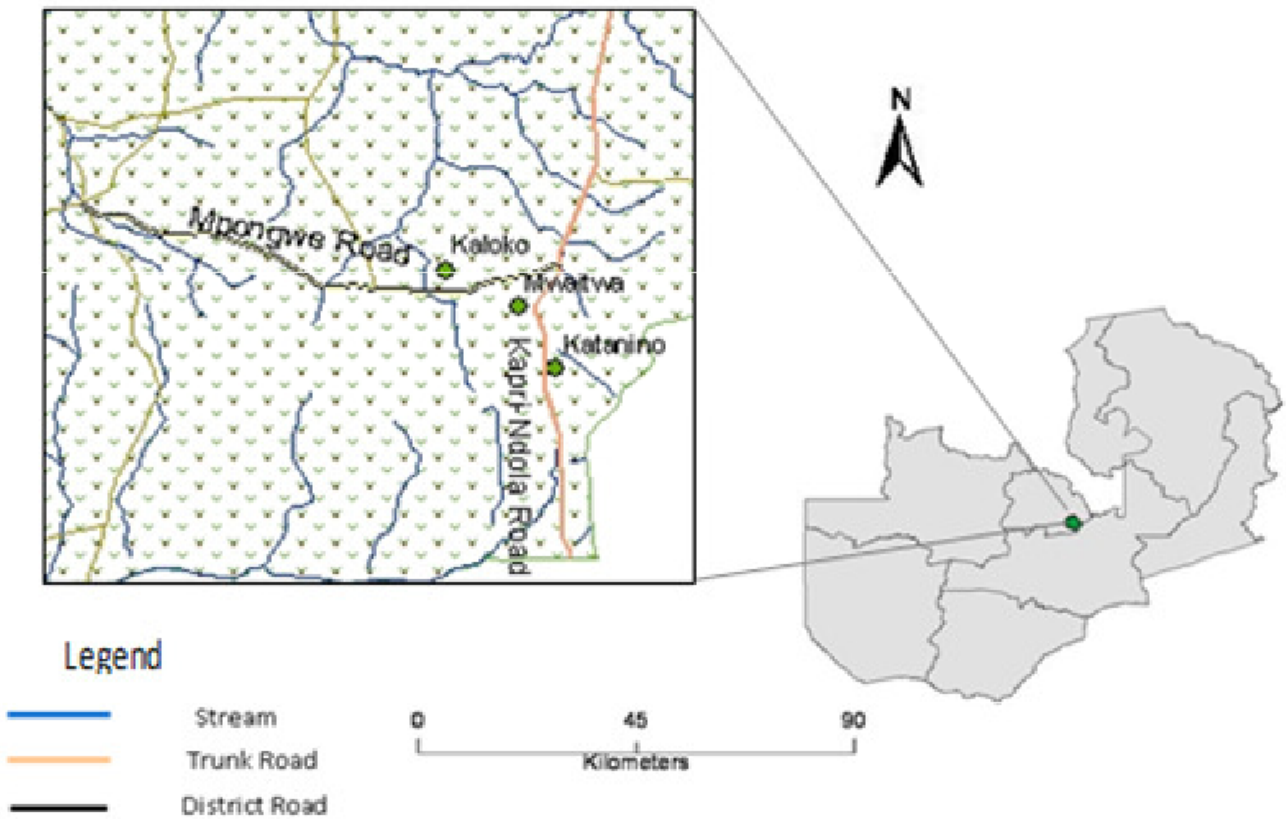

Figure 1. Map of Zambia showing study area in Masaiti District, Copperbelt Province.

Figure 2. *I. angolensis* multiple stems in a ten year abandoned slash and burn regrowth stand.

These points were used to scale the software during data analysis.

Data analysis

Image *J* 1.37 version (National Institutes of Health, 2007) software was used in counting rings and also in determining the ring widths of the key species. Thereafter, the Bonferroni test using STATISTICA statistical package version 6.0 (StaSoft, inc., 2003) was used to determine the relationship that exist in growth rates within species under different disturbances, and also between different species under similar disturbances.

