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Research Article

Comparison of the Growth of Six *Eucalyptus* Species in Angola

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Eucalyptus species have been planted in Angola since the early twentieth century. The species introduction experiment of Tchianga, in the Angolan Highlands, was established in 1966/1967. The experiment included several tropical pines and eucalypts. The plots were 43 years old when measured in 2009. Species included *Eucalyptus saligna* Sm., *E. camaldulensis* Dehnh., *E. macarthurii* H. Deane & Maiden, *E. resinifera* Sm., *E. siderophloia* Benth., and *E. grandis* Hill ex. Maiden. *E. saligna* had the highest stand volume at 43 years (1427 $m^3\ ha^{-1}$), followed by *E. grandis* (1006 $m^3\ ha^{-1}$). *E. macarthurii* and *E. camaldulensis* had the lowest stand volume (423 and 511 $m^3\ ha^{-1}$, resp.). Using X-ray analyses of increment cores, it was possible to study the temporal development of the stand characteristics. An analysis of the mean annual increment showed that the optimal rotation length for most of the studied eucalypts is around 22 years with the exception of *E. resinifera*, for which 12–15 years is the best. *E. saligna* had the highest maximum mean annual increment (MMAI) of 37 $m^3\ ha^{-1}$ attained at 22 years of age. *E. grandis* reached its MMAI of 25 $m^3\ ha^{-1}$ at 28 years. The results suggest that *E. saligna* is the most recommended *Eucalyptus* species for new plantations in Angola.

1. Introduction

Eucalypts were introduced to South Africa by colonial government officials, missioners, and settlers in the early nineteenth century [1]. Angola followed the same path, with the construction of the Benguela Railway, marking the start of the establishment of *Eucalyptus* plantations in Angola. The railway linked the Atlantic deep water harbour of Lobito with the Congolese and Rhodesian copper fields. The railway quickly consumed the fuel from the native miombo forest, and as a response, the railway company, Caminho de Ferro de Benguela (CFB), established large eucalypt plantations close to the railway from the wettest central highlands to the border with Belgian-ruled Congo. Although trees were planted all along the railway, most of the stands were established in Huambo district (Figure 1). In the early days of eucalypt plantations in Angola, *E. camaldulensis* was the favoured species. However, based on the field experience, the dominance soon changed to the *saligna-grandis* complex [2, 3]. *E. saligna* and *E. grandis* showed excellent performance with annual growth rates close to 40 $m^3\ ha^{-1}$ [3]. Due to the good growth of *E. saligna* and the increasing wood demand of the national timber market, some private farmers also started to plant eucalypts. In the area of Benguela, German settlers growing sisal, *Agave sisalana*, started to plant eucalypts. The Sanguengue farm, located in Alto Tchiumbo area, was acquired by German settlers who established *E. saligna* nurseries and planted more than 20000 ha, mainly eucalypts, but also some *Pinus patula*, *P. elliottii* and *Cupressus lusitanica* [4].

Since the 1950s, interest in pulp production increased as the national and international paper market needed extensive raw material sources. The Companhia de Celulose do Ultramar Portugues (CCUP), owned by the colonial Portuguese government, started the acquisition of *Eucalyptus* plantations [3]. New plantations of mainly *E. saligna* but also *Pinus patula* and *Cupressus lusitanica* were established as a fibre source for the national cellulose mill.

Latest reforestation projects also included large plantations of *P. patula* for supplying the fast-growing construction industry of the flourishing Angolan economy during the 1970s. At the time of independence, in 1975, more than 100000 ha of eucalypts were established in the Angolan Highlands [5, 6].

Although *Eucalyptus* is the main genus planted in Angola for timber, fuel wood, and pulp, there are few studies about the growth of *Eucalyptus* in the country. In the early 1940s, CFB Forest Services started some research activities related mainly to species selection and forest management. Sampaio [7] and Silva [3] reported the results of those experiences, creating manuals and summarising management techniques to be used in Angola. In addition, Sardinha [8] studied the mechanical and chemical characteristics of *E. saligna* growing in Angola. Plantation management was largely based on South African, Portuguese and Zimbabwean experiences. The colonial authorities, aware of the potential of *Eucalyptus* plantations in the Highlands, started to establish species introduction plots and silvicultural experiments. Trials were set up in the Cuima plantation area, Saccala perimeter, and Tchianga University campus (Figure 1). The trial species were mainly *Eucalyptus*, but also tropical *Pinus* species were included. In the 1960s and 1970s, tropical *Eucalyptus* were also tested in other Southern African countries, especially South Africa and Zimbabwe, where the seeds used in the Angolan trials were imported from. Therefore, the Tchianga species introduction experiment will provide benchmark information about the performance of several *Eucalyptus* species in Angola.

