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MODELLING TREE VOLUME IN TROPICAL RAINFOREST OF AFI RIVER FOREST RESERVE IN CROSS RIVER STATE, NIGERIA

Aigbe H.I and Ekpa N.E

Abstract— In this study, volume equations were developed for Afi River Forest Reserve in Cross River State, Nigeria. Multistage sampling technique was used for the study. The sampling entailed primary, secondary and tertiary sampling units. A total of 611 trees were measured in 10 tertiary sample plots (40m x 50m). Tree identification and detailed growing stock of outside bark diameters at breast height (dbh), base; middle and top, merchantable height and total height were measured for tree species with dbh ≥ 10 cm within the tertiary sampling units. Individual tree basal area and volumes were computed using basal area $\left(\pi D^2/4\right)$ and Newton's formulae $\left[V = h/6(A_b + 4A_m + A_t)\right]$ respectively and extrapolated to per-hectare estimates. The results show that an average number of trees per hectare was 323 (68 species) and the diameter at breast height ranged from 11.10cm to 180.00cm. Volume equations for individual species, all species combined and species group were developed for the forest reserve. Species specific volume equations were developed for tree species with n ≥ 3 to obtain coefficients that serve as basis for grouping the species. Both simple and multiple regression equations were fitted. The general form of the multiple regression equation fitted to data is: $Y = b_0 + b_1 X_1 + b_2 X_2 + ...b_n X_n$. All tree species with $n \geq 3$ formed the basis for species grouping and were grouped into 5 clusters using cluster analysis of SPSS 17.0. Measures of distance between cluster means were computed to evaluate the effectiveness of the clustering procedure. Species with n < 3 were subjectively added to the 5 clusters. Series of equations were fitted and compared. The equations selected as the final predictive equations for the forest reserve were those with the lowest Standard Error of Estimate (SEE), highest coefficient of determination (R^2), significant F-ratio and unbiased estimates as well as with residual plots that show conformity with the assumption of independence of errors. The volume equations developed show that generalised logarithmic functions $(\ln V_i = b_0 + b_1 \ln(D_i^2 H_i) + \varepsilon_i)$ performed better than other equations forms. The findings of this study revealed that the predictive models generated are good management tool for the forest reserve. More studies aimed at providing qualitative and quantitative assessments are required in order to further close the existing information gap in the study area.

Index Terms— Tropical rainforest, modelling, volume equations, species grouping, total stem volume

INTRODUCTION

The tropical rainforest are the most biodiverse of all terrestrial ecosystems and are home of two-thirds of all plants and animals living on land (Onyekwelu *et al*., 2008; Schmitt *et al*., 2009; FAO 2010, and IUCN, 2010). The Nigerian forests, which cover a total area of about 360,000 km² (out of which about 95,563 km² are reserved) are sources of various forms of food, drugs, timber, fuel wood, fibre, spices, resins and other forest products that currently support the Nigerian economy (FRIN, 2000). This natural vegetation formation is also the main repository of the genetic diversity of both flora and fauna in the country, while it protects the Nigerian environment against drought and erosion (FRIN, 2000). Up till date, degradation, fragmentation and conversion of the forests to other forms of land uses are progressing at alarming rates. Out of all the forests that remained relatively undisturbed in Nigeria until the 1980s, significant portions have been lost during the last three decades (Onyekwelu *et al*., 2008). FAO (1999) estimated that tropical countries are losing 127,300 km² of forest annually due to anthropogenic activities and over 350,000 ha of forest and natural vegetation are lost annually in Nigeria (NEST, 1991). Recent global forest resources assessment revealed that Nigeria is one of the five countries in the world with the highest annual rate of deforestation for the period 2000 – 2010 (FRA, 2010). Between 1990 and 2000, Nigeria lost about 2.7% of its forests to deforestation which increased to about 18.56% (about 2.06 million ha) between 2000 and 2010 (FRA, 2010; FAO, 2011). A cumulative 47.5% of Nigeria's forests were lost to deforestation between 1990 and 2010 (FRA, 2010).

