Models for Predicting Stem Diameter from Crown Diameter of Open Grown Trees in Sondu-Nyando River Catchment, Kenya

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Abstract: Information on stocks of trees on farm is scanty and in many cases lacking. Assessing the stocking density of trees on farms require models relating tree bole diameter with its crown diameter. However, bole-crown diameter models of open grown trees on farms is lacking in the Lake Victoria basin and indeed in Kenya. The focus of this study was to develop regression equations that would predict individual tree Diameter at Breast Height (DBH) from its crown diameter (Cd) for selected open grown tree species in Sondu-Nyando River catchment. Stratified random sampling was used and GPS readings, DBH and Cd, collected from 20 unequal sized sample plots, along selected agro ecological gradients. The models were developed using DBH and Cd measurements from 578 trees of five most dominant tree species (*Cupressus lusitanica*, *Eucalyptus saligna*, *Grevillea robusta*, *Persea americana* and *Croton megalocarpus*). The DBH - Cd models displayed good fit ($R^2 > 0.586$). *Persea americana* had the highest adjusted R^2 (0.875) and *Eucalyptus saligna* the lowest ($R^2 = 0.586$). F-test showed regression coefficients were significant in all the models. Residuals were more concentrated in lower diameters, implying a negative exponential DBH distribution. The Linear, Exponential and Power models performed well with the highest R^2 (up to 0.875, 0.676 and 0.655). The developed models are applicable across species groups and not across species.

Key words: Bole diameter, crown diameter, exponential function, power function, species dominance, species groups

INTRODUCTION

Population growth and human activities such as settlements, agriculture and construction are threatening forests globally. Trees on Farm (ToF) form an integral part of the farm landscape and contribute to ecological and economic functions of a farmland ecosystem. Trees on farm provide woodfuel, promote dry seasonal flow, stabilise soils, improve soil texture and fertility, and ameliorate the microenvironment making it more conducive for enhanced biodiversity of flora and fauna in farmlands. It is therefore prudent to have a reliable inventory to facilitate productive and sustainable management of on-farm tree resources.

Tree crown diameter is well correlated with tree bole diameter (Gering and May, 1995; Kigomo, 1980, 1991, 1998; Lockhart *et al.*, 2005; Hemery *et al.*, 2005). This relationship is particularly useful for determining stand density and stocking relationships (Dawkins, 1963; Goelz, 1996; Kigomo, 1980, 1991, 1998), and tree and stand volumes from aerial photographs (Bonnor, 1968; Gering and May, 1995). Furthermore crown diameter bears a definite relation with its bole diameter irrespective of site

and age and, in some cases, irrespective of silvicultural treatments (Dawkins, 1963; Kigomo, 1998).

If relationships between bole diameter and tree crown diameter are known, Basal Area (BA) or volume of trees on farm can be estimated from bole diameters derived from crown diameters. Just as a tree's Diameter at Breast Height (DBH) is often used as a surrogate for a tree's crown dimensions (Kigomo, 1980, 1991, 1998; Lockhart *et al.*, 2005), a tree's crown diameter can equally be used as the surrogate for DBH. With recent advances in remote sensing technology, an easier way of inventorying these resources would be measuring tree crown diameter (Cd) from remotely acquired high resolution digital imagery. Bole diameter would then be predicted from crown diameter and the tree volume or Basal Area (BA) estimated. Such an approach would require developing models to predict DBH from crown diameter (Cd) which are lacking.

The focus of this study, therefore, is to develop models that predict individual tree bole diameter from its crown diameter for open grown trees, in parts of Sondu-Nyando River catchments. Specifically, the objective is to determine the species composition and species

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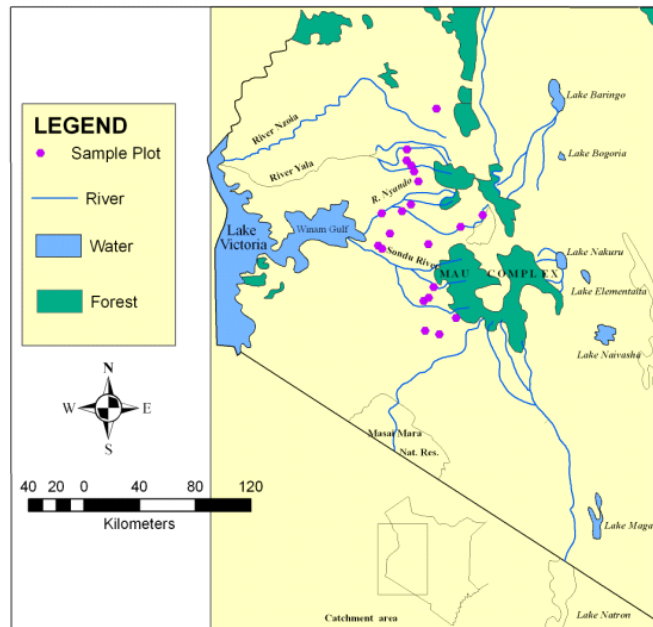
Fig. 1: Location and distribution of sample plots in the study area

dominance, and to develop regression equations that predict individual tree DBH from its crown diameter for selected open grown tree species in the study area.