Following the independence, 27 years of civil war ensued. During this period, no new research was conducted, and no experiments were established. In addition, the existing research experiments suffered from extensive illegal logging, especially close to the main cities due to the lack of any other secure fuel source. The Tchianga campus remained the only place with preserved forest stands [9]. However, the Tchianga experiment was affected by seasonal fires. In July 2005, a fire initially designed for cleaning the nearby agriculture plots, became uncontrollable and destroyed some of the eucalypt plots. Since the same may easily happen again, the probability of permanently losing this unique resource of growth records is high.

The natural habitats of *Eucalyptus* genus extends across the Australia mainland and some species into New Guinea. The natural distribution of *E. grandis* is between latitudes 16 and 33°S in the coastal regions of New South Wales (NSW) and Queensland (Qld), where it is found at altitudes of 350–900 m with mean annual rainfall between 1000 and 1800 mm with a summer-autumn maximum [10]. It is sensitive to drought and needs at least 20 mm of rainfall during each of the driest months of the year. E. saligna's natural distribution occurs in valleys and sheltered slopes and ridges of NSW and Qld at altitudes of 300–1200 m between 28 and 35°S. The mean annual rainfall is 800–1500 mm with a marked summer maximum [10]. *E. saligna* tolerates short dry periods and seasonal frosts. *E. camaldulensis* is widely distributed in mainland Australia [11]. It is confined chiefly to inland river and flood plains, where the mean annual rainfall is less than 650 mm. *E. macarthurii* is frost resistant and restricted to the southern Central Tablelands in NSW at an altitude near 600 m and with rainfall uniformly distributed (750–1200 mm per year). *E. resinifera* is naturally distributed on the coastal sites of northern NSW and Qld between latitudes 17 and 34°S, with annual rainfall of 1000–1500 mm uniformly distributed or with summer maximum. *E. siderophloia* is naturally common in wet and fertile soils in NSW [11].

Eucalypts are extensively used in large scale plantations in temperate regions, but more commonly in tropical and subtropical regions around the world. They are mainly used as pulp raw material and fuel wood, as well as sawn timber and reconstituted wood products. *Eucalyptus* genus is globally one of the most planted tree genera; it is estimated that there are over 15 million ha of eucalypt plantations, of which over 10 million ha are in the tropics [12]. Over 2 million ha are in Africa, where *E. grandis* and *E. camaldulensis* are the most planted species [1].

Many species introduction experiments, similar to the one in Tchianga, were established in Africa in the early 1950s and 1960s. Widely studied species include *E. grandis* in South Africa [13–18] and Zimbabwe [19], *E. camaldulensis* in Zimbabwe [20, 21] and *E. macarthurii* in South Africa [17].

The purpose of the present research was to report the growth performance of six *Eucalyptus* species in the Central Highlands of Angola. The aim was to calculate the current yield and examine the temporal development of the stand. Finally, this study is also contributing to produce information from the Tchianga experiment before it disappears.

2. Material and Methods

2.1. Description of the Region. The Central Highland region of Angola covers approximately 7.9 million ha. The region is mainly a flat plateau at 1500 to 1800 m altitude, including some hills and mountains up to 2600 m, which is the elevation of Angola's highest peak, Moco [22–24]. The climate is classified as Cwb (Köppen classification system), temperate with cold winter and hot summer. There is a rainy season from October to April coinciding with the hottest period, with a total precipitation between 1100 and 1400 mm, and a dry cold season with almost no rain from June to August. The remaining months, May and September, present transitional characteristics. December is the wettest month, while a dry period of two to three weeks frequently takes place mainly in January. The annual temperature is 20°C, with mean monthly maximum of 27°C and minimum of 11°C. In some areas the temperature can fall to 0°C. The Highlands' soils are dominated by Oxisols (USDA taxonomy), with a pH between 5.5 and 6.5, and low nutrient content [22, 23, 25, 26].

2.2. Description of the Experiment. The experiment was set up in the rainy season of 1966/1967 and is located in the Tchianga research station (12°43′S, 15°48′E) in Huambo region. It lies at an altitude of 1650 m and has a typical flat Oxisol. The annual precipitation is 1400 mm. The species introduction experiment includes 22 *Eucalyptus* species and

