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Determination of Growth Rate and Age Structure of *Boswellia papyrifera* from Tree Ring Analysis: Implications for Sustainable Harvest Scheduling

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ABSTRACT

Boswellia papyrifera is a multipurpose deciduous species that grows in Combretum – Terminalia deciduous woodlands of Ethiopia. It is widely known for its commercial frankincense production. The *B. papyrifera* woodland is under a problematic state of population decline due to heavy encroachment and unsustainable tapping. To sustainably manage such a sensitive ecosystem needs exact knowledge of growth rates and age structure of trees where such information on tropical trees under natural condition is rather poor. In this study growth rate and age of *B. papyrifera* was determined from tree ring analysis. The study was carried out in Lemlem Terara, Metema district, Ethiopia. The mean annual diameter growth rate of *B. papyrifera* derived from the mean ring-width is 2.32mm and varies among sample trees. All sampled trees showed a comparable general growth trend which can be divided into three phases – i) good growth in the beginning, ii) phase with depression in middle and iii) increase in ring width. The average age of *B. papyrifera* trees growing in the study site is estimated to be about 75 years. Although there is strong correlation between diameter of a tree and age, the result from this study highlighted that age-size relations should be used cautiously as the diameter may not reflect the true age. The result from this study is important input to develop strategic plan for the species regarding tapping frequency and intensity as per the annual increment of the species. For further dendrochronological studies of the species, it is recommended to take samples from different size classes and slope gradients for better and reliable results. In future, the use of tree ring analysis as a tool to understand growth dynamics and age structure of trees species, and their response to climate variability should be strengthen in Ethiopian.

Keywords: *Boswellia papyrifera*, Annual growth rings, Diameter growth rate, Age structure, Ethiopia.

1. INTRODUCTION

Boswellia papyrifera is a deciduous multipurpose tree species that grows in a savanna belt that stretches from northern Nigeria eastwards to the highlands of Eritrea and Ethiopia (Rijkers et al., 2006). In Ethiopia, it grows in Combretum – Terminalia deciduous woodlands (Demissew, 1996). It is widely known for its frankincense production which is extracted by wounding the bark of the tree several times during the dry season (Rijkers et al., 2006). Frankincense production is an important source of revenue for the country as well as for the local people

(Tilahun et al., 2007; Lemenih et al., 2007) and therefore *B. papyrifera* is one of the most important economic tree species in the country. Besides, the tree has various local uses including medicinal values, leaves as source of fodder for animals, flowers as a source of nectar for bees and wood used for different purposes (Gebrehiwot et al., 2003; Eshete et al., 2005). Its ability to grow on marginal lands such as dry and rocky sites makes this species to plays a key role in the ecology of drylands (Gebrehiwot et al., 2003).

Despite its high economic, social and ecological role, *B. papyrifera* is facing rapid population decline (Eshete et al., 2005; Lemenih et al., 2007), and it is among those important woody species that are highly endangered (Gebrehiwot et al., 2002). Hence, development of management strategies to ensure sustainable utilization of the resource is critical. In this regard, information on growth rate and age of the species is important silvicultural data to manage the resource in a sustainable way (Therrell et al., 2007). Knowledge on growth rates of *B. papyrifera* could yield important information in planning resin tapping frequency and intensity for the species. Besides, knowing the age of *B. papyrifera* trees in a population could be important to study past events such as drought occurrence in the study site (Fichtler et al., 2003; Gebrekirstos et al., 2008). Nevertheless, there is no information available on growth rate and age of the species.

The application of tree ring analysis for estimation of growth rates and age of tropical trees has been limited due to the assumption that tropical trees do not form annual growth rings (Lang and Knight, 1983; Lieberman et al., 1985). Although detection of annual growth rings is more difficult and complicated for tropical trees than for temperate trees due to lack of strong seasonality in climate, in many tropical areas there is seasonality in rainfall which can induce seasonal growth of trees thereby produce annual growth rings (Fichtler et al., 2003). The presence of annual growth rings has been proven for many tropical species including *B. papyrifera* (Stahle et al., 1999; Worbes et al., 2003; Verheyden et al., 2004; Schongart et al., 2006; Gebrekirstos et al., 2008; Sass-Klaassen et al., 2008; Nzogang, 2009; Tolera et al., 2013). This is evident that tree ring analysis can be potentially used to study growth rates and age determination of tropical trees. Hence, this study aims at determining growth rate and age of *B. papyrifera* from tree ring analysis which will be an important input to develop strategic plan for the species regarding tapping frequency and intensity as per the annual increment of the species.