MATERIALS AND METHODS

Description of the study area: The study, undertaken in Kenya, was done in parts of Nyando and Sondu River catchments (Fig. 1). It covered Nandi South, Nandi North, Kericho, Buret, Bomet and Nyando districts, between longitudes 34º57′ W and 35º28′ E, and latitudes 0º10′ S and 0º57′ N. The altitude ranges from 1200 to 2400 m above sea level. The catchment receives rainfall ranging from 1200-2350 mm annually and temperatures ranging from 15 to 28ºC. According to Jaetzold and Schmidt (1983) the area comprises three main Agro-ecological zones namely: the Lower Marginal Sugarcane-Cotton zone, Wheat-Maize zone and the Tea-Dairy zone. Soils in the Sugarcane-Cotton zones are moderately deep, dark grey to black, gravely clay to clay with calcerous deeper sub-soil that are poorly drained. The upper Nyando plateau (Wheat-Maize zone) soils are well drained, moderately deep, red/reddish brown to dark red friable clay of moderate to high fertility. Soils in the Tea-Dairy zones are deep, well drained, reddish brown to brown fertile soils.

The physiography of the major part of the region is undulating upland and low land underlain by basement system rocks, intermediate igneous rocks and quartzite. The area is generally an agricultural zone with crops such as tea, maize, wheat and multipurpose trees and shrubs.

This is particularly evident in Nandi, Kericho and Bomet. In Nyando there are some sections of grassland, rice and sugarcane plantations. Generally trees are found within the farms, in tea plantations and on boundaries.

Sampling techniques and data collection: To derive the relationship between crown diameter (Cd) and bole diameter at breast height (DBH) a total of 3101 trees were measured in the study area between September and October 2007. To select the trees for measurement a stratified random sampling design was used. Topographic maps were used to identify farming areas. Accessible, unequal sized sample plots (farms) were randomly and proportionately allocated along selected transects based on ecological gradients. (You could tell the minimum and maximum size)

In each sample plot, GPS locations were recorded and complete enumeration of trees done. However, where the farm was more than 5 hectares or had dense woodlands/woodlots, a portion of it (at least 10%) was sampled. For each tree or shrub with DBH >1 cm, the species name, DBH over-bark and the crown diameter (average of maximum and minimum) were measured from the vertical projection of the edge of a tree crown down to the ground (Husch *et al*., 1982; Gering and May, 1995; Lockhart *et al*., 2005).

Methods of data analysis: Species dominance (Importance Value, IV) derived by summing up the percentages of Relative density, Relative Dominance and Relative Frequency (Curtis and Mclntosh, 1950;

Table 1: The ten most dominant open grown species and their species dominance rating

Tree species	Frequency	No of stems measured for CD	Basal area cm^2	Relative frequency	Relative density	Relative dominance	Importance value (IV)
Cuppresus lusitanica	12	176	32070.92	57.14	12.92	12.38	82.44
Grevillea robusta	12	132	25772.04	57.14	9.69	9.95	76.78
Eucalyptus saligna	10	149	33457.71	47.62	10.94	12.91	71.47
Persea Americana	9	64	12432.72	42.86	4.70	4.80	52.35
Croton megalocarpus	9	61	4364.22	42.86	4.48	1.68	49.02
Croton macrostachyus	7	49	10849.56	33.33	3.60	4.19	41.12
Vangueria infausta	7	29	4487.77	33.33	2.13	1.73	37.19
Markhamia lutea	7	32	3369.40	33.33	2.35	1.30	36.98
Psidium guajava	7	19	2280.50	33.33	1.40	0.88	35.61
Oryris lanceolata	5	53	6732.47	23.81	3.89	2.60	30.30

