Chapter 4

Predicting the growth in tree height and crown size of three street tree species in the City of Tshwane, South Africa

Abstract

The aim of the study was to determine the relationships between tree height and age, crown height and age, crown diameter and age as well as for crown base height and age for the commonly used street trees *Combretum erythrophyllum*, *Rhus lancea* and *Rhus pendulina*. Using years after planting as the explanatory variable, values for tree height, crown height and crown diameter were modelled using a logarithmic relationship. The relationships for predicting tree height, crown height and crown diameter were applied to compare size and growth for the species 10, 15 and 30 years after planting. It was observed that *Combretum erythrophyllum* and *Rhus pendulina* have virtually the same tree height at ages of 10 and 15 years whereas *Rhus lancea* is considerably smaller at the same age. In terms of mean annual growth rate, *Combretum erythrophyllum* starts with a mean annual tree height growth rate of 912 mm yr^{-1} for the first five years of growth while that of *Rhus lancea* is 786 mm yr^{-1} and *Rhus pendulina* has a mean annual growth rate of 894 mm yr^{-1}. However *Rhus pendulina* has the same mean annual growth rate (467 mm yr^{-1}) for the five to ten year period than that of *Combretum erythrophyllum* while *Rhus pendulina* has the fastest mean annual tree height growth rate (317 mm yr^{-1}) for the 10 to 15 year period. Mean annual crown height

growth rate analysis for the first five years of tree growth ranked the species in the same order as the tree height growth rate for the same period. *Combretum erythrophyllum* has the fastest mean annual crown diameter growth rate for the first five years of growth (709 mm yr^{-1}), when compared to that of *Rhus lancea* (655 mm yr^{-1}) and that of *Rhus pendulina* (664 mm yr^{-1}). These results can be used in forecasting the physical dimensions of these species as a function of time. These dimensional relationships can be used to simulate the dynamic growth of the trees in illustrations of a project when using computer aided design (CAD) applications. The results could also be used in the process of modelling energy use reduction, air pollution uptake, rainfall interception, carbon sequestration and microclimate modification.

Keywords: allometry, regression, size relationships, street trees, tree dimensions, tree growth, urban forests

Introduction

Information relating to tree height, crown diameter, crown height and crown base height dimensions can be applied to model air pollution uptake, microclimate amelioration, carbon sequestration and rainfall interception in urban environments (Peper *et al.*, 2001a).This information on tree dimensions also enables the calculation of the growth of tree height and tree crown dimensions and their inter-relationships, which permit urban foresters to calculate, amongst others, the costs and benefits of the urban forest. It furthermore enables the analysis of alternative management scenarios to determine the optimal management practices with the aim of creating more sustainable urban forests (McPherson *et al.*, 2000 as cited by Peper *et al.*, 2001a).

In South Africa available information on dimensional relationships of commonly propagated urban trees is usually based on personal observations and often lacks extensive scientific validation. The observations are based on perceptions of rates at which trees grow (Kirsten & Meyer, 1992; Joffe, 1993). Subjective terms such as *slow*, *moderate, quick* or *fast* are used to describe tree growth without these terms being substantiated with quantitative values. In contrast, the results presented here may be used to model dimensional growth of these three species with statistical methods and were derived from measurements of 282 street trees.

Apart from the urban ecological functions that urban trees fulfil they are also used in a landscape architectural context to derive spatial and aesthetic functions (Grey & Deneke, 1978; Arnold, 1980; Larsen & Kristoffersen, 2002). Urban and landscape architectural tree planting demands knowledge of *inter alia* tree height and crown growth. Planning tree spacing and tree positioning in relation to structures can be improved with more accurate information on tree growth. Furthermore, accurate information of tree crown growth may provide more realistic and better landscape architectural planting designs (Larsen & Kristoffersen, 2002).

The aim of the research presented here was to determine the relationships between tree height and age, crown height and age, crown diameter and age as well as that of crown base height and age for the commonly used street trees *Combretum erythrophyllum*, *Rhus lancea* and *Rhus pendulina*.

Methodology

The street trees were measured in the winter and early spring (April - September) of 2002 in the City of Tshwane, Gauteng Province. The measurements were made between the suburbs Doornpoort (Ovenbush Street: 25˚ 39' 08.7'' S - 28˚ 15' 21.7'' E) in the north and Erasmuskloof (Piering Street: 25˚ 50' 04.7'' S - 28˚ 14' 58.3'' E) in the south, as well as between Pretorius Park (Pretoria East Cemetery: 25˚ 49' 36.2'' S - 28˚ 19' 20.8'' E) in the east and the suburb of Pretoria North (Brits Street: 25˚ 40' 40.8'' S - 28˚ 09' 05.4'' E) to the west of the city. The tree height, crown base height (height from the ground to the lowest leaves of the crown) and crown diameter were measured with a 3 m range pole (Figure 4.1). Crown diameter measurements were taken in two directions, one parallel and the other perpendicular to the centre line of the road. The mean of the two measurements was used to calculate the diameter.