In 2001, the total forest cover in Cross River State was 6,406 km²,

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accounting for about 30% of the state's total land area and reflecting a 24.24% decline in the state's forest cover (Oyebo *et al*., 2010). Further decline of the forest cover to 6102 km^2 was reported between 2001 and 2008, reducing forest share of the land area to 28.68%. Afi River Forest Reserves is being degraded at alarming rates. Deforestation in Afi River Forest Reserve between 1991 and 2001 was estimated at 25.1% (Oyebo *et al*., 2010). These changes have resulted in the loss of some plant species and a decline in environmental quality as well as in the biodiversity conservation status of the forest. The sustainable management and use of these resources is essential for the nation's economic and environmental security (Akinsanmi, 1999).

Sustainable forest management requires estimates of growing stocks within the forest. Such information guides forest managers in timber valuation and proper management prescriptions. For timber production and proper stock taking, an estimate of growing stock is often expressed in terms of tree volume, which can be estimated from easily measurable tree attributes such as diameter and height. Alternatively, tree volume can be estimated using volume equations based on relationships between volume and attributes such as diameter and height. The equations once properly developed serve as efficient tools for obtaining reliable growing stock estimates. According to Avery and Burkhart (2002), volume equations are used to estimate average content of standing trees of various sizes and species. The reliability of volume estimates depends on the range and extent of the available sample data, and how well volume equations fit this sample data. Therefore, forest growth and yield modeling has been an intrinsic part of forest management planning and research for more than two centuries (Sheykholeslami *et al*, 2011).

Generally, models in forestry include recruitment, growth and yield, site index, mortality models. The role of models in forestry, especially in tropical natural forest ecosystems, cannot be overemphasised. Models are veritable tools for effective management of any forest stand (Adekunle, 2007) but the pronounced heterogeneity in species composition and structure even within small areas of tropical forest constitutes a major challenge in development of volume equations for natural tropical forests. According to Akindele and LeMay (2006), this challenge can be resolved by using data for each species to develop equations for individual species; combining data for all species and developing a single set of equations for them or by classifying species into groups and combining data for each group to develop equation for each group. Grouping the species helps to avoid the need for separate equations for species with few data, and it could also facilitates a reduction in the number of functions to a more manageable number (Vanclay, 1991). Various techniques have been proposed for grouping trees in mixed-species stands. According to Gitay and Noble (1997), there is no universally applicable concept for aggregating species into groups. The type of classification depends on the context of the performed aggregation (Kohler, *et al*., 2000) and the type of data available (Akindele, 2005).

The objective of this study is to develop tree volume equations for the tropical tree species in Afi River Forest Reserve. The equations developed will serves as an efficient management tool to ensuring sustainable management of the forest resources.

Methodology

Study Area

Afi River Forest Reserve lies approximately between latitudes 6^{o} 08ʹ and 6^{o} 26ʹN and longitudes 8^{o} 50ʹ and 9^{o} 05ʹE and covers a total land area of 383.32 km^2 including the area known as Afi Mountain (Figure 1).

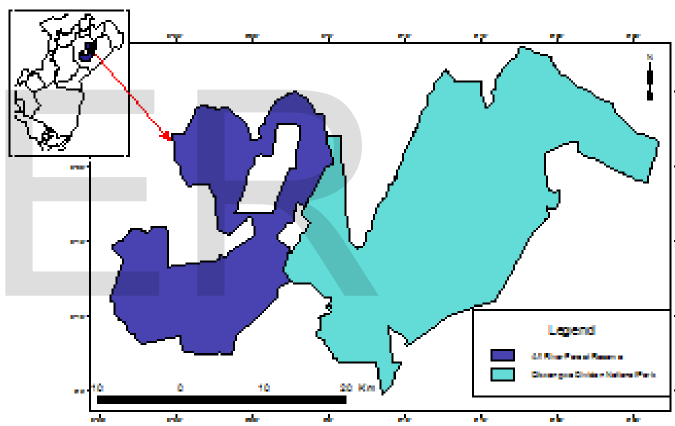

Fig. 1: Map of Afi River Forest Reserve

The topography of the study area is extremely complex with many connected ridge systems, isolated peaks and outcrops, with altitude ranging from 200 to 1200m above sea level. The reserve is characterized by large tracts of rock outcrops especially on the North-East axis. The hills of the reserve are extension of the Cameroon Mountains geological formation. The fast moving and high gradient streams drain the Afi River Forest Reserve, constituting an important watershed.