Kigomo *et al*., 1990) was determined for each species. Importance value is a useful tool in showing overall dominance of species and has been used successfully for this purpose and in comparing stocking robustness in different natural forest stands (Kigomo *et al*., 1990). Out of the recorded tree species, the five most dominant species were selected for further analysis. For each of the selected tree species, about a third of the data, selected randomly, was reserved for model validation while the rest were used in model calibration. Scatter graphs were plotted and models (linear, power, exponential, logarithmic and polynomial) fitted. Hoaglin and Welsch's (1978) leverage coefficient ($h_i = 1/n+(xi-\mu)^2/\mathring{a}x^2$) and standardized residuals, ϵ_{si}, ($\epsilon_{si} = \epsilon_i/(Se(1-h_i)^{1/2})$) were used to identify outliers. Crown diameters with $\epsilon_{si} > t_{0.01\ (n-2)}$ were excluded in the model calibration. Model coefficients α and β, and the coefficient of determination, R^2, were determined using Least Square Method (LSM), where α = y-intercept and β = regression coefficient. The F statistic and the significance F were then computed and the results tabulated. These parameters were used to determine the best fit models which were validated using the t-test, Pearson correlation coefficient and examination of residual plots.

RESULTS AND DISCUSSION

Species composition and dominance rating: The total number of trees measured was 3101 trees belonging to 114 genera. The ten most dominant were *E. saligna* (647), *C. lusitanica* (327), *G. robusta* (168), *C. megalocarpus* (117), *P. americana* (72), *M. lutea* (86), (*P. guajava* (68), *C. macrostachyus* (92), *V. infausta* (95), and *Rhus natalensis* (99) as shown in Appendix B by their Importance Value (IV) ratings. All trees were measured for DBH but Crown diameter was only measured on open growing trees.

Out of the 3101 trees recorded, 1362 were open growing trees belong to 93 genera. Crown diameter and DBH were measured on all them. The DBH ranged from 1 to 54 cm with means ranging from 6.59-14.1 cm (Appendix A). Importance Value rating showed that the ten most dominant open growing species were:

C. lusitanica, *G. robusta*, *E. saligna*, *P. americana*, *C. megalocarpus*, *C. macrostachyus*, *V. infausta*, *M. lutea*, *P. guajava* and *O. lanceolata.* Only two out of the ten tree species, measured for DBH and Cd, had less than 30 individual trees (*V. infausta* and *P. guajava*). Their species dominance ratings are shown in Table 1. The five most dominant tree species were selected for further analysis and modeling.

When the Importance values and the number of stems were tested for linear relationship, the Pearson correlation coefficient, r, was 0.886 implying that stocking (stems per ha) and species dominance are highly and linearly correlated

Model calibration and validation: In all the species, Hoaglin and Welsch (1978) leverage coefficients (h_i) for all the data points were lower than their threshold value of 4/n indicating consistency in the observations within the models. Though some of the standardized residuals (ϵ_{si}) were large, they generally tended to zero, with a mean of -0.0256 cm. Since a large residual for a point with a low leverage value does not unduly influence the regression line (Sokal and Rohlf, 1981) only points with relatively high residuals, $\epsilon_{si} > t_{0.01\ (n-2)}$ were considered outliers and excluded in calibration of the models. Exclusion of notable outliers significantly improved the R^2 values. For example in *C. lusitanica*, p-value was (p≤0.0026) and R^2 improved by a margin of between 0.081-0.135. The α and β coefficients, R^2, computed F-statistic, significance F and the standard errors of the fitted models are tabulated as in Table 2.

Generally, adjusted R^2 values in all the fitted models were ≥0.50, with relatively high F-values of between 90 and 281, except for the exponential model on *E. saligna* (Table 2). Of the fitted models, the Linear, Exponential and Power models performed better with the highest R^2 and F-values (Table 2 and 3). In all cases the residuals in these best fit models were randomly distributed, with the mean tending to 0 and standard error not exceeding 2.946 cm, except for *E. saligna* which was 5.862 cm. In all data sets there was more concentration of residuals in lower diameters than in higher diameters, implying a negative exponential distribution.

