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STEM DISTRIBUTIONS AND HEIGHT-DIAMETER ALLOMETRIES FOR TWO SPECIES OF *Irvingiaceae* (*exell* and *mendonça*) IN A TROPICAL MOIST FOREST OF SOUTHERN NIGERIA

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ABSTRACT

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The study investigated stem distributions and height-diameter relationships of two Irvingiaceae species in Oban Forest, Cross River State, Nigeria with a view to suggesting appropriate management strategies for their conservation in the area. Using systematic sampling technique, six 2km-transect was cut in each of the primary and secondary forests in the area. Four 50m×50m plots were laid alternately along each transect. Thus, twenty-four plots were used in each of the two forest types, making a total of 48 sample plots for the study. On each of the sample plots, Irvingia wombulu and Klainedoxa gabonensis were identified and their growth parameters measured on the trees with DBH≥10cm. Data were analyzed using descriptive and inferential statistics. The result reveals that there were average of 3 and 4 I. wombulu and K. gabonensis stems/ha respectively in the area. About 47% of I. wombulu fell in the height class 10-20m, about 36% of K. gabonensis fell in the height class 21-30m. Both species have fewer stems in the height class of >40m. Tree diameter distributions reveal that about 33% of I. wombulu were in the class 10-39cm. Only 16% of K. gabonensis belong to this class. About 20% of K. gabonensis encountered fell in the diameter class ≥100cm. There were significant differences between most of the tree growth parameters for the two species. However, the species were found to exhibit similar growth patterns in the two forest types. All the height-diameter models presented in the study were significant. In all I. wombulu gave better models than the K. gabonensis, going by their modelling efficiencies and tests of bias. The models were therefore recommended for predictions in the study area.

Keywords: Size distributions; models; Irvingiaceae; forest types; rain forest

INTRODUCTION

Literature is replete with the immense contributions of *Irvingia wombulu* and *Klainedoxa gabonensis* to the existence of human and animal populations. For example, it has been reported that livelihoods of many West and Central African dwellers are tied to the fruiting ability of *I. wombulu* (Sunderlans *et al*., 2002; Lejoy *et al*., 2003; Ewane *et al*., 2009; Ewane, 2010). The most well-known use of the tree is the oily seed kernels of the species. The kernels form an important part of the West and Central African diet, providing carbohydrate and protein. Fat extracted from the kernels can be used for food, and is also suitable for soap, cosmetics and pharmaceuticals (Ainge *et al.*, 2001). The roots, leaves and the bark are used medicinally, often mixed with palm oil to treat diarrhoea, by women to shorten their breast feeding period, for colic, dysentery, hernias, yellow fever, as an anti-poison and antibiotic for healing scabby skin and particularly when boiled, as a painkiller for toothache (Ainge *et al.*, 2001). It has been found to contain a narcotic-type analgesic agent and may also contain a non-narcotic active agent. Fresh bark is used to add a bitter taste to palm wine. It is also harvested as a 'chewing-stick' for mouth wash and dental hygiene. The leaves have been used as animal fodder (Ainge *et al.*, 2001).

Similarly, David (2013) documented the roles of *K. gabonensis* in the diets of large mammals such as elephant, lowland gorilla and yellow backed duikers. *K. gabonensis* fruits mesocarp serves as food for elephants and lowland gorillas. Yellow backed duikers (*Cephalophus sylvicultor*) also swallow the fruit and then regurgitate the pyrenes after digesting the mesocarp. These animals are also believed to play a role in the dispersal of the species (David, 2013).

On the other hand, tree height and diameter have been reported to be key components of stem volume, which is a determinant of carbon stock in plants (Egbe and Tabot, 2011). They are widely used as measures of the site quality and stand productivity (Husch *et al*., 2003). Tree height distribution is an important factor in many silvicultural prescriptions and in assessing wildlife habitat (Husch *et al*., 2003). The vertical structure can be described using the actual heights. The height may be calculated or the height distribution can be specified using many of the same models as used for diameter (Husch *et al*., 2003). Diameter has been used as surrogate of age in many tropical forest studies (Okojie, 1996; Akindele, 2005). These authors further affirmed that the determination of age in a tropical forest is meaningless due to high species diversity and different time and period of recruitments in such forests. Hence, diameter is used instead.

Although useful, the measurement of tree height in tropical forest inventories is time-consuming and expensive (Scaranello *et al*., 2012). Consequently, there are few forest models that use tree height as an independent variable (Fang and Bailey, 1998). An alternative to height measurement for all individuals is the application of site-

specific height-diameter allometries that relate DBH with measured tree height (Batista *et al*., 2001). However, height-diameter relationships vary within a geographic region (Peng *et al*., 2001) due to species composition and local environmental conditions. Hence, there is a growing consensus that the use of site specific height-diameter models fitted using field measures of tree height is an important alternative to reduce uncertainties in forest yield, biomass estimation and forest structure in tropical forests (Chave *et al*., 2005; Nogueira *et al*., 2008; Feldpausch *et al*., 2010). Moreover, tree height-diameter allometry establishes quantitative relationships between some key characteristic of trees, which are fairly easy to measure and other attributes that are often more difficult to measure and assess. Direct measurements of forest structure are taken on intensively sampled, relatively-small field plots, and these data are used to create allometric equations that predict forest parameters from easily measured tree attributes (Adeyemi, 2012).
The two species are highly valued in different respects, for instance, the wood of the species are used locally for construction, being fine-grained, hard, heavy timbers. They are also used for making poles and stakes, and live branches are made into walking sticks or thatched roof supports. Branches are also used as firewood (Harris, 1996). However, their distributions and structural characteristics in the Oban forest have not been documented. Further, their prevalence is not yet known. In the same vein, the information on height-diameter allometries is non-existent for the two species in the area. This study therefore, investigated the distributions and structures of the two species in Oban Forest with a view to suggesting appropriate management strategies for their continued existence in the forest. Height-diameter models were also formulated for the species height growth predictions in the area.