Crustaceous sedimentary sandstone occupies a significant area of the study site, with volcanic eruptions that sometimes comprises columnar basalt in some places (Nsor, 2004). Old sedimentary soils tend to be sandy with structure less profiles and incipient laterite. Generally, the soils vary from clayey-loam to loamy-clay and normally red with high content of iron oxide. They are acidic and low in nutrient status, which makes them unsuitable for ara-

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ble crop production (Agbor, 2003).

Annual rainfall varies from 3,000 mm to 3,800 mm (Agbor, 2003) while the mean annual temperatures are 22.2°C and 27.4° C on Afi mountain and lowland, respectively. Balogun, (2003) indicated that the mean annual relative humidity is 78% at 7.00 Hr.

The vegetation of Afi River Forest Reserve generally falls within the tropical high forest vegetation zone. The rainforest occupies the foot of the mountain. At about 700m above sea level, the forest structure changes gradually into sub-montane vegetation, while above 500m, the vegetation have been changed into grassland as a result of annual bush fire (Agbor, 2003).

Data Collection

Three stage sampling procedure, which was made up of primary, secondary and tertiary sampling units was used for data collection. One randomly selected primary unit of 1000 m x 1000 m (100 ha in size) was divided into 20 secondary units of rectangular plots (otherwise known as strip plot) of 50 m by 1000 m (5 ha in size), out of which 4 plots were randomly chosen. Each selected secondary units (strip plot) were then divided into 25 equal tertiary plots of 40 m by 50 m (0.20 ha in size). A total of ten sampling plots (tertiary units) were randomly chosen within the randomly selected secondary plots and all trees above 10 cm diameter were considered for measurement within the tertiary plots (0.20 ha) (Aigbe *et al*, 2014). Growth data including stump diameter, diameter at breast height (dbh, at 1.3m); diameters over bark at the base, middle and merchantable top; merchantable height and total height were collected on trees with dbh ≥ 10 cm in all the 10 selected sample plots.

Data Analysis

Fitting Volume Equations for Individual Species

The model used for this study followed the Schumacher-Hall volume model (Schumacher and Hall, 1933). The model is expressed as:

$$V_i = b_0 + b_1 D_i^{b_2} H_i^{b_3} + \varepsilon_i \qquad \text{Equation 2}$$

Where:

V = tree volume (m³);

D = diameter at breast height (cm);

H = Total stem height (m);

b_0, b_1, b_2 and b_3 are the regression parameters, while ε_i is the error term.

The model indicates that tree volume increases proportional to certain powers of D and H. According to Akindele (2005), Edminster, *et al*, (1980), Abayomi (1983), and Omule *et al* (1987), D was fixed to the power of 2 while H was fixed to the power of 1 to give the expression:

$$V_i = b_0 + b_1 D_i^2 H_i + \varepsilon_i \qquad \text{Equation 3}$$

Clutter *et al*. (1983) referred to this equation as the 'combined variable' volume function. All the regression statistics were computed using SPSS 17.0 software. The equations developed formed the species specific volume equations.