Table 2: The models' α, and β coefficients, R^2 and the F-statistics

Species	Model type and model coefficients	R^2	Adjd R^2	SE	F^1
C. lusitanica (n = 119)					
	$Y = 4.0811x-2.8089$	0.621	0.618	4.873	192
	$Y = 2.4479x^{1.1179}$	0.643	0.640	0.434	210
	$Y = 2.2384e^{0.3913x}$	0.679	0.676	0.411	247
	$Y = 10.989Ln(x)-1.1937$	0.522	0.518	5.471	128
	$Y = 0.4369x^2+0.967x+1.6571$	0.641	0.635	4.761	104
	$Y = -0.1796x^3+2.5229x^2-6.0972x+8.2797$	0.652	0.643	4.707	72
	$Y = -0.0988x^4+1.3979x^3-6.0378x^2+12.181x-4.3085$	0.662	0.650	4.660	56
E. saligina (n = 102)					
	$Y = 2.5093x + 4.1659$	0.590	0.586	5.862	144
	$Y = 3.9568x^{0.8703}$	0.483	0.478	0.564	93
	$Y = 5.5965e^{0.1709x}$	0.373	0.367	0.621	59
	$Y = 10.894Ln(x)+1.2848$	0.556	0.551	6.103	125
	$Y = -0.0328x^2+2.944x+3.2131$	0.592	0.584	5.876	72
	$Y = 0.0199x^3-0.4872x^2+5.625x-0.6434$	0.605	0.593	5.813	50
	$Y = 0.0021x^4-0.0441x^3+0.1334x^2+3.4657x+1.5463$	0.606	0.590	5.833	37
G. robusta (n = 84)					
	$Y = 3.776x-0.6307$	0.639	0.634	4.752	145
	$Y = 2.6988x^{1.1516}$	0.659	0.655	0.443	158
	$Y = 2.8325e^{0.3568x}$	0.620	0.615	0.468	134
	$Y = 11.43Ln(x)-0.2647$	0.598	0.593	5.015	122
	$Y = -0.1977x^2+5.331x-3.1279$	0.646	0.638	4.731	74
	$Y = -0.0907x^3+ 1.0104x^2+0.6883x+1.6997$	0.654	0.641	4.710	50
	$Y = 0.0493x^4-0.955x^3+6.073x^2-10.778x+9.878$	0.663	0.646	4.676	39
P. Americana (n = 41)					
	$Y = 2.5286x+0.549$	0.878	0.875	2.946	281
	$Y = 2.3423x^{1.0553}$	0.848	0.844	0.350	218
	$Y = 2.7492e^{0.2523x}$	0.772	0.766	0.429	132
	$Y = 10.049Ln(x)-0.4464$	0.871	0.868	3.026	264
	$Y = -0.1839x^2+4.4973x - 2.7737$	0.905	0.900	2.640	180
	$Y = -0.0133x^3+0.0355x^2+3.5045x - 1.6940$	0.905	0.898	2.667	118
	$Y = 0.0233x^4-0.5023x^3+3.3941x^2-5.0369x+4.8367$	0.914	0.905	2.573	96
C. megalocarpus (n = 41)					
	$Y = 2.2268x+0.1993$	0.698	0.690	2.939	90
	$Y = 2.3265x^{0.9134}$	0.614	0.604	0.454	62
	$Y = 2.2645e^{0.2872x}$	0.622	0.612	0.449	64
	$Y = 6.8396Ln(x)+0.6411$	0.642	0.633	3.198	70
	$Y = -0.1166x^2+3.1721x-1.1708$	0.704	0.688	2.949	45
	$Y = -0.1731x^3+2.006x^2-4.1894x +5.7012$	0.759	0.740	2.693	39
	$Y = -0.004x^4-0.104x^3+1.6091x^2-3.3286x+5.1216$	0.759	0.733	2.729	28

[1]: the corresponding significant F was 0.0000

Table 3: Selected models for the five most dominant tree species

Species	Model	Observations	R^2	AdjdR^2	SE	F^1	Mean residuals
C. lusitanica	y = 2.2384e0.3913x	119	0.679	0.676	0.411	247	1.017
E. saligna	y = 2.5093x + 4.1659	102	0.590	0.586	5.862	144	- 0.655
G. robusta	y = 2.6988x1.1516	84	0.659	0.655	0.443	158	- 0.213
P. Americana	Y = 2.5286x + 0.549	41	0.878	0.875	2.946	281	- 0.146
C. megalocarpus	Y = 2.2268x + 0.1993	41	0.698	0.690	2.939	90	0.013
Mean							0.0034

[1]: the corresponding significant F was 0.0000

Table 4: Validation Residual Statistics

Species	Mean residuals	SD of residuals	Correlation coefficient, r	p-value	Observations, n	Distribution of residuals
C. lusitanica	0.763	7.118	0.720	0.704	45	Randomly distributed
E. saligna	0.105	5.548	0.631	0.942	36	Randomly distributed
G. robusta	0.864	5.408	0.700	0.632	37	Randomly distributed
P. Americana	0.662	4.449	0.869	0.327	19	Randomly distributed
C. megalocarpus	- 0.911	2.408	0.913	0.657	17	Randomly distributed