MATERIALS AND METHODS

The study was conducted in Oban Forest of Cross River State, Nigeria. The area lies within the Lower Guinea region, and contains a large number of plant species with a narrow distribution - essentially the area from the Cross River in Nigeria to the Sanaga River in Cameroon. The Oban Forest is divided into two major sub-divisions (Oban West and Oban East) for administrative convenience. It occupies an area of about 300,000 hectares. Oban forest lies within longitudes 8° 02' and 8° 55'E, latitudes 5° 00' and 6° 00'N (Fig. 1). The vegetation is lowland rain forest and other characteristic tree species include *Berlinia confusa*, *Coula edulis*, *Hannoa klaineana*, *Khaya ivorensis*, *Terminalia ivorensis*, *Lophira alata*, *Strombosia spp* and *Diospyros spp.*

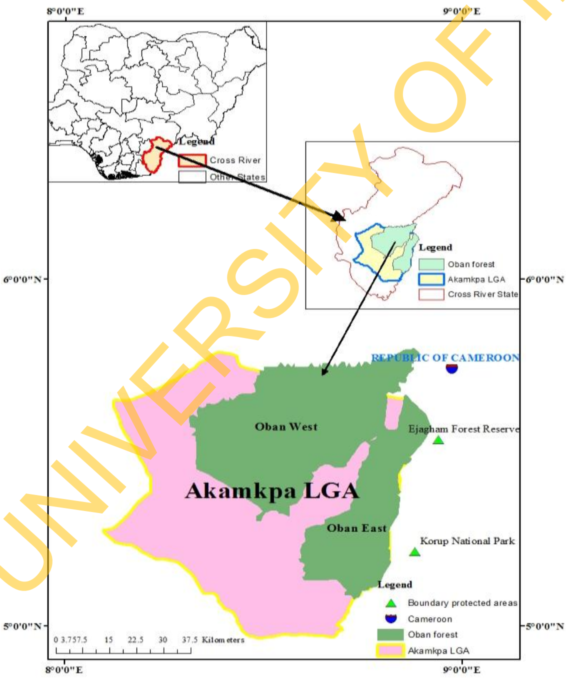

Fig. 1: Map of the study area

Data collection

Systematic sampling technique was adopted for plots' location in this study. Six 2km-transect each were cut in the two forest types (primary and secondary forests) at an interval of 600m from each other. Four 50m × 50m were laid alternately along each transect. Twenty-four sample plots each were used in the primary and secondary forests. A total of 48 sample plots were used for the study. On each of the sample plots, tree growth parameters: Diameter at breast height (DBH), diameter at the base (D_b); diameter at the middle (D_m); diameter at the top (D_t); tree total height (THT); Stem quality or tree bole length (SQ); crown length (CL) and crown diameter (CD) were measured on all the *I. wombulu* and *K. gabonensis* trees with DBH ≥ 10cm found in the area.

Data Analysis

Basal density estimation: The basal area, a measure of basal density was computed for each of the individual *Irvingia wombulu* and *Klainedoxa gabonensis* trees in the sample plots as follows:

$$BA = \frac{\pi\ (DBH)^2}{4} \qquad (1)$$

Where, BA = Basal area (m^2) and π is a constant, which equals 3.143. The basal area for each plot was obtained by adding individual tree basal area in each plot, i.e.

$$BA_p = \sum_{i=1}^{n} BAi \qquad (2)$$

Where, BA_p = Basal area per plot; BA_i = Basal area for *ith* tree in the plot. The basal area per hectare was then obtained by multiplying the plot basal area by 4 (4 being the number of 0.25ha sample plots in a hectare).

Volume estimation per hectare: The volume of individual trees in the plot was calculated using Newton's formula, as presented by Husch *et al.* (2003):

$$V = \frac{h}{6}\left(A_b + 4A_m + A_t\right) \qquad (3)$$

Where, V = tree stem volume (m^3); h = tree total height (m); A_b, A_m and A_t are cross-sectional areas at the base, middle and top of the trees respectively.

$$A_i = \frac{\pi\ Di^2}{4} \qquad (4)$$

The stem volume equation was re-written as:

$$V = \frac{h}{24}\left(\pi D_b^2 + 4\pi D_m^2 + \pi D_t^2\right) \qquad (5)$$

Where, D_b, D_m and D_t are tree stem diameters at the base, middle and top respectively. The stem volume per plot was determined by adding up the volumes of individual trees within the plot. The volume per hectare was then obtained by multiplying the plot stem volume by 4.

Descriptive Statistics: Descriptive statistics were computed for all the measured tree parameters, with particular references to species frequencies/ha, diameter at breast height and tree total height.