Volume Equations for Groups of Species

All species with $n \geq 3$ formed the basis for species grouping. In overall, all the species were grouped into 5 clusters. Values of the model parameters obtained by fitting Equation 3 to the individual species data served as input data for the cluster analysis. Two step clustering algorithm of SPSS 17.0 version was used to group the species into 5 clusters. Measures of distance between cluster means were computed to evaluate the effectiveness of the clustering procedure. Tree species with $n \leq 2$ were all subjectively assigned to the five clusters. Volume equations were developed from diameter at breast height (dbh) and total stem height for each group. The equations below (Equations 4 – 7) are some of the equations that were tried to developed models for each cluster:

$$V = \beta D^2 H + \varepsilon_i \qquad \text{Equation 4}$$

$$V = \alpha + \beta D^2 H + \varepsilon_i \qquad \text{Equation 5}$$

$$\ln V = \alpha + \beta_0 + \beta_1 \ln D \ln H + \varepsilon_i \qquad \text{Equation 6}$$

$$V = \alpha + \beta_0 D^2 + \beta_1 H + \beta_2 D^2 H + \varepsilon_i \qquad \text{Equation 7}$$

Where V = Total stem volume (m³); D = dbh (cm); H = Total stem height (m); ε_i = error estimate and α, β, β_1 and β_2 = regression coefficients.

Criteria for Model Assessment

The following criteria were used in assessing the fitted equations:

(a) Significance of regression equation using the F-ratio test statistics. The F-ratio is an indication of whether or not the regression equation may be used for prediction. It is given by:

$$F = \frac{Regression \quad Mean \quad Square}{Error \quad Mean \quad Square} \qquad \text{Equation 8}$$

The critical value of F (i.e. $F_{tabulated}$) at α = 0.05 level is obtained at $F(v_1, v_2)$, where V_1 and V_2 are degrees of freedom for regression and error, respectively. Where the variance ratio (F-calculated) is greater than the F-tabulated, the Null hypothesis is not accepted, and it is concluded that regression is significant. This implies that the regression equation may be used for prediction. The contrary holds where the F-calculated is less than the F-tabulated (Aigbe *et al*, 2013).

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(b) The coefficient of determination (R^2): It measures the proportion of variation in the dependent variable that has been accounted for by the linear relationship to the independent variables. R^2 is expressed as:

$$R^2 = \frac{Regression \quad Sum \quad of \quad Square}{Total \quad Sum \quad of \quad Square}$$ Equation 9

The coefficient of determination lies between zero and one (i.e. $0 \leq R^2 \leq 1$). If the decimal fraction is large (i.e. close to 1), most of the variability is accounted for by the relationship, and the regression equation is therefore a good prediction equation. If R^2 is close to zero the linear model is a poor fit to the data and the regression equation is therefore not very useful (Aigbe *et al*, 2013).

(c) Standard error of estimate (SEE) was also used to assess the equations. The equation(s) with the highest R^2 and lowest SEE were chosen and adjudged the best.

$$\text{SEE} = \sqrt{ESS/n - p} \quad \text{-------------------------} \ (10)$$

n = number of observations

p = number of estimated coefficient

Residual Analysis: The final models chosen were subjected to residual analysis using the scatter diagram of the residuals over a range of independent or dependent variable to investigate the homogeneity of variance and thus conformity of the regression equation to the assumption of regression analysis. Residuals are considered homogenous if the spread of the residuals on the positive and negative sides of the plot have a constant breadth and are horizontal, does not follow any systematic trend and the deviation of the predicted values from the observed values are random (Aigbe *et al*, 2013).

Model Validation

The model verification is a qualitative assessment of the consistency of the model outputs when compared with the general observations. The validation data set (i.e. the one tenth of the data (observed value) set aside for model validation and that were not used for model calibration, was used for this purpose. The validation was done by testing for significant difference between the predicted value and the actual (observed) value using paired t-test. If there is no significant difference (p>0.05) between the observed and predicted values, then it means the model is acceptable (Aigbe *et al*, 2013).