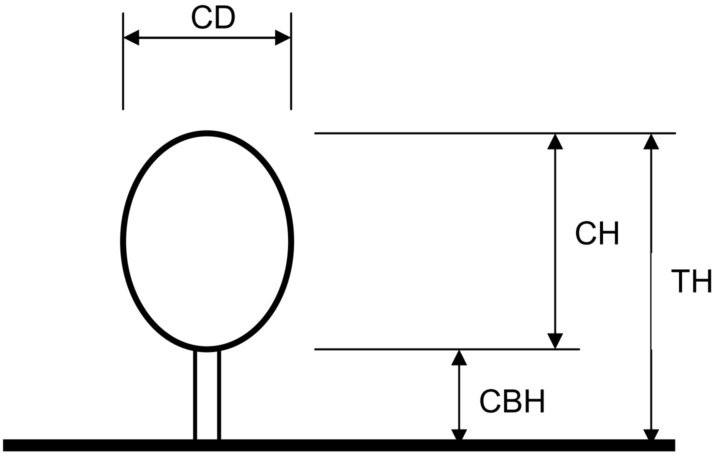


Figure 4.1. The dimensions measured for each tree: tree height (TH), crown height (CH), crown base height (CBH) and crown diameter (CD).

During data gathering the selection of the largest individual street trees during data gathering for statistical analysis can easily result in biased data, which could artificially inflate predictive regression estimates (Clark & Clark, 2000). The problem was avoided in the current study by stratified random sampling. Apart from the necessary stratified age distribution, the streets were selected at random within each age group and the selection of trees in the streets was also performed at random. For this purpose a random number between one and ten from a random number table was used and where possible the first tree to be measured from the beginning of a street block was selected based on the random number. Thereafter every second tree was measured. However, when many trees occurred in a street every third or fourth tree was measured depending on the total number of trees in the street. If there were, however, only a few trees that could be measured, then each consecutive tree was measured. Trees with obvious defects that could have hampered growth or trees with growth abnormalities were not measured.

The aim was to collect data for 10 individual trees per street, which also results in 10 measurements per age group since all the trees in a street were planted at the same time. Measuring 10 trees per street was not always possible due to a limited number of trees per street. Where there were more than one age group of a certain species per street then the second age group was only measured if it were clearly distinguishable by size and if it represented a desired age category.

Of the 282 trees measured, 105 were *Combretum erythrophyllum* (river bushwillow), 107 *Rhus lancea* (karee) and 70 *Rhus pendulina* (white karee). All three species are indigenous to South Africa (Joffe, 1993; van Wyk & van Wyk, 1998). However, *Rhus pendulina* does not naturally occur in the Gauteng Province since its distribution is mostly limited to the Orange River valley and a short distance upstream in some of its tributaries.

When collecting the data for *Combretum erythrophyllum* trees, trees in 13 streets in seven suburbs were measured. Five streets had less than 10 trees that could be measured per street. *Rhus lancea* data were collected in 10 suburbs and 10 streets as well as one parking lot area (see below). There was only one site where less than ten trees per street were measured for *Rhus lancea*. Data for *Rhus pendulina* was collected in seven suburbs and seven streets in which 10 trees were measured per street.

The measured trees were planted between 1955 and 2001 and their ages were derived from the planting dates obtained from the City of Tshwane Metropolitan Municipality (Municipality). The planting dates refer to the date at which the trees were physically planted in the streets. The ranges of years and the minimum and maximum ages sampled for each species are shown in Table 4.1. Planting dates for trees planted prior to 1995 were obtained from aerial photographs and personal communication with botanical and horticultural staff, since the Municipality kept planting date records only from 1995. In the past, the policy was to plant mostly exotic street trees. This rendered it difficult to find old individuals, of the species investigated, of which the age was known. Therefore, two sets of trees from parking lots were incorporated into this study. They are tree sets measured for *Rhus lancea* and *Rhus pendulina* with planting dates of 1970 and 1987 respectively. The tree age distribution of a species depended on the planting strategy of the Municipality. This strategy did not dictate definite numbers per species to be planted each year within the city, which resulted in data that was not evenly distributed per tree age.

The majority of the measured street trees grew in non-irrigated managed lawn residential environments. The average tree to curb distance and road reserve width were 2.1 m and 6.5 m respectively. The mean planting distance was 14 m but driveways and road infrastructure often resulted in irregular planting distances. These irregular planting distances were not included in the calculation of the mean planting distance.

The tree height and crown dimensions were regressed on age to compute the growth rate of each dimension for each species. In analysing stem circumference growth several growth curve models were tested (see Chapter 2): exponential (Zhang, 1997), first degree logistic (Brewer *et al.*, 1985), Gompertz (du Toit, 1979), Lundqvist (Brewer *et al.*, 1985) and Richards family (du Toit, 1979). However, the logarithmic equation (Peper *et al.*, 2001a; Peper *et al.*, 2001b) was considered to provide the most appropriate fit to stem circumference versus age data and was therefore used to determine the dimensional growth rates for the individual species in this study. Age was used as independent variable and the tree height and crown dimensions were modelled using the following equation:

$$E(y_i) = a[\log(x_i + 1)]^b \quad (1)$$

where

y_i = observed response for the i^{th} tree, i = 1,2,…, n;