Height and diameter classifications: All the measured trees were classified into five height classes: <10m; 10-20m; 21-30m; 31-40m and >40m, which correspond to the suppressed, intermediate, co-dominant, dominant and emergent canopy layers in the forests following Jimoh *et al.* (2012). The diameters at breast height of all the measured trees were classified into classes of: <20cm, 20-39cm, 40-59cm, 60-79cm, 80-99cm, ≥100cm. The frequency and percentages were then computed for each of the height and diameter classes.

Correlation analysis: Correlation analysis was carried out to examine the linear associations among the tree growth parameters. Karl Pearson's product-moment correlation co-efficient was computed for each pair of the tree growth parameters as follows:

$$r = \frac{\sum XY - \frac{\left(\sum X\right)\left(\sum Y\right)}{N}}{\sqrt{\left[\sum X^2 - \frac{\left(\sum X\right)^2}{N}\right]\left[\sum Y^2 - \frac{\left(\sum Y\right)^2}{N}\right]}} \qquad (6)$$

Where, X and Y are individual measurements of the tree growth parameters to be compared, N is the total number of the pairs or sampled trees.

Comparison of the tree growth parameters between the two species in the two forest types: Student's t-statistics (t-tests) were computed for each of the tree growth parameters, and in the two forest types, to investigate significant differences between the two tree species and the two forest types as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S^2 \frac{\left(N_1 + N_2\right)}{\left(N_1\right)\left(N_2\right)}}} \qquad (7)$$

Where, $\bar{X}_1$ = mean of the measured values for a particular growth parameter for *Irvingia wombulu*, or in the primary; $\overline{X}_2$ = mean of the measured values for the parameter of *Klainedoxa gabonensis*, or in the secondary forest, N_1 = number of *Irvingia wombulu*/ha, or in the primary forest, N_2 = number of *Klainedoxa gabonensis*/ha, or in the secondary forest and S^2 = pooled within-group variance (for independent samples with equal variance). The t has $(N_1\text{-}1) + (N_2\text{-}1)$ degrees of freedom.

Height-diameter equations: Five sets of height-diameter models were developed in this study. The first set comprises height-diameter allometries for *I. wombulu* while the second set was for *K. gabonensis*. The following height-diameter models were developed for the two species:

$$H = a + bDBH \quad \text{......(8)}$$

$$H = a + bD_m + cD_t \quad \text{......(9)}$$

$$H = a + bDBH + cCD \quad \text{......(10)}$$

$$H = a + bDBH + cSQ \quad \text{......(11)}$$

$$H = a + bDBH^2 + cSQ \quad \text{......(12)}$$

Where, H = tree total height; DBH = tree diameter at breast height; D_m = tree stem diameter at the middle; CD = tree crown diameter; SQ = stem quality; a, b and c are regression constants to be estimated.

Model assessment: For all the models, the following statistics were computed for model assessments:

$$R^2 = 1 - \frac{\sum_{i=1}^{m}\sum_{i=1}^{n_i}\left(H_{ij} - \hat{H}_{ij}\right)^2}{\sum_{i=1}^{m}\sum_{j=1}^{n_i}\left(H_{ij} - \overline{H}_{ij}\right)^2} \quad \text{......(13)}$$

$$SEE = \sqrt{\frac{\sum_{i=1}^{m}\sum_{j=1}^{n_i}\left(H_{ij} - \hat{H}_{ij}\right)^2}{n-p}} \quad \text{......(14)}$$

Where, $\hat{e}$ is the difference between the measured tree total height (H_{ij}) and the estimated tree total height ($\hat{H}_{ij}$); $\overline{H}_{ij}$ is the mean measured tree height; *SSE* is the error sum of squares, *SST* is the total sum of squares, '*n*' is the number of trees in the model-fitting data set, and '*p*' is the number of regression coefficients in the fitted equations. The model was also assessed by testing the overall significance of the regression by computing the F-statistics for all the developed models. The F-statistics value for each of the models was compared with the tabulated value of '*F*'. Any model with its F-statistics greater than the tabulated F-value was adjudged suitable for prediction and was retained. Those with their F-statistics lower than the tabulated F-values were disregarded, and therefore were not presented in this study. For models with good fits, the intercept must be closed to 0 and the slope must be very close to 1, the models must be significant with high coefficient of determination (R^2) and with small values of the standard error of estimate, *SEE* (Adekunle *et al.*, 2004; Adeyemi and Adesoye, 2010; Adeyemi, 2012).

Model validation: Model validation was done by dividing the data into two sets. First set (the calibrating set) comprised tree data from 24 *Irvingia wombulu* and 34 *Klainedoxa gabonensis* trees. These were used for model generations. The validating set comprised tree data from 12 *Irvingia wombulu* and 16 *Klainedoxa gabonensis* stems. These were used for validating the models (Akindele and LeMay, 2006; Adeyemi, 2012). The model outputs were individually compared with the observed tree total height values as the response variable while the model outputs were the explanatory variables for each of the allometric equations. After the model validation, the two sets of the data were then pooled to generate the final height-diameter and stem quality allometries presented in this study. Tests of bias were also computed to determine the absolute differences between the measured variables and the model outputs using:

$$Bias = \hat{E} = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n_i}\left(H_{ij} - \hat{H}_{ij}\right)}{n} \quad \ldots\ldots(5)$$

Where, H_{ij} and $\hat{H}_{ij}$ are the measured and the predicted values for tree total height respectively. The value of bias must be relatively small for the model to be acceptable for management purpose (Adeyemi, 2012).