2. MATERIAL AND METHODS

2.1. Study Site

The study was carried out in Lemlem Terara in Metema district. Metema is one of the districts in Amhara region of Ethiopia where *B. papyrifera* is widely growing (Fig 1). The study site is geographically located at 12^0 40' N and 36^0 17' E with an altitudinal range of 810 to 990 m.a.s.l. The annual rainfall of Metema ranges from 660-1100 mm with mean annual rainfall of about 884 mm (Groenendijk et al., 2012). Metema has a uni-modal rainfall pattern. The vegetation of the study site is characterized as woodland forest where it is dominated by Acacia, Boswellia and Commiphora species. The density of *B. papyrifera* in the study site is estimated to 175 stems per hectare, with total density including other tree species of 749 stems per hectare. Diameter of *B. papyrifera* ranges from 9 – 45 cm and height ranges from 6 – 16 m (Eshete et al., 2005).

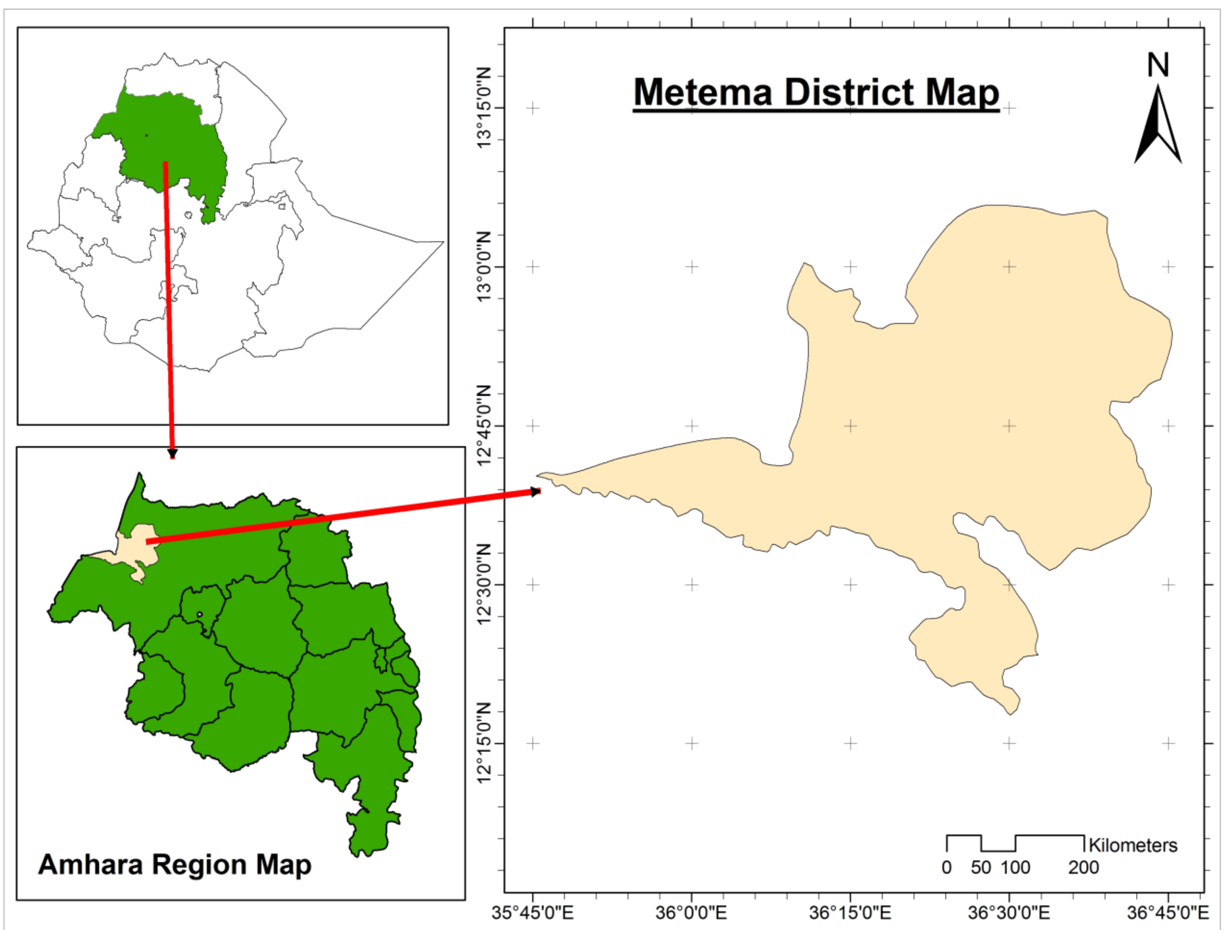

Figure 1. Map of the study area.

2.1 Sample Collection and Preparation

Four *B. papyrifera* sample trees, two tapped and two untapped trees (with no indication of tapping scars in their bark) were selected and felled using chain saw. The untapped trees in this case were considered either they never experienced tapping or at least have been rested for many years. The untapped trees were situated in relatively less accessible topography which might limit tapping activity in those areas. Sample discs were collected from sample trees at 1.3 m height. Sample discs were air dried and the transverse section of the stem discs were sanded using progressively finer textures of sandpaper (80 – 1200 grit) in order to get clear and smooth surface for macroscopic investigation. Dust was removed from the cell lumina using air compressor to improve visibility of growth-ring boundaries. Of course the sample size we used for this study is small. But, destructing large number of sample trees is not advisable as the species is endangered.

2.2 Growth-ring Identification and Marking