n = number of observations

x_i = age of the i[th] tree

a, b = parameters to be estimated

$E(\ )$ = expected values

$\log$ = natural logarithim

A description of the statistical models and procedures are presented elsewhere (Peper *et al.*, 2001a; Peper *et al.*, 2001b) as well as in Chapter 3. An equation presented in the original publications by Peper *et al.* (2001a) and Peper *et al.* (2001b) has been corrected based on e-mail correspondence with P.J. Peper (pjpeper@ucdavis.edu, USDA Forest Service, Center for Urban Forest Research, c/o Department of Environmental Horticulture, University of California, One Shields Avenue, Davis, CA 95616-8587, http://cufr.ucdavis.edu/, 23 April 2003). The altered equation is presented in Table 4.2. It is important to mention that a bias correction was applied (Baskerville, 1972). Statistical analysis was conducted using SAS (SAS® version 8.2, SAS Institute, SAS Campus Drive, Carry, NC 27513).

The growth performance of the species for the estimated tree dimension parameters (Table 4.3) was analysed in terms of mean annual growth rate (AGR) (Jalota & Sangha, 2000) as follows:

$$AGR_5 = \frac{a-b}{t} \qquad (2)$$

where AGR_5 is the mean annual growth rate in mm yr^{-1}, a is the largest tree dimension (mm), b is the smallest tree dimension (mm) and t is a five year time period between the measurements.

Results

The ranges of years and the minimum and maximum ages of each species are shown in Table 4.1. The regression coefficients and coefficients of determination (r^2) to predict tree height, crown height and crown diameter growth by age are presented in Table 4.2 and the curves derived by fitting the logarithmic equation to the data of the three species are illustrated in Figure 4.2 to Figure 4.4. Tree height, crown height and crown diameter regressed on tree age with confidence intervals at a level of 95% to the estimated means are shown for each species. The coefficients of determination for the height and age relationship are 0.73, 0.66, and 0.67 for *Combretum erythrophyllum*, *Rhus lancea* and *Rhus pendulina* respectively. The coefficient of determination for the crown height and age relationship for *Combretum erythrophyllum* is 0.74, but is lower for *Rhus lancea* (0.54) and *Rhus pendulina* (0.59). Coefficients of determination for the crown diameter and age relationship are 0.74, 0.75, and 0.69 for *Combretum erythrophyllum*, *Rhus lancea* and *Rhus pendulina* respectively.

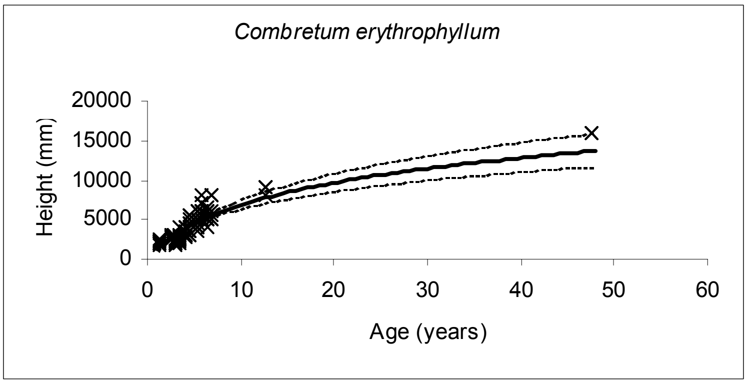
Table 4.1. The minimum age (years since planting in the streets), maximum age and range of years for which measurements were made for each species

Species	Minimum age (years)	Maximum age (years)	Range (years)
Combretum erythrophyllum	1.2	47.6	46.4
Rhus lancea	1.3	32.6	31.3
Rhus pendulina	3.4	15.6	12.2

Table 4.2. Sample size (n), estimated regression coefficients (A, b) and mean standard error (MSE) values for predicting height, crown height, and crown diameter growth as well as coefficients of determination (r^2). Height, crown height, and crown diameter can be predicted by $\hat{y}_i = EXP\{MSE/2 + (\hat{A} + \hat{b}\log(\log(x_i + 1)))\}$, where $\hat{y}_i$ = height, crown height, or crown diameter to be estimated, $\log$ is the natural logarithm of the argument and EXP = the inverse of the natural logarithm and x_i = age

		Height vs age				Crown height vs age				Crown diameter vs age			
Species	n	A	b	MSE	r^2	A	b	MSE	r^2	A	b	MSE	r^2
Combretum erythrophyllum	105	7.56927	1.4186	0.05714	0.73	6.76034	2.04386	0.1129	0.74	6.65704	2.46067	0.16217	0.74
Rhus lancea	107	7.83069	0.7411	0.02771	0.66	7.02305	1.10703	0.10113	0.54	7.17049	1.51863	0.07633	0.75
Rhus pendulina	70	7.54832	1.44173	0.03256	0.67	6.87739	1.78497	0.07126	0.59	6.93671	1.95978	0.05492	0.69

(a)