Table 1. Number of stem sections selected for each species under each disturbance category.

Disturbance type	Slash and burn			Charcoal production			Mature	
	Years since disturbance cessation							
Species	7-8	10	15+	7-8	10	15+	7-8	10
	Number of stem sections per age class of each disturbance type							
J. paniculata	20	21	21	20	20	20	20	20
B. floribunda	20	20	20	20	20	20	20	20
I. angolensis	20	20	20	21	21	20	20	20

RESULTS

Correlation between number of growth rings and stand age since disturbance cessation

The growth ring boundaries were reasonably distinct in all three species from both the charcoal and slash and burn regrowth stands (Figure 3a, b and e) although, the less clear growth rings were observed in older stands (Figure 3c). Less clear rings were typical of the discs from mature woodlands (Figure 3d and f). Additionally, the plotted profiles of all the studied species clearly showed distinct growth rings. The number of growth rings showed a strong positive linear relationship with stand age in both slash and burn ($r = 0.9019$; $P < 0.01$; slope of curve = 0.97; $n = 182$) and charcoal ($r = 0.9246$; $P < 0.01$; slope of curve = 1.01; $n = 182$) regrowth stands (Figure 4). However, the discs from mature woodland of the same diameter as those from the regrowth stands did not show any distinct growth rings (Figure 3 d, f). The slope of 0.97 for the slash and burn regrowth stand curve indicates one missing growth ring in every stand age, while the slope of 1.01 for the charcoal regrowth stand curve shows the occurrence of one additional growth ring per every stand age.

Correlation between the number of growth rings and DBH

All the species studied showed strong correlation between the number of growth rings and the DBH of a tree, in both slash and burn ($r = 0.8806$; $P < 0.01$; slope of curve = 0.83; $n = 182$) and charcoal ($r = 0.9068$; $P<0.01$; slope of curve = 1.21; $n = 182$) regrowth stands (Figure 5). The slope of 0.83 for the slash and burn regrowth stand curve indicates a growth ring in every 1 - 2 cm change in DBH. The slope of 1.21 for the charcoal regrowth stand curve indicates a growth ring in every 1 cm change in DBH.

Growth rate in charcoal and slash and burn regrowth stands

Table 2 shows the mean annual ring widths observed in individual key species in charcoal and slash and burn regrowth stands. Mean annual width was significantly different between species within the same disturbance category ($P < 0.005$) with stand age. *I. angolensis*, with the mean ring width of 5.60 mm in charcoal regrowth stands and 5.40 mm in slash and burn regrowth stands, exhibited the highest growth rate amongst the key species. Generally, the ring width tends to increase from the youngest stands to the stands of ten years in age in all three species (Table 2). Thereafter, the ring width tends to reduce. However, there is no significant difference in mean ring width within the same species under different disturbance factors.

DISCUSSION AND CONCLUSION

Correlation between number of growth rings and stand age, and DBH size

All three selected species for this study showed that the number of growth rings can be used as a good estimate of stand age in both charcoal and slash and burn regrowth stands. However, the slope of the positive linear regressions suggests that in slash and burn regrowth stands there is about one missing growth ring every stand age (slope of 0.97) and that in charcoal regrowth stands there is an additional one ring per every stand age (slope of 1.01). This shows that a tree in a 20 year old slash and burn and charcoal regrowth stands will have 19 and 21 rings, respectively. In charcoal regrowth stands, an additional growth ring may be attributed to the fact that young plants are left behind during clearing for charcoal production. Additionally, some stumps tend to sprout as clearing for charcoal proceeds and consequently develop into trees. Missing or locally absent growth rings are frequently due to very dry years or droughts (Stokes and Smiley, 1968). However, the absence of one ring in slash and burn regrowth stands every year cannot be attributed to the occurrence of drought as the charcoal regrowth stands in the same area did not show the same patterns**.** Additionally, the rainfall data (1261 ± 55 mm) (Zambia Meteorological data, unpublished) indicated that the study area received within the normal range of rainfall for the period included in the study (see MTENR, 2003). Therefore, the missing ring suggested by the slope in slash and burn regrowth stands may be attributed to