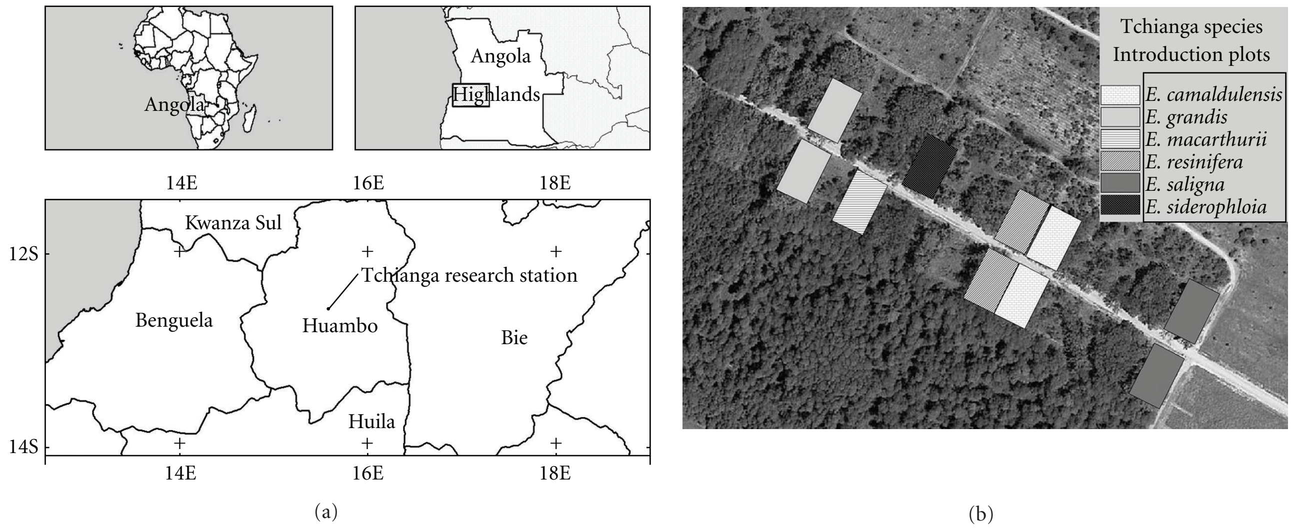

Figure 1: Location of the Tchianga species introduction experiment in the Central Angolan Highlands. The analysed sample plots of the six *Eucalyptus* species are shown (image obtained from Google Earth).

14 *Pinus* species of unknown provenances. There are three blocks with two repetitions for the main species. The plots are located in a flat area on homogeneous soil. The initial stocking of the trial for *Eucalyptus* was 1600 trees ha^{-1}. No treatments have been applied since planting. Lack of management, illegal loggings, and seasonal fires have resulted in the deterioration of many of the plots. Therefore, only ten plots were measured in the species introduction experiment (Figure 1). Two plots were measured for all species, except for *E. macarthurii* and *E. siderophloia*. The selected plots included only those *Eucalyptus* species that remain with a stand density higher than 250 trees/ha and were not significantly damaged in recent fires. In addition, twelve *E. saligna* plots were measured in six different locations in the Angolan Highlands to be used in height modelling. Those plots included 6-, 13-, and 36-year-old *E. saligna* stands.

2.3. Description of the Measurements. The plot size, excluding two border lines on each side, was 1031 m^2 (27.5 m × 37.5 m), and stand density varied from 294 to 833 trees/ha. Diameter at breast height (dbh) was measured on each tree, while height and bark thickness were measured on 12 trees per plot covering the whole range of tree sizes. Five-mm thick radial cores were taken from each tree measured in the Tchianga experiment with an increment borer.

Once the cores were air-dried, cleaned, and fixed onto sheets, they were scanned with a high resolution X-ray device. The X-ray images were used to measure annual rings creating a radial increment file. An X-ray densitometer, Itrax, device was used to measure the increments (Figure 2). Discriminating false rings, identifying the limit of adjacent rings within the large growth of the first years, and discerning the small growth of the final years were the main challenges in the measurement. The data set consisted of 8977 annual ring measurements. All cores did not hit the pith, and some were broken. The total number of annual rings in the measured trees was 12556 (292 trees × 43 years = 12556), which means that about 28% of the annual rings were not measured.

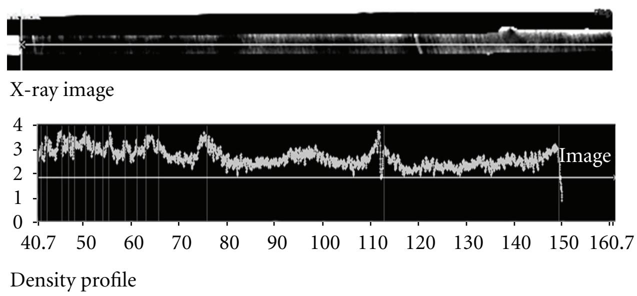

Figure 2: An example of X-ray image and density profile of an increment core.

A species-specific model was fitted between single bark thickness (bark, mm) and diameter (d, cm). This model was used to calculate the bark thickness of all the trees. The bark model was as follows:

$$B = a_0 + a_1 d, \tag{1}$$

where B is single bark thickness (cm) and d is diameter at breast height (cm). In the calculations, it was assumed that the $(d - 2 \times B)/d$ ratio (underbark/overbark diameter, henceforth referred to as u/o ratio) has been constant for the whole life of the tree.