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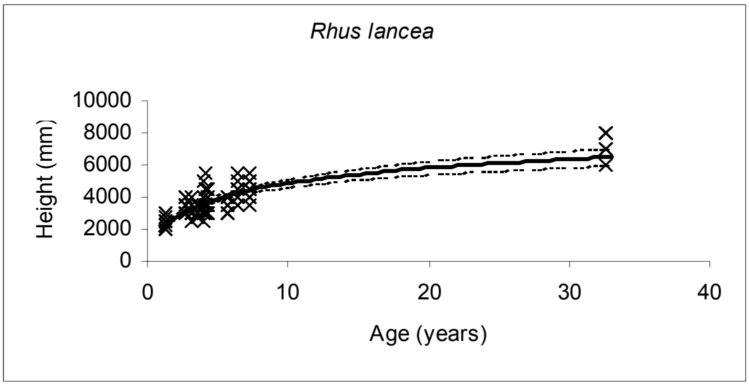

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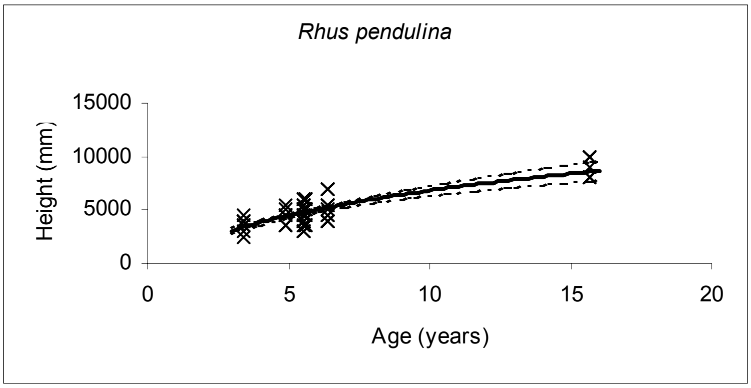
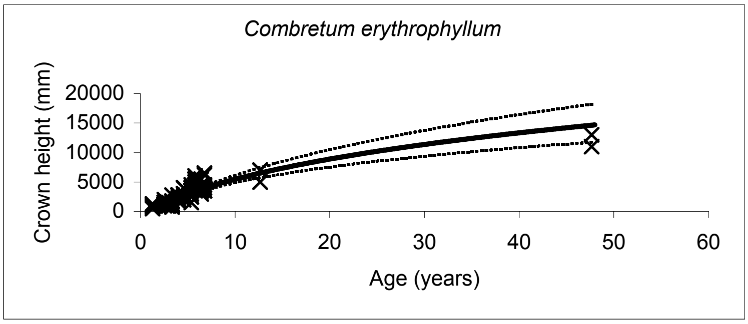


Figure 4.2. Tree height regressed on tree age (years) by a logarithmic equation indicating confidence intervals at a level of 95% to the estimated mean. (a) *Combretum erythrophyllum*, (b) *Rhus lancea* and (c) *Rhus pendulina*.

(a)



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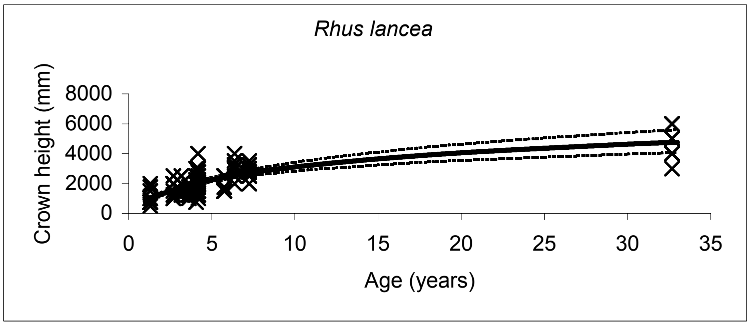

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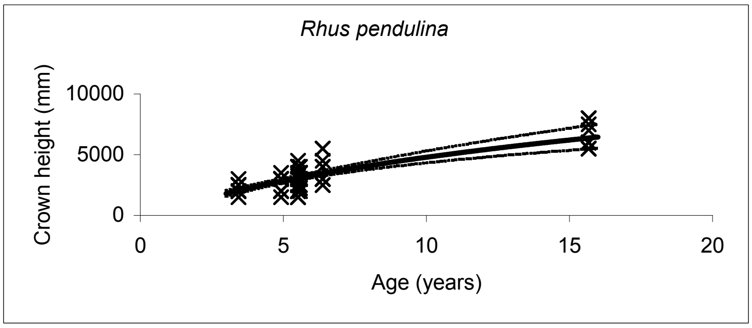
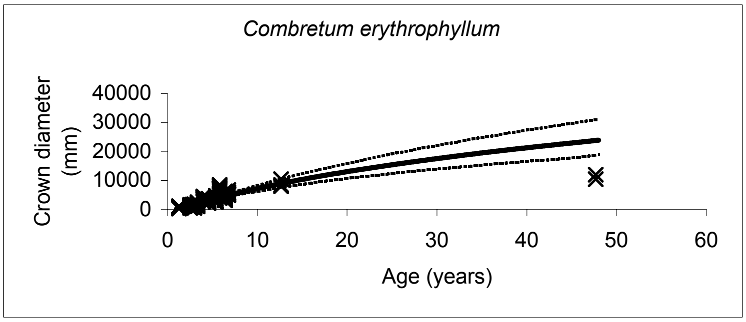


Figure 4.3. Crown height regressed on tree age (years) by a logarithmic equation indicating confidence intervals at a level of 95% to the estimated mean. (a) *Combretum erythrophyllum*, (b) *Rhus lancea* and (c) *Rhus pendulina*.