RESULTS AND DISCUSSION

Table 1 presents the descriptive statistics for the species distributions and tree growth parameters. *Irvingia wombulu* and *Klainedoxa gabonensis* had average of 3 and 4 stems/ha respectively in the study area. The average number of *I. wombulu* stems/ha was higher in the secondary forest (4) than in the primary forest (3). However, *K. gabonensis* had higher number of stems/ha in the primary forest (7) than the secondary forest (2). The numbers of stems/ha are small compared to stems/ha recorded for *Coula edulis*, *Strombosia grandifolia* and *S. postulata* in the area, which are most prevalent in the ecosystem (Adeyemi, 2012). The higher abundance of *I. wombulu* in the secondary forest may be due to the fact that human beings dispersed the fruits more often in the area than they do in the primary forest since the anthropogenic activities were more visible in the secondary forest, which happens to be the buffer of the protected area (the primary forest). However, the presence of human in the area may have been a curse for *K. gabonensis* as the activities of illegal loggers were also more prevalent in the secondary forest (the buffer) because of lesser restriction to the forest resources in the area compared to the primary forest (the protected core of the area).

Considering the mass fruiting habits of the two species, one would expect that such species would pre-dominate the area. The few numbers of stems/ha recorded may be due to the high rate of utilizations of the two species by both human and animal populations, which may have threatened the regeneration and recruitment potentials of the two species in the area. For instance, it has been said that the contributions of *Irvingia wombulu* fruits to rural economy are immense, as the livelihoods of many depend greatly on it (Sunderland *et al*., 2002; Lejoy *et al*., 2003; Ewane *et al*., 2009; Ewane, 2010). Similarly, the survival of many wild mammals, such as elephant, lowland gorilla and the duiker species (especially the yellow backed duiker, *Cephalophus sylvicultor*), depend significantly on the availability of *Klainedoxa gabonensis* fruits (David, 2013). Hence, the two species are faced with use pressures and animal predation of seeds in the area.

The mean tree total height (THT) for *I. wombulu* and *K. gabonensis* were 24.96±9.46m and 29.53±9.29m respectively. The mean stem quality (SQ) were 16.62±7.19m and 18.80±6.89m respectively for the two species. The mean DBH for the two species were 38.2±28.0cm and 60.3±55.4cm respectively. The mean crown lengths for the two species were 8.34±4.96m and 10.73±6.60m respectively. *I. wombulu* had mean crown diameter of 6.72±4.05m while *K. gabonensis* had mean crown diameter of 10.28±6.88m. The mean tree basal area (BA)/ha for *I. wombulu* was 0.072±0.108m^2/ha while that of *K. gabonensis* was 4.82±19.58m^2/ha. The mean stem volumes (V) for the two species were 46.92±9.91m^3 and 139±213.33m^3/ha. Details of the descriptive statistics for the tree growth parameters are shown in Table 1.

Table 1: Descriptive statistics for the tree species and growth parameters

Species	Variable	N/ha	Min.	Max.	Mean	Std. Dev.
Irvingia wombulu	THT (m)	3	13.00	47.00	24.96	9.46
	SQ (m)	3	8.50	36.00	16.62	7.19
	DBH (cm)	3	12.10	106.12	38.2	28.0
	D_m (cm)	3	8.20	92.15	60.3	4.20
	D_t (cm)	3	7. 50	78.50	25.13	3.64
	CL (m)	3	2. 00	2250	8.34	4.96
	CD (m)	3	2.12	15.77	6.72	4.05
	BA (m^2)/ha	3	0.0037	0.48	0.072	0.108
	V (m^3)/ha	3	1.92	84.12	46.92	9.91
Klainedoxa gabonensis	THT (m)	4	12.00	48.50	29.53	9.29
	SQ (m)	4	5.60	34.50	18.80	6.89
	DBH (cm)	4	14.16	304.46	60.3	55.4
	D_m (cm)	4	13.21	215.50	45.87	6.69
	D_t (cm)	4	8.75	187.25	37.64	5.40
	CL (m)	4	2.50	26.25	10.73	6.60
	CD (m)	4	2.00	31.63	10.28	6.88
	BA (m^2)/ha	4	0.267	121.33	4.82	19.58
	V (m^3)/ha	4	3.17	715.83	139.00	213.33

N.B: N: number of trees/ha; THT: tree total height; SQ: stem quality, or tree bole length; DBH: diameter at breast height; D_m: diameter at the middle; D_t: diameter at the top; CL: tree crown length; CD: tree crown diameter; BA: tree basal area; V: tree stem volume

The mean values for the tree total height of the two species reveal that majority of the stems are tall trees. Young stems of the two species were not common in the area. This may be a result of intensive activities of *Irvingia wombulu* collectors in the area. Similarly, it appears that *Klainedoxa gabonensis* stems, which could have been mother trees, supporting regenerations of younger ones might have been lost to illegal logging in the past before the forest was reconstituted into a protected area. Ainge *et al.* (2001) have reported that the two species are very good for local construction, and as timber species. Perhaps, the feeding activities of wildlife may have also threatened regeneration of the species.

The stem basal areas of 0.072m^2/ha and 4.82m^2/ha are far below the 15m^2/ha suggested by Alder and Abayomi (1994) for a well-stocked tropical rain forest in Nigeria. This may be due to the fact the forest is mixed with numerous species, which may have resulted in the survival of the fittest in the stand. A case of the dominance of *Olacaceae* family was reported in the area by Adeyemi (2012). Moreover, these two species are threatened by the activities of *Irvingia wombulu* fruits harvesters and large mammals that depend majorly on the fruits of *Klainedoxa gabonensis*. Besides, a case of stocking may be down played since the ecosystem is not made up only of the two species considered in this study.