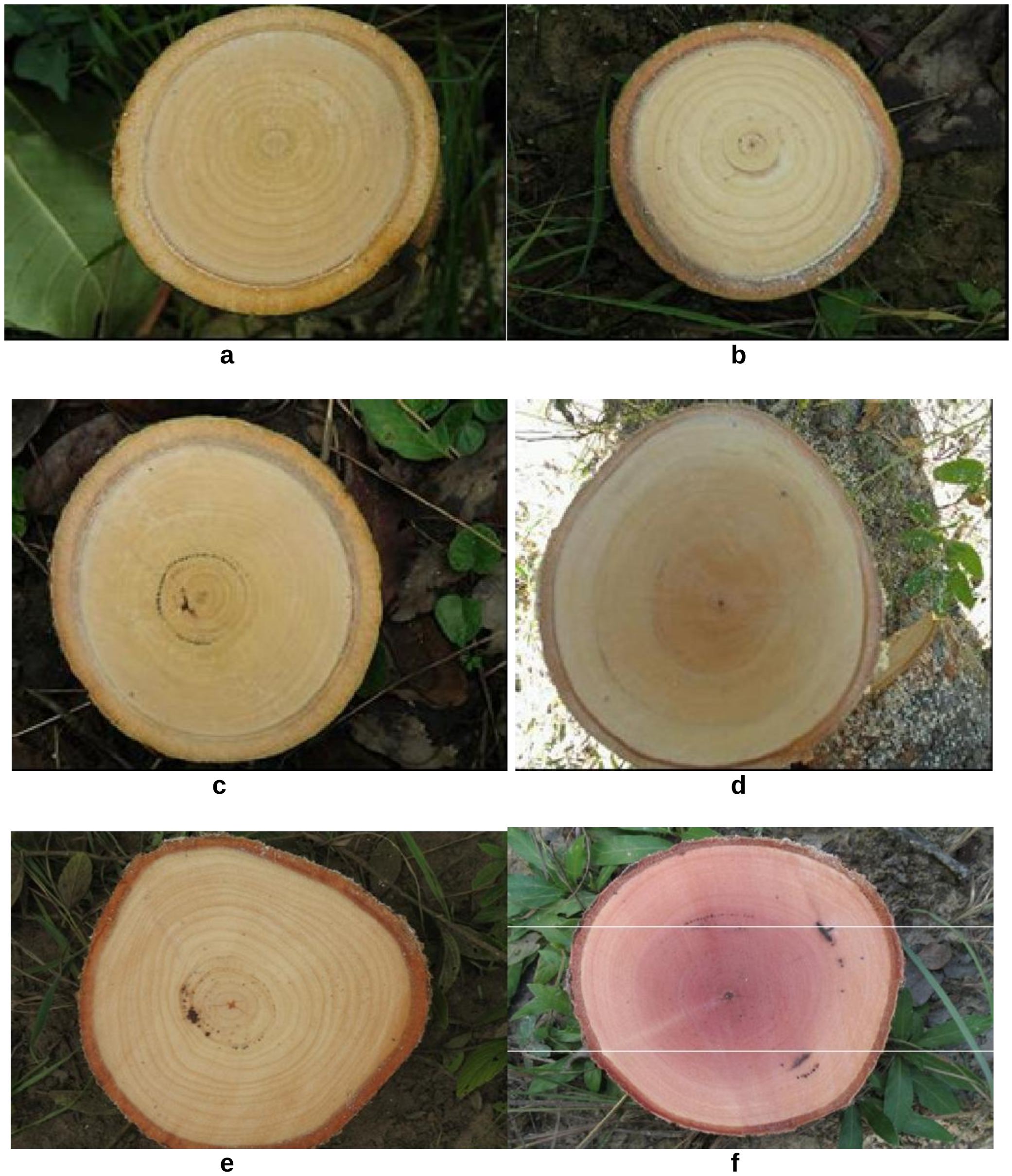

Figure 3. (a) *Julbernadia paniculata* (10 year old charcoal regrowth stand), (b) *Brachystegia floribunda* 10 year old slash and burn regrowth stand), (c)*Brachystegia floribunda* (16 year old slash & burn regrowth stand), (d) *Brachystegia floribunda*, (Mature woodland stand), (e) *Isoberlinia angolensis* (15+ year old slash and burn regrowth stand), (f) *Isoberlinia angolensis* (Mature woodland stand) Discs of *Julbernadia paniculata* (a), *Brachystegia floribunda* (b, c, d) and *Isoberlinia angolensis* (e, f) from different stands.

constant removal of seedlings or sprouts observed during the cultivation period as they are considered as weeds. Additionally, delayed stem development due to shoot die-back resulting from frequent fires as slash and burn sites normally have higher incidences of fires (Boaler and Sciwale, 1966) may also contribute to discrepancies between stand age and the number of growth