Wood-anatomical features that could possibly define growth-ring boundaries were carefully examined macroscopically and microscopically. Following the anatomical features that defines ring boundaries, concentric growth rings around the entire cross-section of sample discs were detected and they were marked. Marking process for growth-ring boundaries was done in four radii and rings were counted and cross-checked along the four radii. To avoid incorrect marking of ring boundary, very obvious ring boundaries ('pointer years') were marked bolded along all the radii and number of ring boundaries in between bold marks was cross-checked for their consistency along the four radii. By doing this the possibility of missing a ring boundary due to its indistinctiveness or marking a false ring boundary was minimized.

2.3 Ring-width Measurement

Ring-widths were measured with a precision 0.01 mm using a digital measuring device LINTAB which is connected to a computer program TSAP (Time series analysis and presentation). In case trees have an asymmetric growth pattern along the circumference of their trunk, ring widths can vary considerably around the circumference of the tree. For this reason, ring-widths were measured along four radii on each sample discs. The measurements from the four radii were subsequently averaged to calculate an average ring-width series for each tree.

3. RESULTS

3.1 Growth Rate and Growth Pattern

As growth rings in *B. papyrifera* are confirmed to be annual from the cambial marking experiment, the mean ring-widths values indicated in table 1 represent mean annual diameter increments of sampled individual trees. Based on the result from the mean ring-width of the sample trees, the average annual diameter growth rate of the species is 2.32mm. There is large variation in mean annual diameter growth rate among sampled individual trees (Table 1). For instance, mean annual diameter increment of T_{3u} is twice of the mean annual diameter increment of T_{1t}. There is no systematic difference between tapped and untapped trees in their growth rate.

Table 1. Number of rings and mean annual diameter increment of four *B. papyrifera* trees**.**

Sample Tree Code	***Number of Rings***	***Mean annual diameter increment (= 2*Mean ring width, mm)***	***Standard Deviation***
T_{1t}	75	1.63	0.57
T_{2t}	68	2.34	0.58
T_{3u}	77	3.18	0.72
T_{4u}	78	2.17	0.50

Note: *T_{1t}= Tree No 1, tapped; T_{2t}= Tree No 2, tapped; T_{3u}= Tree No 3, untapped; T_{4u}= Tree No 4, untapped.*