(a)



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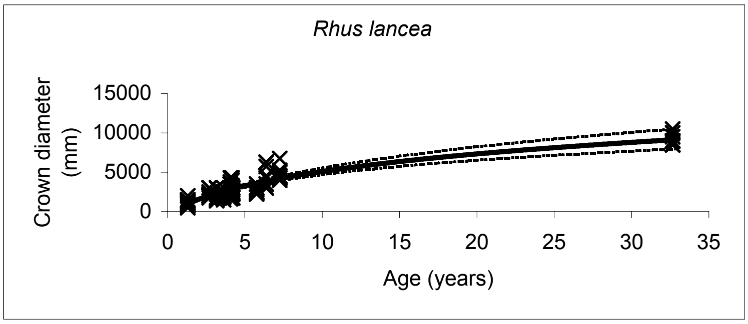

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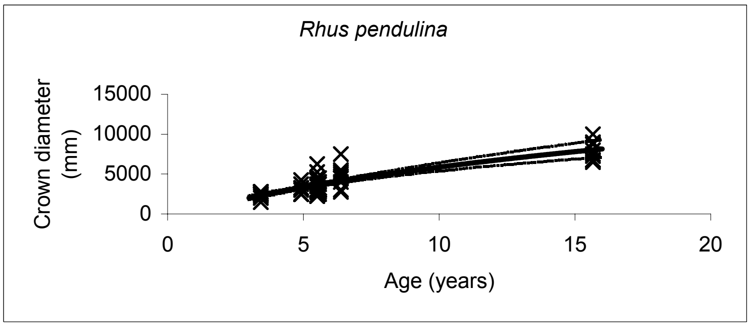


Figure 4.4. Crown diameter regressed on tree age (years) by a logarithmic equation indicating confidence intervals at a level of 95% to the estimated mean. (a) *Combretum erythrophyllum*, (b) *Rhus lancea* and (c) *Rhus pendulina*.

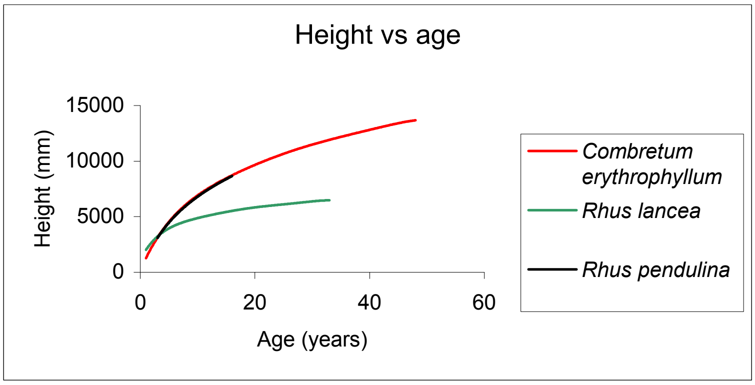
Pruning of the lowest branches regulates branching height and crown base height. In urban forests the lowest branches are pruned for aesthetic purposes and because they also often interfere with traffic they are removed (Larsen & Kristoffersen, 2002). Hence the crown base height is a function of cultural activities rather than natural tree growth. As a result the crown base height measured data are inappropriate for this analysis and therefore the results are not presented.

The regressions of all three species are shown in Figure 4.5 to enable comparisons and the prediction of tree sizes for 10, 15 and 30 years after planting. Annual growth rates at five-year intervals are shown in Table 4.3.

When comparing the species in terms of a height and age relationship it is observed that *Combretum erythrophyllum* and *Rhus pendulina* have virtually the same tree height at 10 and 15 years of age when trees of both species have a mean tree height of approximately 7 m and 8 m respectively. The tree height of *Rhus lancea* is much lower at the same ages (Figure 4.5a and Table 4.4).

Regarding crown height one notices that *Rhus pendulina* starts with a similar crown height growth to that of *Combretum erythrophyllum* but shows a slower growth rate towards the upper end of the curve (Figure 4.5b). Judging by the slope of the curves it may be conjectured that this divergence will continue with time. Concerning crown diameter growth rate one observes that *Combretum erythrophyllum* grows faster than *Rhus pendulina*, which in turn grows faster than *Rhus lancea*.