Species height and diameter distributions

The result of the species height distributions is presented in Fig. 2. There were no stems in the height class <10m (suppressed layer). About 47% and 20% *of I. wombulu* and *K. gabonensis* stems respectively fell in the height class 10-20m (intermediate layer). The height class 21-30m (co-dominant layer) were represented by 27.8% and 36% of *I. wombulu* and *K. gabonensis* respectively. About 14% and 24% of the two species respectively were in the height class 31-40m (dominant layer). The emergent (height class >40m) was represented by 11.1% and 20% of *I. wombulu* and *K. gabonensis* in the area.

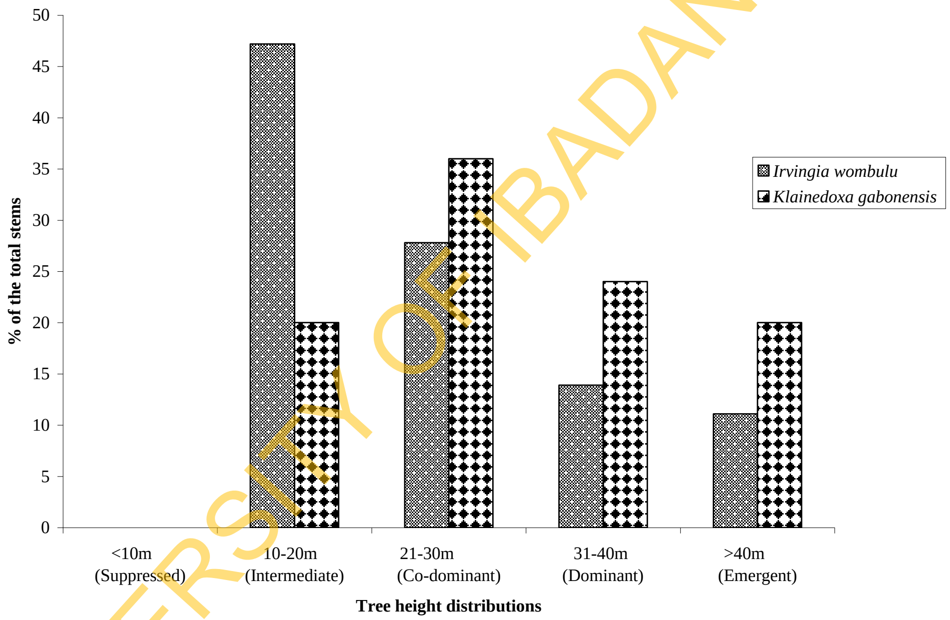

Fig. 2: Tree height distributions for the two tree species in the study area

The patterns of growth in the two species are slightly different. For *Irvingia wombulu*, the canopy structure is such that the largest proportion of the stems are in the middle (intermediate) layer, which according to Michael (2001), harbours most species of rain forest wildlife due to availability of food at this level. However, majority of *K. gabonensis* stems belong to the higher canopy. This may be due the fact that the species is threatened by wildlife-use pressure. Or the young ones as well as the saplings could not withstand serious competitions with other species in the ecosystem. Hence, few stems escaped early successional stages. The diameter (DBH) distributions for the two species are shown in Fig. 3. The results reveal that majority (33.3%) of *I. wombulu* stems were in the lowest diameter class (<20cm). Sixteen (16%) of *K. gabonensis* stems fell in this class. About 31% and 32% of *I. wombulu* and *K. gabonensis* belong to the diameter class 20-39cm respectively. The diameter class 40-59cm had 13.9% and 20% *of I. wombulu* and *K. gabonensis* respectively. For *I. wombulu*, the diameter class ≥100cm was least represented with only 5.6% of the total stems. Twenty (20%) of *K. gabonensis* stem are found in this class. For this species, the diameter class 80-99cm was least represented with only 4% of the total stems present in the area.