Results and Discussion

A total of 611 individual trees were measured in the 10 sample plots. The results indicated that the average number of trees per hectare in Afi River Forest Reserve was 323 (Table 1). The tree density indicates a well stock forest reserve when compare to other reports elsewhere in the tropical region of the world. The number of trees per hectare obtained in this study is higher than the 152 and 171 trees per hectare reported for tropical Barro Island in Panama by Hubbell and Foster (1983) and Thorington *et al.* (1983), respectively as well as the 104 trees per hectare for tropical Jengka Reserve, Malaysia (Ho *et al.* 1987). The values was however lower than the 508 – 671 trees per hectare reported for three natural tropical forests ecosystems in southwestern Nigeria (Onyekwelu *et al*., 2008) as well as the 385 and 535 trees per hectare reported by Sidiyasa, (2001) in Wain River, East Kalimantan. Other densities reported for various tropical ecosystems include: 1420 trees per hectare for Amazonia tropical rainforest (Campbell *et al.*, 1986); 391 to 617 trees per hectare for tropical rainforest in Costa Rica (Heaney and Proctor, 1990); 440 to 553 trees per hectare for equatorial forest of kongo island, Zaire (Mosango, 1991); 1533 and 1183 trees per hectare for slope forest and alluvium forest, in Caledonia, respectively (Jaffre and Veillon, 1990).

The dbh's in the dataset set ranged from 11.1 to 180.0 cm, and merchantable height ranged from 2.7 to 55 m. There was more variation in the merchantable height. Mean basal area per hectare for Afi River Forest Reserve was 102.77 m^2 (Table 1). The implication for the values of average basal area per hectare for this forest reserve is that the forest is well stocked when compared proportionally with report of Alder and Abayomi (1994), which stated that for a well-stocked tropical rainforest in Nigeria, the average basal area is 15 m^2. The value of basal area obtained in the study area is higher than what was reported by Adekunle *et al*, (2004) and Onyekwelu *et al.* (2008) for some tropical forests in southwestern Nigeria.

The mean merchantable volume per hectare recorded in the study area was 2,570 m^3. While total stem volumes per hectare was 3,154 m^3. The mean volume per hectare recorded in this study is higher than the values reported for tropical rainforest ecosystems in Nigeria by previous researches (e.g. Adekunle *et al*., 2004 who reported 181.36 m^3/ha in Shasa Forest Reserve; 227 m^3/ha in Ala Forest Reserve; 91.71 in Omo Forest Reserve; and Adekunle and Olagoke, 2008 who reported 262.36 m^3/ha). The higher values obtained in this study is an indication that Afi River Forest Reserve is probably one of the richest of the tropical rainforest left in Nigeria, which was also reported by ITTO (2011).

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Table 1: Summary of tree/stand growth characteristics for Afi River Forest Reserves

	Afi River Forest Reserve			
Mean number of Trees/ha	323			
	Min	**Max**	**Mean**	**Std Error**
Dbh(cm)	11.1	180.0	57.7	0.0125
D_{st}(cm)	12.7	180.0	64.0	0.0131
MTH(m)	2.7	55	25.4	0.373
THT(m)	12	62.2	31.9	0.399
Basal Area/ha (m^2/ha)	59.1	157.0	102.8	0.015
Merchantable Vol/ha(m^3/ha)	586.50	1536	2570	0.470
Total Vol/ha (m^3/ha)	1692	4317	3154	0.554

Dbh-diameter at breast height, D_{st} -outside bark stump diameter, Vol-volume, MTH-merchantable height, THT-total height
Source: Field work, Aigbe *et al*, 2014

In terms of their taxonomy, a total of 68 tree species distributed among 29 families and 62 genera were encountered in the study area as indicated in Table 2. The Caesalpinioideae family has the highest frequency in terms of both number of species and total number of observations per hectare. However, other dominant families were Mimosoideae Euphorbiaceae and Meliaceae. Of the 68 species documented in the study area, *Pycnathus angolensis*, *Staudtia stipitata*, and *Brachystegia eurycoma* had the highest density with 29, 16, and 15 trees per hectare, respectively, which accounted for 9.5%, 5.7% and 4.9% of the total tree density per hectare, respectively. Some few species have one tree per hectare, indicating that these species might be under threat of extinction due probably to anthropogenic factor. FORMECU (1999) reported that tropical tree species (less than 10 individual per hectare) that are vulnerable and threatened with extinction are endangered species. Ihenyen *et al.*, (2009) and Alamu and Agbeja (2011) also reported that one tree species per hectare is endangered. This is very typical of data from the tropical forest where, in spite of high species diversity, most tree species are locally rare (Kochummen *et al.*, 1990; Lieberman and Lieberman, 1994; Clark and Clark, 1999).