(a)



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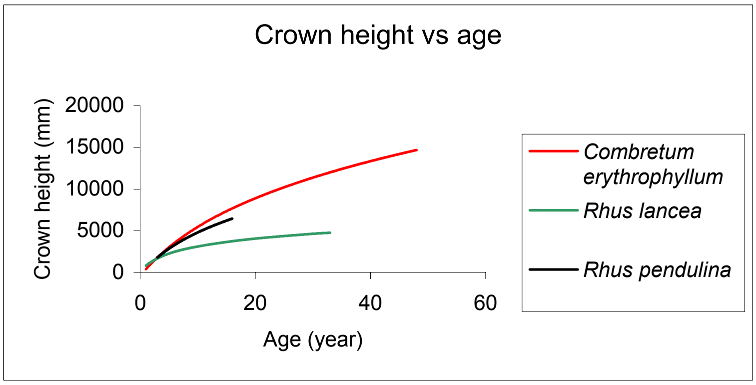

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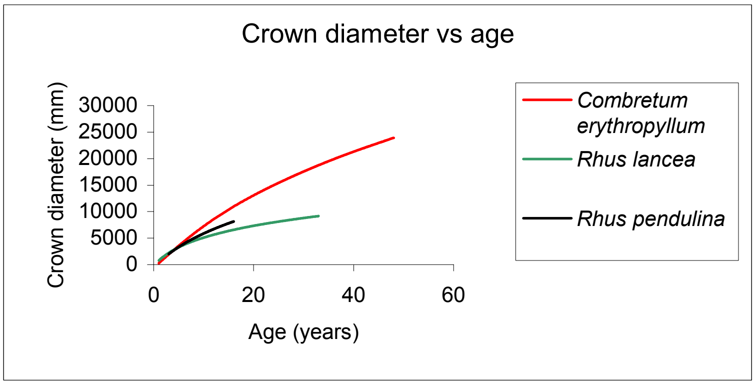

Figure 4.5. Tree height, crown height and crown diameter are regressed on tree age for *Combretum erythrophyllum*, *Rhus lancea* and *Rhus pendulina*. All three the species are shown on one graph to facilitate growth comparisons. Tree height versus age (a), tree crown height versus age (b) and tree crown diameter versus age (c).

Table 4.3. Mean annual growth rate (mm yr^{-1}) calculated with five year intervals for tree height, crown height and crown diameter for each of the tree species investigated.

	Tree height (mm yr^{-1})			Crown height (mm yr^{-1})			Crown diameter (mm yr^{-1})		
Years	*Combretum erythrophyllum*	*Rhus lancea*	*Rhus pendulina*	*Combretum erythrophyllum*	*Rhus lancea*	*Rhus pendulina*	*Combretum erythrophyllum*	*Rhus lancea*	*Rhus pendulina*
0 - 5	912	786	894	601	450	569	709	655	664
>5 - 10	467	190	467	490	143	388	743	365	511
>10 - 15	315	111	317	377	83	283	624	252	387
>15 - 20	240	78	-*	309	59	-*	537	194	-*
>20 - 25	195	60	-*	264	46	-*	474	159	-*
>25 - 30	165	49	-*	232	38	-*	426	135	-*
>30 - 35	143	-*	-*	207	-*	-*	389	-*	-*
>35 - 40	126	-*	-*	187	-*	-*	358	-*	-*
>40 - 45	113	-*	-*	172	-*	-*	332	-*	-*

*No data available

Table 4.4. Predicted sizes are shown for 10, 15 and 30 years after planting

	Height (m)			Crown height (m)			Crown diameter (m)		
Species	10y	15y	30y	10y	15y	30y	10y	15y	30y
Combretum erythrophyllum	6.89	8.47	11.47	5.45	7.33	11.36	7.26	10.37	17.56
Rhus lancea	4.87	5.43	6.36	3.10	3.65	4.62	5.09	6.35	8.79
Rhus pendulina	6.80	8.39	-*	4.78	6.20	-*	5.87	7.80	-*

*Oldest *Rhus pendulina* trees measured were 15.6 years.

Rhus lancea, in comparison with the other species, shows a tendency to reach near asymptotic growth rates relatively early in its growth development for all three tree dimensions analysed and is also the smallest tree.

Combretum erythrophyllum starts with a mean annual tree height growth rate of 912 mm yr^{-1} for the first five years of growth while that of *Rhus lancea* is 786 mm yr^{-1} and *Rhus pendulina* has a mean annual growth rate of 894 mm yr^{-1}. However, *Rhus pendulina* has the same mean annual growth rate (467 mm yr^{-1}) for the five to ten year period than that of *Combretum erythrophyllum* while *Rhus pendulina* has a marginally faster mean annual tree height growth rate (317 mm yr^{-1}) for the 10 to 15 year period (Table 4.3). *Combretum erythrophyllum*'s mean annual tree height growth rate declines from 912 mm yr^{-1} in the first five years to 113 mm yr^{-1} in the five years between the ages 40 years and 45 years. However, *Rhus lancea*'s mean annual tree height growth rate declines from 786 mm yr^{-1} in the first five years to 49 mm yr^{-1} in the five years between the ages 25 years and 30 years. *Rhus pendulina* also shows a decline in its mean annual tree height growth rate from 894 mm yr^{-1} in the first five years to 317 mm yr^{-1} in the five years between the ages 10 years and 15 years.