Stand development was backtracked to reconstruct the growth history of each tree and plot based on the measured radial increments. This required information on each year's growth for every tree in the stand. Since some radial growth measurements were missing, a linear model was fitted separately for each year and plot, in order to predict the

Table 1: Stand characteristics of six tropical *Eucalyptus* species at 43 years in the Tchianga experiment. The last column shows the mean annual mortality rate.

Species	Number of plots		N	G	D_g	H_g	Volume	Mortality rate
	Yield[1]	Height[2]	trees/ha	$m^2\ ha^{-1}$	cm	m	$m^3\ ha^{-1}$	% $year^{-1}$
E. saligna	2	14	652	67.8	44.4	41.3	1427	2.1
E. resinifera	2	2	531	34.2	32.2	39.0	680	2.8
E. camaldulensis	2	2	302	25.8	36.6	38.8	511	3.9
E. macarthurii	1	1	294	25.0	36.8	33.1	423	3.9
E. siderophloia	1	1	833	55.0	34.4	30.6	858	1.5
E. grandis	2	2	476	34.6	35.5	57.1	1006	2.9

N: number of trees per hectare; G: stand basal area; D_g: basal-area-weighted mean diameter; H_g: basal-area-weighted mean height.
[1]Number of plots used in growth and yield analysis.
[2]Number of plots used for mean height modelling.

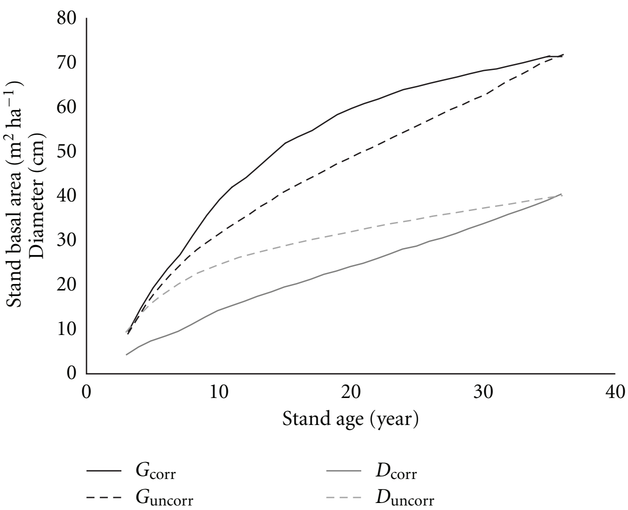

Figure 3: Past stand basal area and mean diameter calculated both with (G_{corr}, D_{corr}) and without (G_{uncorr} and D_{uncorr}) considering the effect of mortality. G_{corr} and D_{corr} include trees which were dead in the measurement of 2009 but were living at earlier stages of stand development.

widths of those annual rings which were not available as a measurement. The model was as follows:

$$ir_{i,t,k} = a_{t,k} + b_{t,k} \times d_{i,t,k}, \tag{2}$$

where $d_{i,t,k}$ is overbark breast height diameter of tree i in plot k at the end of year t (cm), $ir_{i,t,k}$ is the radial growth during year t (cm), and $a_{t,k}$ and $b_{t,k}$ are model parameters for plot k in year t.

The tree and stand characteristics one year ago were calculated as follows: (i) obtain underbark diameter by multiplying overbark diameter with the u/o ratio; (ii) calculate underbark diameter in year $t-1$ by subtracting the doubled radial growth (measured or predicted) from the underbark diameter; (iii) get overbark diameter in year $t-1$ by dividing the underbark diameter by the u/o ratio; (iv) calculate 1-year overbark diameter increment as the difference between current dbh and dbh one year earlier; (v) obtain tree age in year $t-1$ by subtracting one year from current tree age; (vi) calculate stand characteristics (basal area, mean diameter, etc.) using tree dimensions in year $t-1$. The same process was repeated until a young sapling stand state was reached.

In the absence of temporal mortality information, only the average mortality rate of each plot could be calculated, using the planting density, N_0, and the remaining number of survivors, N_T (Table 1). Assuming that the annual survival rate is constant, the number of survivors in year T (N_T) is

$$N_T = N_0^{-kT}. \tag{3}$$

Parameter k, the average annual mortality rate, can be calculated from N_0, N_T, and T as follows:

$$k = \frac{(\ln(N_0) - \ln(N_T))}{T}. \tag{4}$$

The annual mortality rate calculated in this way made it possible to gradually increase the number of survivors when stand development was backtracked from 2009 to the year of stand establishment. The additional trees, that is, the mortality, were assumed to be the most suppressed and among the smallest trees of the stand. Their diameter was assumed to be a weighted average of the minimum and mean diameter of the measured trees (survivors in 2009) in the respective backtracking year $D_{mortality} = 0.75D_{min} + 0.25D_{mean}$. These trees were taken into account when calculating the past stand basal areas and mean diameters (Figure 3).