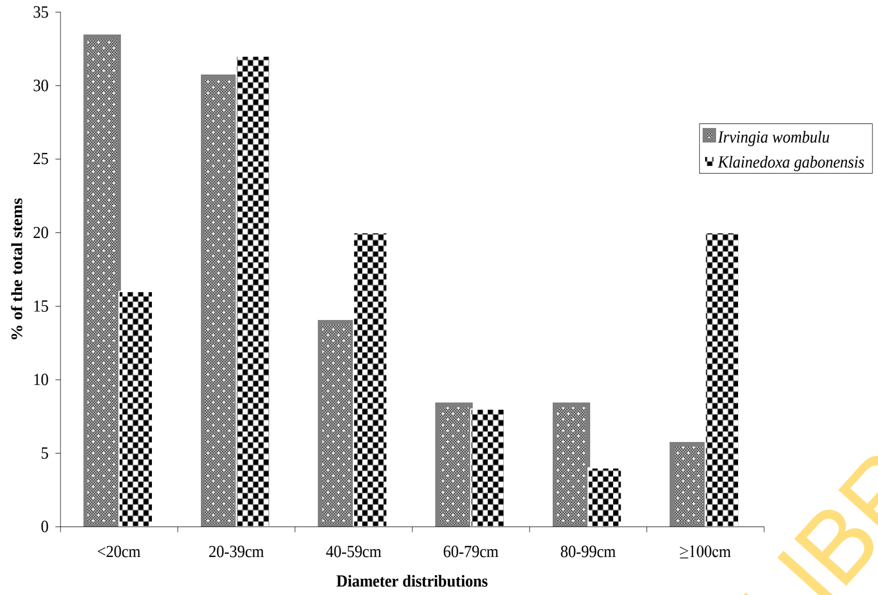

Fig. 3: Diameter (DBH) distributions for the two tree species in the study area

There were more stems in the lower DBH classes than in the upper classes. This is consistent with reports of previous workers (Boubli *et al*., 2004; Bobo *et al*., 2006). The implication of this is that the species are still undergoing regeneration and recruitment, which are vital indicators of forest health and vigour (Jimoh *et al*., 2012). The fewer number of *Irvingia wombulu* stems with DBH values >40 cm can be attributed to the fact that there might be a limited number of this species that naturally grow up to this diameter class, and their seedlings need to meet optimal conditions for growth (Hartshom, 1980 and Jimoh *et al*., 2012).

Correlation among the species growth parameters: Table 2 presents the results of correlations among the tree growth parameters. There were generally high correlations among the species growth parameters. These are expected since the effects of most of the growth attributes are additive. The results for the two species reveal that diameters at breast height, middle and top of the bole length are highly positively correlated. The tree total height also had highly positive correlations with the other tree growth parameters in *I. wombulu*. However, there are weaker correlations between tree total height and other growth parameters in *K. gabonensis* with lower correlation co-efficient compared to the values among *I. wombulu* parameters. For *I. wombulu*, basal area and the tree crown diameter are least correlated with a correlation co-efficient of 0.138. A similar result was obtained for stem quality and tree basal area in *K. gabonensis* with a correlation co-efficient of 0.139.

Table 2: Pearson product-moment correlation co-efficient for the species growth parameters

Species		THT	DBH	D_m	D_t	CD	SQ	BA
Irvingia wombulu	DBH	0.852						
	D_m	0.861	0.992					
	D_t	0.826	0.980	0.989				
	CD	0.857	0.712	0.737	0.728			
	SQ	0.865	0.906	0.896	0.851	0.704		
	BA	0.608	0.543	0.520	0.450	0.138	0.616	
	V	0.836	0.917	0.915	0.906	0.777	0.848	0.416
Klainedoxa gabonensis								
	DBH	0.523						
	D_m	0.527	0.983					
	D_t	0.499	0.986	0.991				
	CD	0.421	0.786	0.809	0.814			
	SQ	0.704	0.205	0.209	0.185	0.084		
	BA	0.423	0.933	0.865	0.877	0.683	0.139	
	V	0.494	0.920	0.864	0.863	0.685	0.197	0.984

N.B: THT: tree total height; SQ: stem quality, or tree bole length; DBH: diameter at breast height; D_m: diameter at the middle; D_t: diameter at the top; CL: tree crown length; CD: tree crown diameter; BA: tree basal area; V: tree stem volume

Comparisons of the tree growth parameters between the two species in the two forest types: The results of t-tests for the comparisons of the tree growth parameters between the two species are presented in Table 3. The mean tree total height (THT), DBH, crown diameter and basal area between the two species were significantly different from each other as P<0.05 respectively. The results of the tests for stem quality (SQ), crown length (CL) and stem volume (V) reveal no significant differences between the two species since P>0.05 in each of the cases. In all the tree growth parameters, *K. gabonensis* had the highest mean values compared to *I. wombulu*. Details of the results of the tests are presented in Table 3.

Table 3: Results of the t-test for the comparisons of tree growth parameters between *I. wombulu and K. Gabonensis*

Growth parameter	Species	N/ha	Mean	Std. Dev.	df	T	P-value	Remarks
THT (m)	*Irvingia wombulu*	3	24.96	9.46	84	2.23	0.029	sig.
	Klainedoxa gabonensis	4	29.53	9.29				
SQ (m)	*Irvingia wombulu*	3	16.62	7.19	84	1.41	0.16	ns
	Klainedoxa gabonensis	4	18.80	6.89				
DBH (cm)	*Irvingia wombulu*	3	38.2	28.0	84	2.42	0.018	sig.
	Klainedoxa gabonensis	4	60.3	55.4				
CL (m)	*Irvingia wombulu*	3	8.34	4.96	84	1.92	0.058	ns
	Klainedoxa gabonensis	4	10.73	6.60				
CD (m)	*Irvingia wombulu*	3	6.72	4.05	84	3.00	0.0036	sig.
	Klainedoxa gabonensis	4	10.28	6.88				
BA (m^2)	*Irvingia wombulu*	3	0.0073	0.009	84	3.10	0.0032	sig.
	Klainedoxa gabonensis	4	0.52	1.18				
V (m^3)	*Irvingia wombulu*	12	5.68	9.91	84	1.91	0.061	ns
	Klainedoxa gabonensis	4	16.8	39.4				

α = 0.05; N.B: N: number of trees per hectare; THT: tree total height; SQ: stem quality, or tree bole length; DBH: diameter at breast height; CL: tree crown length; CD: tree crown diameter; BA: tree basal area; V: stem volume

The significantly different means of tree total height, diameter at breast height, crown diameter and basal area between the two species may not be far from the fact that the two species have different growth patterns. Nevertheless, there were no significant differences in the mean stem quality, crown length and stem volume between the two species. This may be as a result of the fact that the species still share some growth features as members of the same family, most especially as they are growing in a common biological and physical environment. Table 4 presents the results of the t-tests for the tree growth parameters *for I. wombulu* between the two forest types. The results reveal that there were no significant differences between the means of all the tree growth parameters in the two forest types since P>0.05 respectively. For *I. wombulu*, the mean values for the tree growth parameters were higher in the secondary forest than in the primary forest except that of basal area shown in Table 4.