The mean annual crown height growth rate analysis for the first five years shows that *Combretum erythrophyllum*, *Rhus lancea*, and *Rhus pendulina* have mean annual growth rates of 601 mm yr^{-1}, 450 mm yr^{-1} and 569 mm yr^{-1} respectively (Table 4.3). *Combretum erythrophyllum* has the fastest mean annual crown height growth rate while that of *Rhus lancea* being the slowest. *Combretum erythrophyllum*'s mean annual crown height growth rate declines from 601 mm yr^{-1}

in the first five years to 172 mm yr^{-1} in the five years between the ages 40 years and 45 years. However, *Rhus lancea*'s mean annual crown height growth rate declines from 450 mm yr^{-1} in the first five years to 38 mm yr^{-1} in the five years between the ages 25 years and 30 years. *Rhus pendulina* furthermore, also shows a decline in mean annual crown height growth rate from 569 mm yr^{-1} in the first five years to 283 mm yr^{-1} in the five years between the ages 10 years and 15 years.

Combretum erythrophyllum has the fastest mean annual crown diameter growth rate for the first five years of growth (709 mm yr^{-1}), when compared to that of *Rhus lancea* (655 mm yr^{-1}) and that of *Rhus pendulina* (664 mm yr^{-1}) (Table 4.3). Consequently *Combretum erythrophyllum* also has the fastest mean annual crown diameter growth rate when compared to the *Rhus* species. *Rhus lancea* shows a consistently slower mean annual crown diameter growth rate in comparison to *Rhus pendulina*. *Combretum erythrophyllum*'s mean annual crown diameter growth rate declines from 709 mm yr^{-1} in the first five years to 332 mm yr^{-1} in the five years between the ages 40 years and 45 years. However, *Rhus lancea*'s mean annual crown diameter growth rate declines from 655 mm yr^{-1} in the first five years to 135 mm yr^{-1} in the five years between the ages 25 years and 30 years. *Rhus pendulina*, also shows a decline in mean annual crown diameter growth rate from 664 mm yr^{-1} in the first five years to 387 mm yr^{-1} in the five years between the ages 10 years and 15 years.

The mean annual growth rate during the period 40 to 45 years for *Combretum erythrophyllum*'s tree height is 113 mm yr^{-1} while its mean annual crown height growth increase for the same period is 172 mm yr^{-1} and the crown diameter increase is 332 mm yr^{-1}. The mean annual growth rate during the period 25 to 30 years for *Rhus lancea*'s tree height is 49 mm yr^{-1} while its mean annual crown height growth increase for the same period is 38 mm yr^{-1} and the crown diameter increase is 135 mm yr^{-1}. The mean annual growth rate during the period 10 to 15 years for *Rhus pendulina*'s tree height is 317 mm yr^{-1} while its mean annual crown height growth increase for the same period is 283 mm yr^{-1} and the crown diameter increase is 387 mm yr^{-1} (Table 4.3).

Discussion

The tree crown dimensions of *Combretum erythrophyllum* increases faster than the tree height at older tree ages. This crown height growth may be attributed to the drooping lower branches of older trees, which results in larger crown height growth increments when compared to tree height. However, the mean annual crown height growth increment increases are less than that of the mean annual tree height growth increment increases for both *Rhus lancea* and *Rhus pendulina*. Relatively larger crown diameter growth compared to tree height and crown height growth suggests that the older trees may have reached near asymptotic tree height growth levels while still growing laterally in tree crowns.

Data for only 15 years is presented for *Rhus pendulina* but it has been reported that certain trees of this species have reached an age of more than 25 years in the City of Tshwane (personal communication: A.E. van Wyk, Botany Department, University of Pretoria, South Africa). This is an additional 10 years of growth which was not reported on in this study and predictions as to growth trends for trees older than 15 years that are based on the results presented, should be done with caution.

It should be noted that *Rhus lancea* starts with the largest dimensions in all instances (Figure 4.5) as well as with a relatively high comparable initial annual growth rate (Table 4.3). This could possibly be ascribed to the fact that *Rhus lancea* trees were in some instances planted in the streets when they were already four years old. This practice was not consistent and accurate ages of the trees when planted in the streets could not be obtained. However, in the analysis it was assumed that all the trees were three years old when planted in the streets (personal communication: S. Paul, City of Tshwane Metropolitan Municipality, 8 April 2002). This may overestimate the size of *Rhus lancea* trees when first planted and therefore may also result in a faster growth rate at an early age.

It can be noticed in Figure 4.2 to Figure 4.4 that the confidence bounds expand with the increase in tree age. This is a common tendency for all the species and reflects the variability within the species due to effects of differences in site conditions, genotype, culture, biotic, and abiotic factors that influence the health and growth of a tree (Peper *et al.*, 2001b).

The regression equations presented are only valid within the sampled range of ages and tree size dimensions. Extrapolations of data beyond the data range from which the regressions were determined are therefore not recommended. This point was emphasized in determining biomass through the use of allometry by

Haase & Haase (1995) and should also be taken into consideration when calculating the growth rate of other parameters.

Application of tree dimensional growth rates

Calculated annual growth rate (AGR) can be used to enable computer aided design (CAD) simulations (Peper *et al.*, 2001b; Larsen & Kristoffersen, 2002) in the landscape architectural industry. Annual growth rates of trees provide landscape architects and architects with tree dimensions at various ages. Tree growth can then be digitally simulated. When presenting the quantitatively derived CAD simulations, the tree growth can be viewed in context of the designed landscape and related architecture. This can result in simulating how the landscape will change over time as the trees increase in age. The visual presentation will allow both architects and clients a more realistic dynamic simulation of their investment.