To calculate the mean tree height in the previous years, the following "guide curve" was fitted for the average dominant height development of eucalypts in the region:

$$H(T) = 47.278(1 - \exp(-0.111T))^{1.424}, \tag{5}$$

where T is stand age. The equation is based on the tree heights of the 10 plots measured in the Tchianga experiment and 12 younger *E. saligna* plots measured in the same region. Then, a multiplier was calculated for each plot by dividing the measured mean height of the plot in 2009 by the guide curve value: $Multiplier = H_{measured}/H(T)$. The guide curve value at age T multiplied by *Multiplier* gave the mean height of the plot at age T.

The predicted mean tree height made it possible to calculate stand volume, which made comparisons to earlier

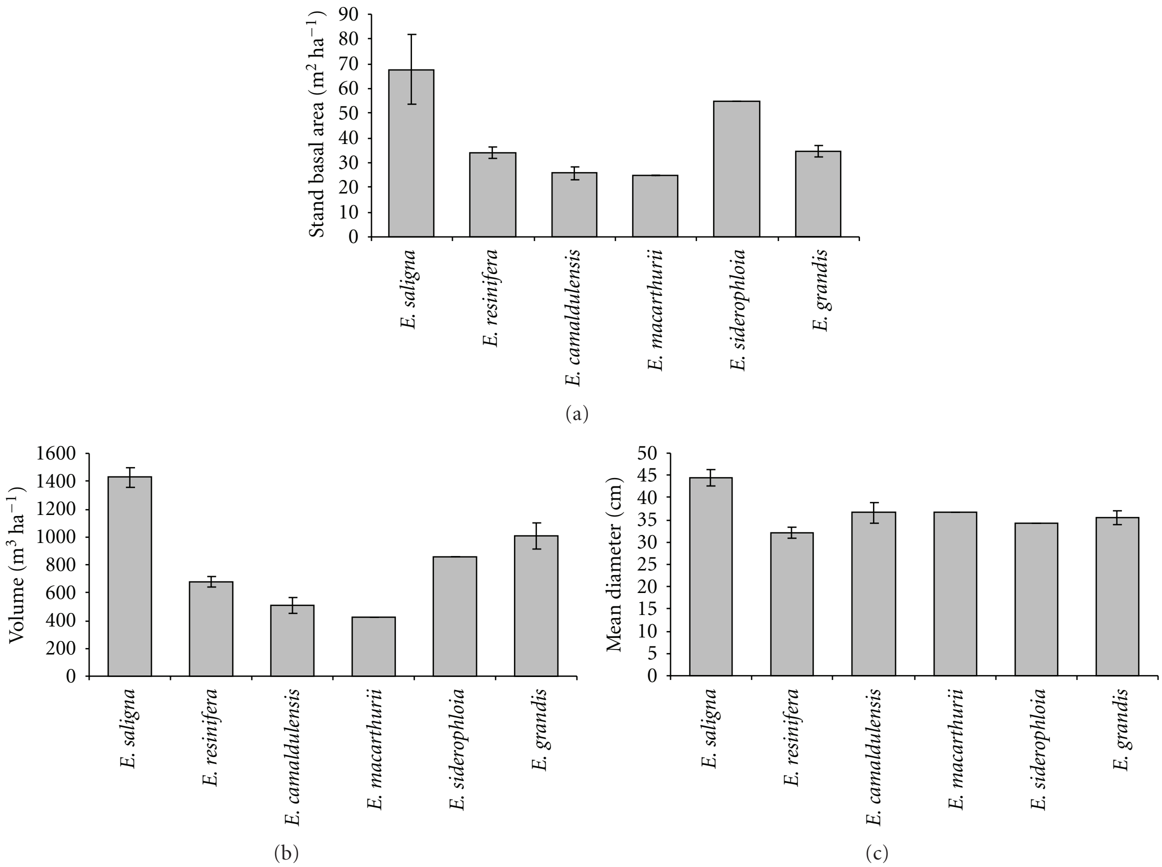

Figure 4: Stand volume, stand basal area, and mean diameter of six *Eucalyptus* at 43 years of age in the Tchianga experiment. The vertical lines indicate the standard error of mean.

research easier as compared to results expressed in stand basal area. The stand volume was calculated from:

$$V = FGH, \tag{6}$$

where F is form factor, G is stand basal area ($m^2\,ha^{-1}$), and H is mean tree height (m). The form factor was taken as 0.51, which is commonly used for tropical *Eucalyptus* species growing in southern Africa [27].

3. Results

There were clear differences between the species regarding stand volume, basal area, and other characteristics (Table 1, Figure 4). *E. grandis* had by far the highest dominant and mean height. *E. saligna* had a high stand basal area and volume together with *E. grandis*. *E. siderophloia* had the highest number of surviving trees per ha with more than 830 trees ha^{-1} at 43 years, followed by *E. saligna* (652 trees ha^{-1}) and *E. resinifera* (531 trees ha^{-1}). *E. macarthurii* and *E. camaldulensis* had the lowest density with less than 305 trees ha^{-1}. *E. saligna* showed high between-plot variability in stand basal area (Figure 4). The mean diameter was quite similar for all the species with the exception of *E. saligna* with 20% higher and *E. resinifera* with 10% lower than the rest of the species.