Table 4: Results of t-test for *I. wombulu* growth parameters in the two forest types

Growth parameter	Forest types	N/ha	Mean	Std. Dev.	df	t	P-value	Remarks
THT (m)	Primary forest	3	24.26	8.52	34	0.36	0.72	ns
	Secondary forest	4	25.40	10.2				
SQ (m)	Primary forest	3	14.88	4.80	34	1.30	0.20	ns
	Secondary forest	4	17.73	8.28				
DBH (cm)	Primary forest	3	36.10	23.0	34	0.37	0.71	ns
	Secondary forest	4	29.50	31.3				
CL (m)	Primary forest	3	9.38	6.41	34	0.90	0.38	ns
	Secondary forest	4	7.67	3.79				
CD (m)	Primary forest	3	6.61	4.13	34	0.12	0.91	ns
	Secondary forest	4	6.78	4.10				
BA (m^2)	Primary forest	3	0.0099	0.0128	34	1.17	0.26	ns
	Secondary forest	4	0.0057	0.0011				
V (m^3)	Primary forest	3	3.74	5.48	34	1.08	0.29	ns
	Secondary forest	4	6.90	11.9				

α = 0.05. N.B: N/ha: number of trees per hectare; THT: tree total height; SQ: stem quality, or tree bole length; DBH: diameter at breast height; CL: tree crown length; CD: tree crown diameter; BA: tree basal area; V: tree stem volume

The result may be an indication of the fact that this species is not sought after as timber species in the area at present or in the past. Rather it is preserved for its fruits, on which livelihoods of many depend. Therefore, there was no threat to its tree growth features in both primary and secondary forests. The results of the t-tests for *K.*

gabonensis growth parameters between the two forest types are presented in Table 5. The results for DBH, crown diameter (CD), basal area (BA) and stem volume (V) reveal that there were significant differences in their mean values in the two forest types (P<0.05). However, there were no significant differences in the mean values of tree total height (THT), stem quality (SQ) and crown length (CL) in the two forest types as P>0.05 for the three variables. For *K. gabonensis*, the mean values for the tree growth parameters were higher in the primary forest than in the secondary forest. Details of the results are shown in Table 5.

Table 5: Results of t-test for *K. gabonensis* growth parameters in the two forest types

Tree growth parameter	Forest types	N/ha	Mean	Std. Dev.	df	t	P-value	Remarks
THT (m)	Primary forest	7	30.04	9.77	48	0.84	0.41	ns
	Secondary forest	2	27.73	7.45				
SQ (m)	Primary forest	7	18.94	7.22	48	0.31	0.76	ns
	Secondary forest	2	18.28	5.84				
DBH (cm)	Primary forest	7	68.20	60.4	48	3.57	0.0009	sig.
	Secondary forest	2	32.30	8.86				
CL (m)	Primary forest	7	11.09	6.80	48	0.78	0.44	ns
	Secondary forest	2	9.45	5.98				
CD (m)	Primary forest	7	11.34	7.37	48	3.50	0.0011	sig.
	Secondary forest	2	6.50	2.40				
BA (m^2)	Primary forest	7	0.64	1.31	48	2.65	0.012	sig.
	Secondary forest	2	0.088	0.042				
V (m^3)	Primary forest	7	20.8	43.8	48	2.63	0.012	sig.
	Secondary forest	2	2.31	1.81				

α = 0.05; N.B: N/ha: number of trees per hectare; THT: tree total height; SQ: stem quality, or tree bole length; DBH: diameter at breast height; CL: tree crown length; CD: tree crown diameter; BA: tree basal area; V: tree stem volume.

Some stems of this species may have been lost to illegal logging, as activities of illegal loggers were noticed in the secondary forest of the area. Table 6 presents the results for the height-diameters models developed for the two tree species in this study. The results for *I. wombulu* and *K. gabonensis* reveal that DBH and stem quality (SQ) are the best predictors of tree total height (model 4) for the two species with the highest co-efficient of determination (R^2 values) of 0.85 and 0.65, and least standard error of estimate (SEE) values of 3.730 and 5.644 respectively. This is closely followed by model 5 with R^2 values of 0.83 and 0.60, and SEE values of 4.630 and 5.966 respectively. For the two species, the models with least R^2 values was model 1 in both cases, which had only the DBH as the predictor of tree total height with R^2 values of 0.73 and 0.27, and SEE values of 5.026 and 7.997 respectively. Details of the models are shown in Table 6.