rings. The discrepancy may also be attributed to delay germination as most plants in slash and burn regrowth stands developed from seed (Syampungani, 2008).

The high correlation between number of growth rings and stand age may be attributed to the fact that the Copperbelt Province experiences strong seasonality in both temperature and rainfall (MTENR, 2003; Tyson, 1986) which according to Stahle et al. (1999) results in annual ring formations. Additionally, these species are deciduous during the annual dry season and their phenology is tightly synchronized with the seasonality of temperature and precipitation (MTENR, 2003; Storrs, 1995). According to Borchert (1991), the seasonality in

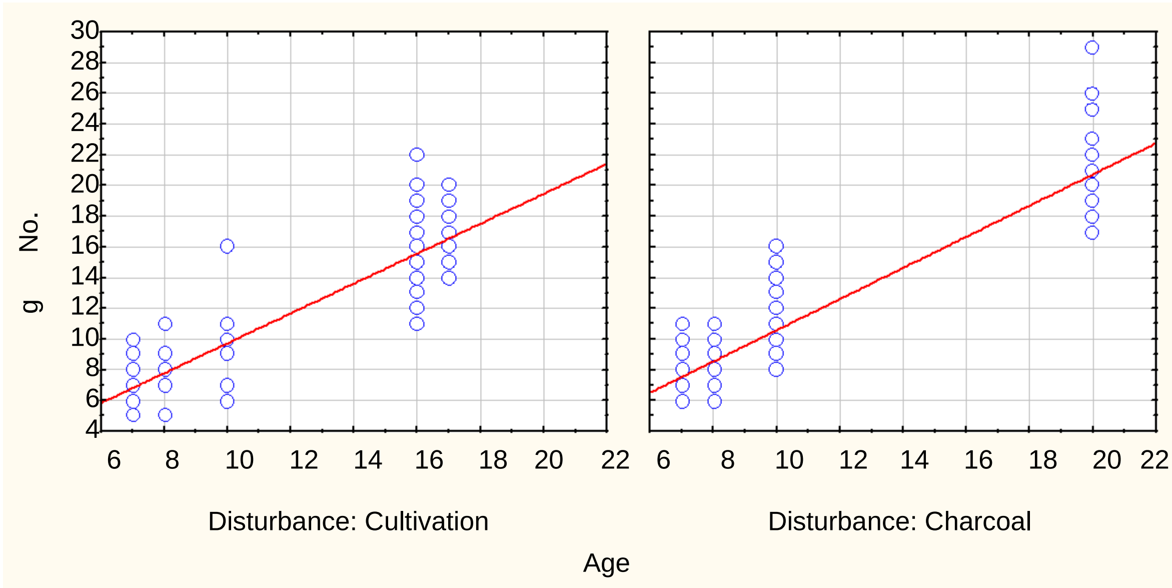

Figure 4. The positive linear relationship between stand age and the number of growth rings in regrowth stands after different years after abandoning slash and burn agriculture (cultivation) and clearing for charcoal production.