The mean annual mortality rate was quite high for *E. macarthurii* and *E. camaldulensis* (3.9%), and slightly lower for *E. grandis* and *E. resinifera* (2.8%). *E. saligna* (2.1%) and *E. siderophloia* (1.5%) had the lowest mortality rates. However, illegal cutting may have increased the observed "mortality rate", that is, the true mortality rate of the species, without any human intervention, would most probably be somewhat lower and mainly affecting the suppressed trees.

The stand basal area increased fast at young ages, slowing down after 10 to 20 years (Figure 5). *E. resinifera* and *E. saligna* had a fast early stand basal area increment but after about 15 years the growth of *E. resinifera* almost stopped. *E. grandis* grew slowly during the first years, but its basal area and volume continued increasing for the whole 43 years of age. Good volume growth of *E. saligna* continued for the whole 43-year period.

Most species had a rather constant increment in mean tree diameter. One reason for the continuing increment is that the smallest most suppressed trees were gradually dying with a consequence that mean diameter increased although the largest trees were growing less (see Figure 3, in which *Duncorr* reflects the growth of the largest trees). The mean diameter of *E. resinifera* was developing faster between 10 and 20 years, and thereafter becoming slower than in the other species (Figure 5).

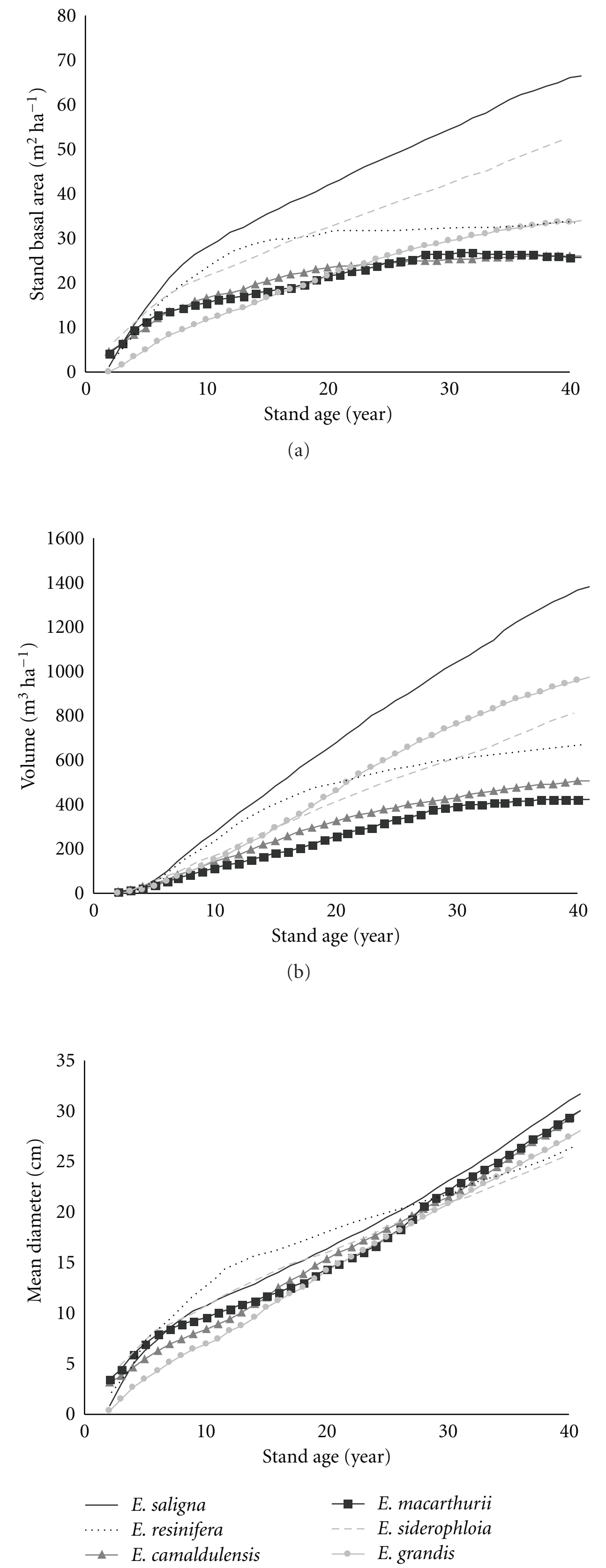

Figure 5: Volume, basal area, and mean diameter development of the analysed eucalypts in the Tchianga experiment.