Table 6: Height-diameter models for the two *Irvingiaceae* species

Species	Model	Allometric Equation	R^2	SEE	F	P-value
Irvingia wombulu	1	$H = 14.0 + 0.288DBH$	0.73	5.026	90.14	0.000
	2	$H = 13.6 + 0.797D_m - 0.552D_t$	0.78	4.612	57.20	0.000
	3	$H = 11.9 + 0.128DBH + 1.21CD$	0.77	4.630	56.64	0.000
	4	$H = 7.51 + 0.165DBH + 0.670SQ$	0.85	3.730	96.17	0.000
	5	$H = 9.80 + 0.00128DBH^2 + 0.741SQ$	0.83	4.081	77.64	0.000
Klainedoxa gabonensis	1	$H = 24.2 + 0.0877DBH$	0.27	7.997	18.09	0.000
	2	$H = 24.4 + 0.360D_m - 0.321cD_t$	0.31	7.887	10.47	0.000
	3	$H = 24.1 + 0.0842DBH + 0.036CD$	0.27	8.080	8.87	0.001
	4	$H = 9.75 + 0.0663DBH + 0.840SQ$	0.65	5.644	42.84	0.000
	5	$H = 11.5 + 0.000206DBH^2 + 0.887SQ$	0.60	5.966	35.86	0.000

N.B: H: tree total height; SQ: stem quality, or tree bole length; DBH: diameter at breast height; D_m: diameter at the middle; D_t: diameter at the top

Table 7 presents the results of bias for model validations. The bias values were generally very small for the five sets of models, when the model outputs were compared with the measured mean tree total heights. The values for *I. wombulu* were -0.011±0.14, -0.003±0.12, -0.004±0.12, -0.039±0.11 and -0.010±0.11 for models 1, 2, 3, 4 and 5 respectively. The bias values for *K. gabonensis* were 0.005±0.16, 0.001±0.15, 0.011±0.16, -0.008±0.11 and -

0.010±0.12 for models 1, 2, 3, 4 and 5 respectively. The results of the model validations further confirmed the suitability of the developed models for tree total height predictions of the two species in the area. However, models 4 and 5 are the most preferred for the two species respectively, going by their modelling efficiencies and fit indices. Moreover, the bias values appeared insignificant in both species.

Table 7: Results of biases for model validations

Tree species	Allometric Equation	Observed value	Predicted value	Bias
Irvingia wombulu	$H = 14.0 + 0.288DBH$	24.96±9.46	24.24±8.08	-0.011±0.14
	$H = 13.6 + 0.797D_m - 0.552D_t$	24.96±9.46	24.34±8.33	-0.003±0.12
	$H = 11.9 + 0.128DBH + 1.21CD$	24.96±9.46	24.18±8.30	-0.004±0.12
	$H = 7.51 + 0.165DBH + 0.670SQ$	24.96±9.46	25.08±9.21	-0.039±0.11
	$H = 9.80 + 0.00128DBH^2 + 0.741SQ$	24.96±9.46	23.81±8.60	-0.010±0.11
Klainedoxa gabonensis	$H = 24.2 + 0.0877DBH$	29.53±9.29	28.74±4.868	0.005±0.16
	$H = 24.4 + 0.360D_m - 0.321cD_t$	29.53±9.29	28.88±5.16	0.001±0.15
	$H = 24.1 + 0.0842DBH + 0.036CD$	29.53±9.29	28.48±4.67	0.011±0.16
	$H = 9.75 + 0.0663DBH + 0.840SQ$	29.53±9.29	29.25±7.47	-0.008±0.11
	$H = 11.5 + 0.000206DBH^2 + 0.887SQ$	29.53±9.29	29.24±7.22	-0.010±0.12

The height-diameter allometries developed in this study also reflect the different growth patterns of the two species. For example, the height-diameter equations for the *I. wombulu* generally have higher co-efficient of determination with lower standard error of estimates than for the *K. gabonensis*. On the whole, *I. wombulu* produced better allometries than *K. gabonensis*. The suitability of the two sets of models for species total height prediction was further justified by the model validation results with very insignificant bias values. Similar justification has been supported by Akindele and LeMay (2006) and Adeyemi (2012), who reported similar bias results in their independent studies. The height-diameter allometries developed for the two species in this study have established the quantitative relationships between some tree growth parameters (diameters, bole length and crown diameter), which are fairly easy to measure and tree height that is often more difficult to measure and assess. These models are crucial to forest management since information on forest structure can be known without direct measurement, which can be very expensive. According to Aboal *et al*. (2005), allometric relationships for estimating tree-level parameters are very important for managing any forest resources.

CONCLUSION

This study has provided some information about the distributions and structures of two species of *Irvingiaceae* family, which are very crucial and fundamental to their sustainable management and extractions. It also gave some insight into the relationships that exist among the growth parameters of the two species, especially tree height and diameter in both cases. Very few stems of the species are encountered per hectare with *Klainedoxa gabonensis* having more stems/ha area than *Irvingia wombulu*. Considering the mass fruiting of the two species, one would expect that such species will be predominant in the ecosystem. However, it has been reported by previous worker that three members of *Olacaceae* dominate the ecosystem. This is not unconnected with the high rate of utilizations of the two species by both human and animal populations. It is therefore recommended that policy makers should institute a law that would encourage enrichment plantings for the two species in order to ensure sustainability and to further support livelihood in the area. The species were found to exhibit some similar growth patterns in both primary and secondary forests. Most of the equations presented for the two species were found suitable for tree height predictions, going by their modelling efficiency. However, some of the models for *Klainedoxa gabonensis* produced poor results with low co-efficient of determination and higher standard error of estimate values. Nevertheless, all the models for the two species were significant, with relatively small bias values. They are therefore recommended for tree height predictions for these two species in the study area. These models can also be adopted in other ecosystems, where the two species exhibit similar growth characteristics.

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