Table 2. Growth rates of selected key miombo woodland species under different disturbances.

Species	Mean annual ring width, mm							
	Stand category and age							
	Slash and burn regrowth stands/age (yrs)				Charcoal regrowth stands/age (yrs)			
	7-8	10	15+	Mean	7-8	10	15+	Mean
B. floribunda	4.8± 0.3	5.8± 0.2	4.7±0.2	5.1± 0.6	3.8± 0.3	4.9±0.3	4.6± 0.1	4.4± 0.6
I. angolensis	5.7± 0.4	5.8± 0.1	4.6± 0.6	5.4± 0.7	5.6± 0.3	6.6±0.4	4.6±0.2	5.6± 0.9
J. paniculata	5.0± 0.2	5.0± 0.2	4.2± 0.2	4.7± 0.5	3.6± 0.2	4.8±0.2	4.7± 0.2	4.4± 0.7

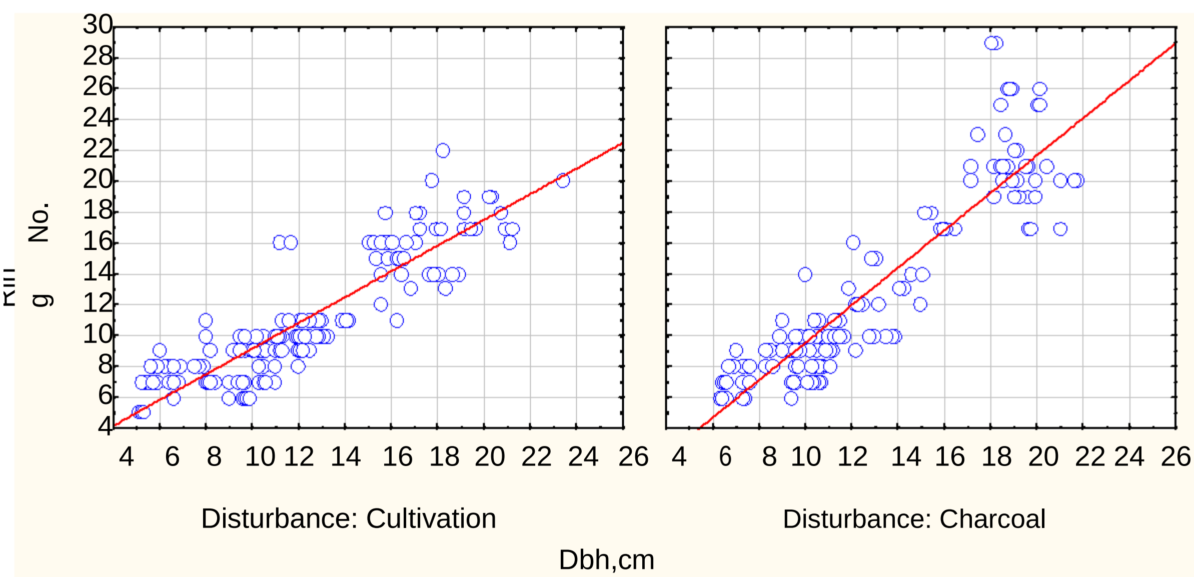

Figure 5. The relationship between DBH and number of growth rings in stems in regrowth stands after different years after abandoning slash and burn agriculture (cultivation) and clearing for charcoal production.

flowering, leaf flush and leaf fall strongly suggests that radial growth is also restricted to the summer wet season. Additionally, Geldenhuys (2005) suggested that the strong and consistent diameter growth of free growing stems in re-growth stands contributes to the clear and wide rings. This may also explain why samples from mature woodlands did not show distinct growth rings. Lack of clear growth rings in samples from mature woodlands would therefore, be attributed to narrow and unclear rings that develop as a result of high competition for either nutrients or light. The linear relationship between growth rings and tree age have been reported in other Miombo ecoregion species, namely *B. spiciformis* in Zimbabwe (Grundy, 1995), *P. angolensis* in Tanzania (Boaler, 1963) and *A. tortilis* in Kenya (Wyant and Reid, 1992).