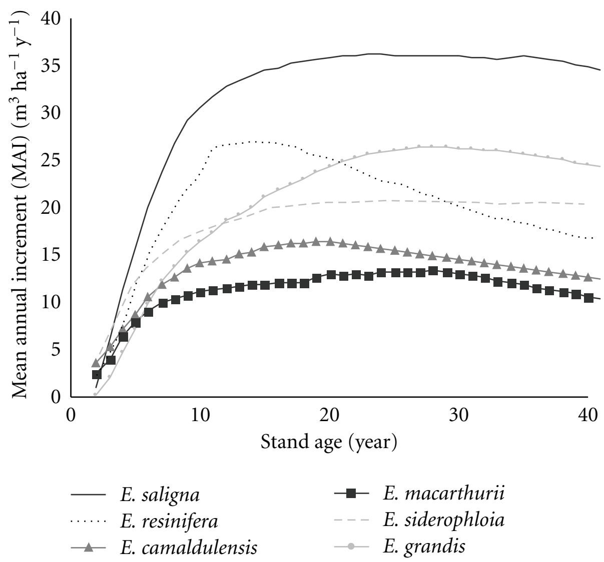

Figure 6: Mean annual increment (MAI) of the six *Eucalyptus* species analysed in the Tchianga experiment.

E. saligna had by far the highest mean annual increment (MAI) with a maximum of 37 m^3 ha^{-1} attained at 22 years of age and subsequently maintained it. Several other species showed a similar trend but with lower MAI values. *E. resinifera* also had high MAI values with 26 m^3 ha^{-1} at 13 years but decreasing thereafter (Figure 6). *E. grandis* showed a different path with a slower MAI during young ages and the highest MAI of 25 m^3 ha^{-1} quite late, at 25–30 years.

4. Discussion

4.1. Analysis of the Methods. The presented methodology to describe stand development, based on analysing the annual rings, has the advantage of being quick and reasonably straightforward. It proved to be highly convenient for completing information from permanent plots where periodical measurements have not been made. It is a scientifically sound methodology, since the results obtained agree with field measurements. Verzino et al. [28] used a similar methodology based on Stokes and Smiley [29] for *P. patula* in central west Argentina. Delgado-Matas and Pukkala [9] also used a similar method for *P. patula* in Angola.

The methodology employed in the current study may be more accurate than the one used in Delgado-Matas and Pukkala [9]. This is partly because of using X-ray analysis, which is more suitable to *Eucalyptus*. This allowed us to determine the density variation along a transect from pith to bark, making it possible to measure the annual growths of eucalypts in tropical conditions. Downes et al. [30] also used X-rays in a densitometry approach when the measurement of variation in cambial activity was difficult. Shrinking of the cores was not a major problem, since the sum of doubled radial growth measurements agreed well with the measured underbark diameters of the trees.

The current study suffers from certain data limitations, specifically the small number of plots on only one site, and only one to two repetitions per species. The plots used in the study have never been systematically thinned, but illegal logging has been done in some plots and uncontrolled fires have also killed trees. Other factors including the presence of false rings and small annual growths in recent years in suppressed trees may have created errors in the measurements. On the other hand, the region of the Angolan Highlands is quite uniform, and the results therefore represent a large area [22].

Stand volume was calculated in order to compare our results with previous studies in the region. The growth rates were calculated using a form factor, stand basal area, and predicted mean stand height. The form factor used, 0.51, is commonly accepted for eucalypt plantations in South Africa [27]. However, different factors are also proposed for each eucalypt species, ranging from 0.431 for *E. grandis* to 0.615 for *E. camaldulensis* [20, 31]. The mean height model was calculated using measured tree heights in 22 plots ranging from 6 to 43 years in stand age. Measured diameter and basal area were corrected adding the effect of dead trees. The mortality rate of a plot was assumed to have been constant, since no information was available on the temporal variation in mortality.

4.2. Analysis of the Results. The traditional belief in Angola is that *E. saligna* and *E. grandis* have the highest volume growth. Our study partly confirms this assumption since *E. saligna* had the best growth. *E. grandis* did not grow very fast at young ages, but it continued growing for the whole 43-year period. Also, *E. resinifera* and *E. siderephlioa* grew well in the Angolan highland conditions. For example, *E. resinifera* grew 25 m^2 ha^{-1} a^{-1} in Tchianga with 15-year rotation length.

The eucalypt species planted in Tchianga showed growth rates substantially higher than in their natural ranges. Zobel et al. [32] and Burgess [33] reported annual growth rates below 13 m^3 ha^{-1} in the natural ranges of the studied species. *E. grandis* and *E. saligna* often have growth rates higher than 35 m^3 ha^{-1} a^{-1} when planted outside Australia. Also other species, like *E. camaldulensis* and *E. resinifera*, with growth rates of 15 m^3 ha^{-1} a^{-1} or more, grow quite fast as exotics [31].