The best models for each species are shown in Table 3. Comparatively these were the models with the highest adjusted R^2, least standard error, highest F-value, least dispersion of data points, lowest magnitude of residuals, and best random distribution of the residuals. For example, in *C. lusitanica*, though both the linear and exponential models performed quite well, the exponential model was preferred because deviation of the residuals
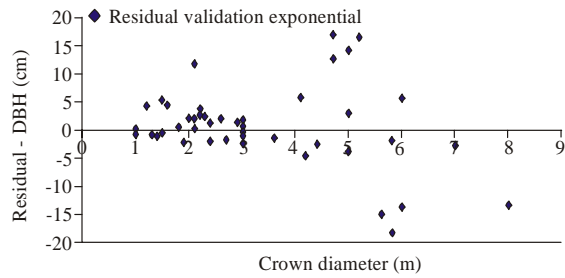
Fig. 2: Residual plots for *C. lusitanica* generated by the exponential model using validation data

was uniformly high for the linear model while they were lower in the exponential model and increasing with increase in crown diameter (Fig. 2). Though polynomial models yielded high R^2 values, the F-values were generally low. The F-statistic decreased as number of variables increased due to widened dispersion range of data points as was evident from the residual plots.

When the species selected models were fitted on data reserved for validation, the t-tests, p-values (Table 4) revealed no significant difference between the measured DBH and Model generated DBH values. Similarly the Pearson correlation coefficients, ranging from 0.631-0.913, showed strong correlations between the observed and predicted DBH values.

Validity of the selected models was further supported by the residual plots, which were randomly distributed around their means. The deviation means tended to zero (ranging from 0.105 to -0.911cm) with a Standard Deviation (SD) ranging between 2.41 and 7.12 cm.

Generally the deviations were smaller for smaller diameters except those for *E. saligna*, which were uniformly higher, compared to the others. The observed high residual deviations in *E. saligna* may be due to

measurement errors. Open growing *E. saligna* trees had crowns characterised by some unilaterally long branches that reduced the accuracy of the mean crown diameter.

These results imply that simple regression models resulted with the best DBH - Cd models and were best described by the Linear, Exponential and Power models. Hemery *et al*. (2005) had concluded that the DBH-Cd relationship is close to linear and it provided the best fit model (Lockhart *et al*., 2005). However, Avsar and Ayyildiz (2005) settled on the power model to describe crown diameter-DBH relationships. Height was not added to the models because it was thought to provide minor improvements to the models (Samantha *et al*., (2000). While the DBH- Cd relationship would be sigmoid for forest grown trees (Dawkins, 1963) it is expected to be linear for open grown tree species. Polynomial models describe height-DBH relationships (Avsar and Ayyildiz, 2005) better than DBH - Cd relationships and hence generally have low F-values.

When measured DBH values were compared with values generated using each of the calibrated models for the species, F-tests revealed no significant differences in *C. lusitanica* (p = 0.803), *P. americana* (p = 0.999) and *C. megalocarpus* (p = 0.994). Thus, although the selected models are the best fits, other calibrated models are equally good and can sufficiently estimate DBH from Cd. However, model generated data for *E. saligna* (p = 0.0301) and *G. robusta* (p = 0.0015) differed significantly from the observed ones implying that not all the species calibrated models could be used on these species.

The possibility of using species group models was explored through the completely randomised design concept. Using the selected models DBH values were generated across the species and ANOVA carried out. Generally, the selected models for *C. lusitanica*, *E. saligna* and *G. robusta* yielded predicted DBH values which were statistically the same, across the three species

Table 5: p-values when selected models were applied across species

Species	Model	C. lusitanica	E. saligna	G. robusta	P. america	C. megalocarpus
C. lusitanica	Y = 2.2384e0.3913x	0.437014	0.124579	0.263135	0.014346	0.059416
E. saligna	Y = 2.5093x + 4.1659	0.011366	0.999897	0.817442	0.049985	5.08E-05
G. robusta	Y = 2.6988x1.1516	0.754911	0.739755	0.391487	0.126665	0.029022
P. Americana	Y = 2.5286x + 0.549	0.061845	0.002188	0.000797	0.999957	0.258092
C. megalocarpus	Y = 2.2268x + 0.1993	0.000439	0.000439	0.000001	0.339039	0.999863