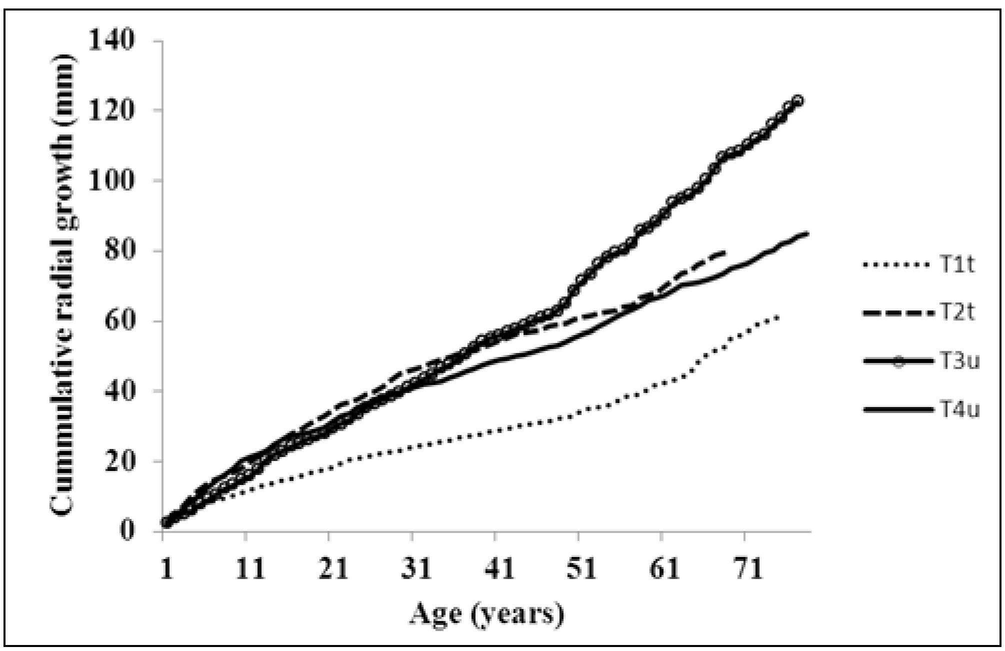

Figure 2. Individual cumulative radial growth of four Boswellia trees.

All the sampled trees show a similar growth trend; not the classical trend of declining ring-width with increasing age but good radial growth at the beginning (juvenile phase), growth depression in the middle part and a trend with increase in radial growth during the last phase (Fig 2). However, the time of depression is not synchronous in all the trees, i.e. the beginning of the depression period and the time of release from the depression is different in all the trees. But, the time of release from the depression phase for the untapped trees is earlier than the tapped trees (Fig 2).

3.2 Tree age

Age was determined by direct counting the number of annual growth rings until the time of sampling. Age of sampled trees is shown in table 2. The average age of *B. papyrifera* trees growing in the study area is about 75 years. However, number of rings indicated in table 2 do not necessarily represent the exact age of the trees because of the sampling height. Stem discs were sampled at 1.3 meter above the ground level and therefore some rings are missed. Hence, the actual average age would be more than 75 years. The age difference among the sampled trees is not high but there is huge difference in their DBH (Table 2). For instance, the age difference between T_{1t} and T_{3u} is only two years but the difference in DBH of the two trees is 12cm.

Table 2. Diameter at breast height (DBH) and age of four *B. papyrifera* trees.

Sample Tree Code	***Diameter at breast height (DBH, cm)***	***Number of Rings (=Age, yr)***
T_{1t}	17.2	75
T_{2t}	20.4	68
T_{3u}	29.2	77
T_{4u}	22.3	78

Note: T_{1t}= Tree No 1, tapped; T_{2t}= Tree No 2, tapped; T_{3u}= Tree No 3, untapped; T_{4u}= Tree No 4, untapped.

4. DISCUSSION

Tree ring analysis yields direct values and lifetime growth rates and therefore more accurate than extrapolations based on short-term growth data by repeated diameter measurement method (Brienen and Zuidema, 2006). As growth rings in *B. papyrifera* are confirmed to be annual (Tetemke, 2010), growth rate of the species was determined from the mean ring-width of sampled trees. The annual diameter growth rate of 2.32mm is similar to the result found by

Tolera et al. (2013) in the locality of our study area. Tree ring analysis has been successfully used in the tropics to determine growth rates of many tropical tree species which form annual growth rings (Worbes et al., 2003; Schongart et al., 2006; Therrell et al., 2007; Nzogang, 2009, Syampungani et al., 2010).