The study has also revealed a highly significant relationship between diameter at breast height and the number of growth rings, in both charcoal and slash and burn regrowth stands for all species (Figure 5). This implies that the bigger the DBH the higher the number of growth rings. This also implies that larger stems selected in the study have given reliable data for use in estimating the age of the Miombo woodland stands.

Growth rate

The mean annual ring width observed between different species under different disturbances revealed that there is a significant difference in mean annual ring width between these species. However, the mean annual ring widths of similar species under different disturbances did not differ significantly although, the modes of regeneration differed between charcoal and slash and burn regrowth stands (Syampungani, 2008). The results seem to suggest that the mode of regeneration does not result in significant differences in growth rate of individual species. Although, the mode of regeneration may be important in influencing the growth rate of plants, there is a general consensus that, in arid regions, it is rainfall that is the dominant factor in determining growth rate (Fahn et al., 1963; Glock 1941) between different areas of different rainfall regimes.

Comparatively, the mean annual ring width values observed in the study (Table 1) are relatively higher than the range of values reported by Chidumayo (1988) in his study of the influence of fire on Miombo species growth. Chidumyo (1988) reported annual growth rate values ranging from 3.6 to 4.8 mm. Additionally, the current mean annual ring width values are higher than the growth rate values observed in *P. angolensis* in South Africa. For example, Shackleton (2002) reported the mean annual diameter of 4.5 mm (mean ring width value of 2.3 mm) and Groome et al. (1957) reported the mean annual diameter increment ranging from 0.3 - 2.8 mm per year (mean ring width range of 0.15 - 1.4mm). Von Maltitz and Rathogwa (1999) reported the growth of 3.5 mm. In Zimbabwe, Grundy (1995) reported the mean growth of 0.27 cm^{-1} $year^{-1}$ for all trees in an area protected from fire and human disturbance. The higher growth rate values in the current study when compared to the previous studies may be attributed to the fact that the current study dealt with the younger stands while the previous works dealt with mature woodland stands. Relative growth rates tend to decline with age of trees. This nonetheless suggests that trees in open areas grow much faster than in mature stands. This confirms Geldenhuys (2005)'s observation in Mozambican Miombo woodlands.

The identification of annual growth rings in *J. paniculata*, *B. floribunda* and *I. angolensis* for both charcoal and slash and burn regrowth stands has important implications for forest ecology and management of Miombo woodlands. Even with the problem of a missing and an additional growth ring in slash and burn and charcoal regrowth stands respectively, the study still suggests that the ring counts could still be used in determining the age of Miombo regrowth stands as the ecosystems has a strongly seasonal, unimodal rainfall pattern. Additionally, the growth rates information generated from the study will help in size predictions of the key Miombo species in that the study has provided a means of collecting growth rate data in both slash & burn and charcoal regrowth stands which is relatively easy. The current data may be supplemented with other growth rate data for trees of known age or measuring larger trees over time. The growth rate data have shown that trees that grow on open areas (areas previously under slash and burn agriculture and charcoal production) will be much faster in growth than tree seedlings that have to start under the canopy of the mature woodland. Trees in slash and burn regrowth stands will therefore reach merchantable sizes (35 - 40 cm DBH) (Chigwerewe, 1996; Geldenhuys, 1996) faster than those in mature woodlands.

However, care must be taken in the use of rings and growth rate data in areas that experience drought or dry years as some studies elsewhere (e.g. Stokes and Smiley, 1968) have shown that droughts result in missing growth rings. Such information would be very useful when used together with the climatic data and also an understanding of the disturbance factor that land was exposed to in order to relate the missing growth rings with drought frequencies and the disturbance factor. Lastly, since the study was carried out in wet Miombo woodlands, it would be important to carry out a similar study in dry Miombo woodlands in order to increase the validity and applicability of this information. Additionally, since the models were derived from species of the same family, future studies should include other species so as to enhance the understanding of the Miombo woodland ecosystem.

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