Table 6: Species groups models

Category	Model	R^2	Adjusted R^2	SE	F
Group 1 (n = 305)					
	Y = 3.1256x + 1.1254	0.593086	0.591743	5.414949	441.6
	Y = 2.9393x1.0441	0.586071	0.584705	0.494045	429.01
	Y = 3.7742e0.2566x	0.488671	0.486983	0.549103	289.57
	Y = 11.285Ln (x) - 0.3336	0.560277	0.558826	5.629018	386.07
Group 2 (n = 82)					
	Y = 2.4956x + 0.023	0.828798	0.826658	3.007039	387.28
	y = 2.2739x1.016	0.754454	0.751384	0.410505	245.80
	y = 2.5113e0.2654x	0.721455	0.717974	0.437219	207.21
	y = 9.0315Ln(x) - 0.3592	0.774621	0.771804	3.450177	274.96

(Table 5) at a 0.05 level of significance. Similarly, models selected for *P. americana* and *C. megalocarpus* generated DBH values that were statistically the same. This implies that the selected species can be categorised into two groups and models that can work across species calibrated.

The *C. lusitanica, E. saligna, G. robusta* data sets were combined into Group 1 and *P. americana* and *C. megalocarpus* into Group 2 and species group models calibrated. The Linear models fitted best in the data sets with the highest R^2 and F values (Table 6). In both cases the residuals were randomly distributed around zero. Group 1 model had a mean deviation of 0.60 with standard deviation of 6.13 cm while those of Group 2 model were 0.78 and 4.38 cm respectively. In both data sets there were more residuals in lower diameters than in higher diameters. Once again, pointing to a negative exponential diameter distribution.

In addition, both group model equations displayed high correlation coefficient, 0.706 and 0.833 respectively. In both Group 1 and 2, t-test showed no significant differences (p-values of 0.531, 0.637) between predicted and measured DBH values.

CONCLUSION AND RECOMMENDATION

Out of a total of 127 tree species that were assessed for crown and stem diameters in the study area the most dominant tree species were *C. lusitanica*, *E. saligna*, *G. robusta*, *P. americana* and *C. megalocarpus.*

Generally, the developed models fitted well (adjusted $R^2 \geq 0.50$, F values of between 90 and 281). Of the fitted models, the Linear, Exponential and Power models performed better showing the highest R^2 (up to 0.875, 0.676, 0.655) and F values (281, 247 158). Five out of the thirty-five calibrated models were selected based on adjusted R^2, standard error, F statistic, dispersion of data points, magnitude of residuals, and random distribution of the residuals, and validated as best for predicting stem diameter from crown diameter . In addition, group models showed better fit by having high R^2 values (0.591 and 0.826) and tested well on validation, revealing that common models can work well for a group of species.

It should be noted that the models developed by this study were based on data collected in Sondu-Nyando Catchment region and also covered a limited range of stem and crown diameters. The models should therefore be used with caution outside this region. Further studies need to be done to test applicability of these models across similar Agro-ecological zones and to relate the growth rates/patterns in both stem and crown diameters of open grown tree species to the fitted models.

Appendices:

Appendix A: Description statistics of data used in model development and validation

Species	Operation	Variable	Observations	Mean	SE	SD	Skewness	Minimum	Maximum
C. lusitanica	Calibration	DBH(cm)	119	9.98	0.72	7.88	1.37	2.5	33
		CD (m)	119	3.13	0.14	1.52	0.57	0.9	7.3
	Validation	*DBH*	45	11.54	1.44	9.65	1.47	2.5	38
		CD (m)	45	3.35	0.26	1.76	0.71	1	8
E. saligna	Calibration	*DBH(cm)*	102	14.07	0.90	9.11	1.21	1	54
		CD (m)	102	3.95	0.28	2.79	1.97	0.8	16
	Validation	*DBH(cm)*	36	11.31	1.21	7.25	0.10	1.5	23.5
		CD (m)	36	2.81	0.31	1.86	1.92	1	10
G. robusta	Calibration	*DBH(cm)*	84	13.00	0.86	7.86	0.36	2	32
		CD (m)	84	3.61	0.18	1.66	0.40	0.5	8.4
	Validation	*DBH(cm)*	37	13.28	1.43	8.68	0.23	1.2	29
		CD (m)	37	3.70	0.29	1.77	-0.01	0.5	8
P. Americana	Calibration	*DBH(cm)*	41	11.21	1.30	8.33	0.46	1.8	30.5
		CD (m)	41	4.22	0.48	3.09	0.77	0.8	10
	Validation	*DBH(cm)*	19	13.92	1.83	7.97	0.66	2.5	33
		CD (m)	19	4.40	0.44	1.93	0.04	1.4	8
C. megalocarpus	Calibration	*DBH(cm)*	41	7.17	0.82	5.28	1.05	1.8	20
		CD (m)	41	3.13	0.31	1.98	0.98	1	8
	Validation	*DBH(cm)*	17	6.59	1.40	5.76	1.86	2.1	22
		CD (m)	17	3.28	0.66	2.73	2.22	1	12