We have tried to compare growth rate between tapped and untapped trees as tapping is likely to have an effect on growth rate of individual trees (Lemenih and Kassa, 2011). In a study conducted by Silpi et al. (2006) on a rubber tree *Hevea brasiliensis*, tapped trees showed 50% decline on growth rate as compare to untapped trees. Unfortunately, in our result no systematic differences in growth rate could be detected between tapped and untapped trees though one of the untapped trees (T_{3u}) showed significantly higher diameter growth rate as compared to the two tapped trees. The untapped trees were taken from inaccessible areas and in most cases the inaccessible areas are steep and with shallow soil depth which might limit growth of trees. Groenendijk et al. (2012) also found that tapped populations of *B. papryfera* show higher growth rate than untapped populations.

As it is shown in the cumulative radial growth curve, all the sample trees have a comparable general growth trend and it can be roughly divided in to three phases – i) good growth in the beginning, ii) phase with depression in middle part and iii) an increase in ring width at the last phase. All the sample trees showed successive narrow rings at the middle part of their corresponding stem discs, suggesting that growth was suppressed continuously during this period of time. This could possibly relate to consecutive bad growing seasons mainly due to unfavorable climatic conditions (drought) during those years (Liang et al., 2003; Gebrekirstos et al., 2008). Nevertheless, the depression time is not synchronous in all the trees (Fig 2) and this suggests that other external factors such as grazing, fire, tapping, incidence of insects or a combination of all factors could have affected individual trees differently. Yet, the sample trees considered in this study are few and it is difficult to generalize about the climate-growth relationship.

But, it is clearly shown in the cumulative radial growth curve that the untapped trees were released from the depression earlier than the tapped trees (Fig 2). As tapping is done by wounding the tree repeatedly, it can cause damage to trees particularly when it is done improperly. When the tapping intensity is high, the vitality of a tree is affected negatively

(Rijkers et al., 2006; Lemenih and Kassa, 2011). Tapping also expose trees to different insect attack and make more susceptible to fire (Abiyu et al., 2006; Lemenih and Kassa, 2011). Besides, improper tapping may lead to physiological damage on a tree thereby reduces its vigor (Lemenih et al., 2007). It is also believed that during tapping a tree may require reallocating of carbohydrates to heal the damaged tissue or wound that might have been allocated to growth (Rijkers et al., 2006; Thaler et al., 2006). Due to all these factors, tapped trees need more time to recover from the growth depression compare to the untapped trees which is clearly indicated in the cumulative radial growth curve.

In general, the diameter of a tree is dependent on age and there is strong correlation between the two variables; with increasing in age, the tree will increase also in diameter. Nevertheless, it is not possible to conclude that the largest tree in a population is the oldest tree (Lieberman and Lieberman, 1987). Trees of the same age could have huge difference in their diameter or trees with similar diameter could significantly differ in their age (Worbes et al., 2003). The result from this study clearly showed that two trees with more or less similar age strongly differ in diameter with one tree being almost twice as thick as the other one. This is due to the huge variation in growth rate of the individual trees. This is commonly observed in many tropical areas where there is high variability in microsites which leads to varying growth rates among individual trees (Worbes et al., 2003). Therefore, the result from this study suggested that the age-size relations should be used cautiously as the diameter may not reflect the true age.

4. CONCLUSION

Tree-ring analysis is a potential tool to provide reliable information about growth rate and age for trees that form annual growth rings. The mean annual diameter growth rate of *B. papyrifera* is 2.32mm. The result we found in this study is evidently showing that *B. papyrifera* from Metema has to be considered as slow growing species. It is difficult to conclude that tapping has an effect on growth rate of the species as there is no systematic difference in growth rate between tapped and untapped trees. Hence, we recommend further research on the effect of tapping on growth rate of the species by collecting sufficient sample disks both from tapped and untapped trees. *B. papyrifera* trees growing in the study site have an average age of about 75 years. The results we found in this study are important input to develop strategic plan for the species regarding tapping frequency and intensity as per the increment of the species. This result also suggests that dendrochronological studies can be applied in Ethiopian to understand growth dynamics and age structure of different tree species in a population and their response to climate variability.

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