Annual growth rate may also provide the designer with quantitatively derived tree age to tree dimensions relationships, which will provide more realistic landscape architectural plans, elevations and perspectives and hence provide more accurate presentation drawings. This method contrasts with the current practice of drawing trees at 75% of their maximum tree dimensions, irrespective of the growth rate of the specific species, when representing trees in presentation and technical drawings.

When placing trees next to or underneath structures like for example buildings and overhead power lines, one will also be able to determine at what estimated age the trees may become problematic. This will in turn also provide the opportunity to calculate long-term pruning and tree maintenance cost as well as, if necessary, alter the designed planting plan or alternatively the choice of tree species to accommodate the associated structures better (McPherson *et al*., 2004). It should be noted that although annual growth rate calculations are quantitatively derived they are still estimates.

Annual growth rate calculations can furthermore be used when predicting the future heating and cooling energy savings from positioning trees in relation to one or two story buildings. Interior building temperature can be moderated by positioning trees strategically on the northern and western side of buildings. This is due to the shade that the trees project on the buildings in summer and when choosing a deciduous tree, the sun which it allows to reach the buildings in winter (McPherson *et al*., 2004). The dimensional growth rates of trees could thus be used in models that predict and calculate, for example, potential air-conditioning energy savings.

Crown and tree dimensional growth rates are used amongst others to calculate rainfall interception and air pollution uptake by urban trees. The regression equations presented in this chapter can be used to model the increase in rainfall interception and air pollution uptake of a young urban forest. It therefore provides a basis from which the rainfall interception and air pollution uptake of recently planted street trees in previously disadvantaged Township areas in the City of Tshwane and elsewhere in South Africa could be modelled. Modelling rainfall interception and air pollution uptake may provide additional information as to the value of the urban forest in monetary terms, which could motivate further urban forest programmes (Maco *et al*., 2004). It is recommended that further studies be done on leaf surface area models, accompanied by meteorological modelling in order to establish *locally* derived rainfall interception and air pollution uptake models. The calculation of monetary benefits and detailed methodology for such modelling could be found elsewhere (Maco *et al*., 2004; http://cufr.ucdavis.edu, accessed April 2005).

Conclusion

The tree height, crown height and crown width of three street tree species were examined. When comparing the species in terms of a height and age relationship it is observed that *Combretum erythrophyllum* and *Rhus pendulina* have virtually the same tree height growth rate. After 10 and 15 years trees of both species have a mean tree height of approximately 7 m and 8 m respectively. The growth rate of *Rhus lancea* is much slower.

In terms of mean annual growth rate, *Combretum erythrophyllum* starts with a mean annual tree height growth rate of 912 mm yr^{-1} for the first five years of growth while that of *Rhus lancea* is 786 mm yr^{-1} and *Rhus pendulina* has a mean annual growth rate of 894 mm yr^{-1}. However, *Rhus pendulina* has the same mean annual growth rate (467 mm yr^{-1}) for the five to ten year period as that of *Combretum erythrophyllum* while *Rhus pendulina* has the fastest mean annual tree height growth rate (317 mm yr^{-1}) for the 10 to 15 year period.

Mean annual crown height growth rate analysis for the first five years of tree growth shows that *Combretum erythrophyllum*, *Rhus lancea*, and *Rhus pendulina* have a mean annual growth rate of 601 mm yr^{-1}, 450 mm yr^{-1} and 569 mm yr^{-1} respectively. *Combretum erythrophyllum* has the fastest mean annual crown height growth rate while that of *Rhus lancea* is the slowest.

Combretum erythrophyllum has the fastest mean annual crown diameter growth rate for the first five years of growth (709 mm yr^{-1}), when compared to that of *Rhus lancea* (655 mm yr^{-1}) and that of *Rhus pendulina* (664 mm yr^{-1}). Consequently, *Combretum erythrophyllum* also has the fastest mean annual crown diameter growth rate when compared to the *Rhus* species. *Rhus lancea* shows a consistently slower mean annual crown diameter growth rate in comparison to *Rhus pendulina*.

These results could be used for forecasting physical dimensions of the species investigated as well as for planning and assessing the consequences of tree-planting schemes in urban environments. In comparison *Rhus lancea* is for example, better suited to be used in landscape projects where space is restricted and where a slower growth rate is desired. *Combretum erythrophyllum* on the other hand, is suitable for larger open spaces and for landscapes where fast tree growth rates are required. The use of *Combretum erythrophyllum* as street trees in the narrower residential road reserves, especially the smaller streets of the City of Tshwane's previously disadvantaged Townships is, however, questionable. This is because this tree species tends to become very large and may be inappropriate for such small spaces.

The mean tree planting distance of 14 m could be reconsidered for *Rhus lancea* when considering its slow growth rate. This distance could successfully be reduced to 8 m or 10 m, which should result in a more aesthetically pleasing street appearance for this species.

The dimensional relationships presented could form a basis for dynamic illustration of the tree growth related to a project when implementing computer aided design (CAD) applications. The results are also important for determining environmental benefits of the urban trees. A literature search revealed no information pertaining to these species' dimensional growth over time in an urban or natural setting, which renders additional significance to the research presented.

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