DBH: diameter at breast height; CD: crown diameter

Appendix B: Species dominance rating and species composition

S. No.	Tree species	Stems no.	IV	S. No.	Tree species	Stems no.	IV
1	*Eucalyptus saligna*	647	107.479	54	*Ekebergia capensis*	3	9.628
2	*Cuppresus lusitanica*	327	91.692	55	*Citrus sinensis*	2	9.598
3	*Grevillea robusta*	168	84.188	56	*Calliandra calothysus*	70	7.203
4	*Croton megalocarpus*	117	53.194	57	*Delonix regia*	9	6.143
5	*Persea Americana*	72	53.153	58	*Acacia schimperi*	32	5.849
6	*Markhamia lutea*	86	51.603	59	*Prosopsis juliflora*	5	5.662
7	*Psidium guajava*	68	51.470	60	*Tipuana tipu*	3	5.641
8	*Croton macrostachyus*	92	45.320	61	*Ficus thonningii*	5	5.562
9	*Vangueria infausta*	95	42.967	62	*Faurea saligna*	1	5.406
10	*Rhus natalensis*	99	35.230	63	*Calodendrum capense*	4	5.306
11	*Acacia lahai*	102	33.392	64	*Annona cherimola*	3	5.236
12	*Casimiroa edulis*	7	29.087	65	*Plectranthus barbatus*	12	5.154
13	*Sesbania sesban*	150	28.958	66	*Bersama abyssinica*	4	5.141
14	*Osyris lanceolata*	65	27.891	67	*Celtis Africana*	3	5.026
15	*Eucalyptus camadulensis*	167	27.043	68	*Piliostigma thonningii*	3	5.005
16	*Rhus vulgaris*	54	26.643	69	*Grewia bicolor*	3	4.948
17	*Erythrina abyssinica*	17	25.884	70	*Combretum collinum sub sp binderianum*		34.937
18	*Prunus Africana*	18	25.296	71	*Vepris nobilis*	5	4.930
19	*Carica papaya*	11	24.762	72	*Polyscias kikuyuensis*	1	4.927
20	*Eriobotrya japonica*	13	24.749	73	*Caesalpinia decapetala*	5	4.923
21	*Mangifera indica*	13	24.564	74	*Azadirachta indica*	1	4.909
22	*Acacia mearnsii*	55	22.479	75	*Hagenia abyssinica*	2	4.900
23	*Bridelia micrantha*	42	22.254	76	*Lophostemon confertus*	1	4.884
24	*Acacia melanoxylon*	21	20.708	77	*Fagara macrophylla*	3	4.875
25	*Trichilia emetica*	37	20.584	78	*Casuarina equisetifolia*	1	4.869
26	*Syzygium quineensis*	20	20.125	79	*Grewia tembensis*	2	4.868
27	*Spathodea campanulata*	8	19.943	80	*Euphorbia candelabrum*	3	4.867
28	*Albizia gummifera*	8	19.525	81	*Olea europaea sub sp europaea*	2	4.864
29	*Ricinus communis*	6	19.274	82	*Trimerea grandifolia*	3	4.862
30	*Thevetia peruviana*	51	16.458	83	*Euphorbia tirucalli*	3	4.859
31	*Lantana camara*	61	16.295	84	*Manihot glaziovii*	1	4.852
32	*Cassia siamea*	35	15.908	85	*Sapium ellipticum*	1	4.846
33	*Balanites aegyptica*	6	15.574	86	*Annona squamosa*	2	4.845
34	*Ficus pennsylvanica*	7	15.430	87	*Schinus molle*	1	4.838
35	*Jacaranda mimosifolia*	7	15.187	88	*Ficus benjamina*	1	4.832
36	*Flacourtia indica*	6	14.901	89	*Citrus limon*	2	4.831
37	*Makaranga kilimandscharica*	7	14.678	90	*Keetia gueinzii*	2	4.827
38	*Melia azedarach*	5	14.667	91	*Terminalia mantaly*	1	4.819
39	*Podocarpus fulcatus*	3	14.658	92	*Acacia siemberiana*	1	4.819
40	*Ekebergia rueppeliana*	6	14.654	93	*Pavetta gardeniifolia*	1	4.815
41	*Acacia xanthophloea*	3	14.607	94	*Maesopsis eminii*	1	4.811
42	*Acacia Senegal*	3	14.591	95	*Gliricidia sepium*	1	4.807
43	*Entada abyssinica*	20	14.484	96	*Acacia hockii*	1	4.807
44	*Fagaropsis angolensis*	4	14.434	97	*Pistacia aethiopica*	1	4.804
45	*Combretum molle*	12	12.216	98	*Acacia nilotica*	1	4.800
46	*Ficus sycomorus*	15	12.173	99	*Acacia elatior*	1	4.799
47	*Euclea divinorum*	5	10.364	100	*Ficus sur*	1	4.798
48	*Warburgia ugandensis*	7	10.213	101	*Morus alba*	1	4.797
49	*Terminalia brownie*	9	9.883	102	*Vitex keniensis*	1	4.797
50	*Hakea saligna*	5	9.806	103	*Gnidia subcordata*	1	4.797
51	*Nuxia congesta*	3	9.742	104	*Eleocharis cellulose*	1	4.795
52	*Olea europaea sub sp Africana*	3	9.723	105	*Phoenix dactylifera*	1	4.795
53	*Bauhinia variegate*	3	9.682	106	Others (7 species)	8	≈4.8 each