The *Eucalyptus* species selected for the study were the ones that had the best growth and survival in the Tchianga species introduction experiment. Among the measured species, *E. saligna*, *E. grandis*, and *E. resinifera* show growth levels similar to the highest results found in literature. The planted forest database (PFDB) reports maximum mean annual growth rates of 48 m^3 ha^{-1} for *E. saligna* (32 observations); 35 m^3 ha^{-1} for *E. grandis* (116 observations); 21 m^3 ha^{-1} for *E. camaldulensis* (123 observations); 18 m^3 ha^{-1} (6 observations) for *E. resinifera* [12, 34]. Some studies report even higher annual growth rates: 30 m^3 ha^{-1} for *E. camaldulensis*, 50 m^3 ha^{-1} for *E. saligna*, and more than 60 m^3 ha^{-1} for some *E. grandis* provenances and hybrids [16, 20, 35–39]. Our results for *E. saligna* and *E. resinifera* were within the medium to maximum values reported. Other widely planted eucalypts such as *E. grandis*, *E. camaldulensis*, and *E. macarthurii* had annual growths that were within the ranges of earlier reports [12].

Burgess [33] and Fonweban and Houllier [40] found *E. saligna* growing significantly better than *E. grandis* in several locations. Burgess [33] reported that different provenances of *E. grandis* and *E. saligna* can have very different growth rates. According to Poynton [41], Silva [3] and Eldridge et al. [42], early provenances of these species introduced to South Africa and later to Angola were originally from South Queensland and North New South Wales. Provenances from these regions can be extremely variable, and the selected ones may not have been the best options for the Angolan Highlands. In addition, *E. grandis* and *E. saligna* were not clearly differentiated as separate species at the time of their introduction to Southern Africa, and many plantations in Angola are *saligna-grandis* complex mixtures [43].

The studied species are adapted to summer rains to uniform rainfall year around, with *E. grandis* being the most summer rainfall type and *E. camaldulensis* the most uniform to winter rainfall type [31]. The Tchianga experiment included species with different rainfall requirements, with the summer rainfall types performing better than the others. This is in line with the expectations, as the area has a clear summer rainfall regime with a three-month drought during the coldest months [22].

The species included *E. macarthurii* that tolerates cold periods and frosts, and *E. camaldulensis* that tolerates drought [17]. However, they performed worse than the less tolerant species such as *E. saligna* and *E. grandis*. On the other hand, the altitude tolerant *E. saligna* grew better than *E. grandis*, which usually performs better at lower elevations. *E. saligna* grows better than *grandis* in upslope, hinterland sites and survives better when subjected to severe frost [31, 33]. The results are in line with the traditional knowledge used in Angolan forestry practice [3].

Burgess [33] found the growth of *E. saligna* to be higher than *E. grandis* during younger stages, but after 4 years of age *E. grandis* started to grow better. The same trend was found in the Tchianga experiment although *E. saligna* always had the best growth rate. *E. grandis* showed low-volume growth at first, but its growth was similar to *E. saligna* after 7 to 9 years. This is well in line with international literature [42].

Borough et al. [44] reported a mean dbh of 25.5 cm and mean basal area of 40.9 m^2 ha^{-1} for nearly 29 year old unthinned *E. grandis* stands in a provenance experiment in New South Wales. The same authors report a mean dbh of 46.4 cm and mean height of 37.4 m for a 39-year-old *E. saligna* stand in Western Australia. Although conditions are different, results of the present study are in line with those experiments in Australia mainland but in areas where *E. grandis* is not growing naturally.

Traditionally in Angola the rotation lengths of *E. saligna* plantations are 8 to 9 years for fuel and pulp production under coppice management and 25 years for timber uses [3, 45]. According to our results, the MAI of *E. saligna* reached its maximum at around 22 years of age and subsequently remained high. Most of the other *Eucalyptus* species showed similar trends. The rotation lengths should be 12 to 28 years for maximal wood production, shortest for *E. resinifera* and longest for *E. grandis*. Our results for *E. saligna* and *E. grandis* suggest somewhat longer rotations than proposed in literature. Rotations between 7 and 20 years are commonly proposed for tropical eucalypts [37, 46]. FAO [34] considered 18 years suitable for *E. saligna* and *E. grandis* and 12 years for *E. camaldulensis.* Du Toit et al. [47] found a 9 to 12 year rotation period to be optimal for *E. macarthurii* and 6 to 11 year for *E. grandis* under coppice management, and 18 to 52 years for timber uses.

The outcomes of the present study suggest that further studies are required on provenances and hybrids of eucalypts in Angolan Highland conditions. Those studies should be in line with recent successful initiatives in other intertropical regions. In addition, the results of this study should be extended to timber and wood characteristics. The results of this study suggest that *E. saligna* should continue to be the main eucalypt planted in the Angolan Central Highlands.

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