Grand total no. of stems = 3101

REFERENCES

Avsar, M.D. and V. Ayyildiz, 2005. The relationships between diameter at breast height, tree height and crown diameter in Lebanon cedars (*Cedrus libani* A. Rich.) of the Yavsan mountain, Kahramanmaras, Turkey, Pak. J. Biol. Sci., 8(9): 1228-1232.

Bonnor, G.M., 1968. Stem diameter estimates from crown width and tree height. Commonw. Forest. Rev., 47: 8-13.

Curtis, J.T. and R.P. Mclntosh, 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology, 31(3): 435-455.

Dawkins, H.C., 1963. Crown diameters: their relation to bole diameter in tropical forest trees. Commonw. Forest. Rev., 42: 318-333.

Gering, L.R. and D.M. May, 1995. The Relationship of diameter at breast height and crown diameter for four species groups in Hardin County, Tennessee. South. J. Appl. For., 19(4): 177-181.

Goelz, J.C.G., 1996. Open-grown crown radius of eleven bottomland hardwood species: prediction and use in assessing stocking. South. J. Appl. For., 20: 156-161.

Hemery, G.E., P.S. Savill and S.N Pryor, 2005. Applications of the crown diameter stem diameter relationship for different species of broadleaved trees. Forest Ecol. Manage., 215(3): 285-294.

Hoaglin, D.C. and R.E. Welsch, 1978. The hat matrix in regression and ANOVA. Am. Stat., 32: 17-22.

Husch, B., C.I. Miller and T.W. Beers, 1982. Forest Measurement. John Wiley & Sons, New York, USA.

Jaetzold, R. and H. Schmidt, 1983. Farm Management Handbook. Vol. 2, Natural Conditions and Farm Management Information. Ministry of Agriculture, Nairobi, Kenya.

Kigomo, B.N., 1980. Crown-bole diameter relationship of *Juniperus procera* (cedar) and its application to stand density control and production survey in natural stands. E. Afr. Agric. Forest. J., 46 (2): 27-37.

Kigomo, B.N., P.S Savill and S. Wodell, 1990. Forest composition and its regeneration dynamics: A case study of semi-deciduous tropical forests in Kenya. Afr. J. Ecol., 28: 174-188.

Kigomo, B.N., 1991. Crown and bole diameter relationship in *Brachyleana huillensis* and its application to silvicultural interventions. E. Afr. Agric. Forest. J., 57(1): 67-73.

Kigomo, B.N., 1998. Morphological and growth characteristics in *Brachyleana huillensis* (Muhugu); some management considerations. Kenya J. Sci. (Series B), 11(1-2): 11-20.

Lockhart, B.R., C. Robert, J.R. Weih and M.S. Keith, 2005. Crown radius and diameter at breast height relationships for six bottomland hardwood species. J. Arkansas Acad. Sci., 59: 110-115.

Samantha, J.G., S.B. Gregory and E.C. Murphy, 2000. Modeling conifer tree crown radius and estimating canopy cover. Forest Ecol. Manag., 126(3): 405-416.

Sokal, R.R. and J.F. Rohlf, 1981. Biometry, N H Freeman and Company, New York, U.S.A.