Table 2: Family and Tree Species in Afi River Forest Reserve and their relative densities/Ha

Family	Species name	Average tree/Hectare	Relative density/Hectare
Anisophylleaceae	*Poga oleosa*	5	0.01471
Annonaceae	*Monodora myristica*	4	0.01307
Annonaceae	*Xylopia aethiopica*	2	0.00654
Apocynaceae	*Alstonia boonei*	3	0.00817
Apocynaceae	*Alstonia congensis*	3	0.0098
Apocynaceae	*Futumia elastic*	6	0.01961
Bombacaceae	*Bombax buonopozense*	4	0.01307
Bombacaceae	*Ceiba pentandra*	2	0.00654
Burseraceae	*Canarium schweinfurthii*	1	0.00327
Caesalpinioideae	*Afzelia Africana*	5	0.01634
Caesalpinioideae	*Berlinia grandiflora*	10	0.03268
Caesalpinioideae	*Brachystegia eurycoma*	15	0.04902
Caesalpinioideae	*Daniellia ogea*	3	0.00817
Caesalpinioideae	*Detarium macrocarpum*	1	0.00163
Caesalpinioideae	*Distemonathus benthamianus*	4	0.01144
Caesalpinioideae	*Erythrophleum suaveolens*	2	0.0049
Caesalpinioideae	*Gossweilerodendron balsamiferum*	2	0.0049
Caesalpinioideae	*Oxystigma manni*	5	0.01634
Combretaceae	*Terminalia ivorensis*	5	0.01471
Combretaceae	*Terminalia superba*	6	0.01961
Ebenaceae	*Diospyros crassiflora*	6	0.01961
Euphorbiaceae	*Claoxylon hexandrum*	1	0.00163
Euphorbiaceae	*Drypetes gossweileri*	1	0.00163
Euphorbiaceae	*Drypetes preussii*	1	0.00163
Euphorbiaceae	*Klainedoxa gabonensis*	4	0.01307
Euphorbiaceae	*Ricinodendron africanum*	3	0.0098
Euphorbiaceae	*Uapaca heudelotii*	8	0.02451
Flacourtiaceae	*Homalium spp.*	3	0.00817
Guttiferae	*Allanblackia flori-*	5	0.01634

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	bunda		
Guttiferae	*Mamea Africana*	9	0.02778
Irvingiaceae	*Irvingia gabonensis*	11	0.03595
Lecythidaceae	*Petersianthus macrocarpus*	1	0.00327
Loganiaceae	*Anthocleista djalonensis*	4	0.01144
Meliaceae	*Carapa procera*	7	0.02288
Meliaceae	*Entandrophragma cylindricum*	3	0.0098
Meliaceae	*Khaya ivorensis*	5	0.01471
Meliaceae	*Lovoa trichilioides*	2	0.0049
Mimosoideae	*Albizia ferruginea*	4	0.01307
Mimosoideae	*Albizia gumifera*	2	0.0049
Mimosoideae	*Albizia zygia*	13	0.04085
Mimosoideae	*Cylicodiscus gabunensis*	4	0.01144
Mimosoideae	*Parkia bicolor*	6	0.01961
Mimosoideae	*Piptadeniastrum africanum*	10	0.03105
Mimosoideae	*Tetrapleura tetraptera*	2	0.00654
Moraceae	*Antiaris welwitschii*	3	0.00817
Moraceae	*Ficus mucuso*	4	0.01144
Moraceae	*Milicia excels*	4	0.01144
Moraceae	*Treculia obovoidea*	3	0.00817
Myristicaceae	*Coelocaryon preussii*	3	0.00817
Myristicaceae	*pycnathus angolensis*	29	0.09477
Myristicaceae	*Staudtia stipitata*	18	0.05882
Ochnaceae	*Lophira alata*	1	0.00327
Olacaceae	*Strombosia pustulata*	1	0.00163
Papilionoideae	*Amphimas pterocarpoides*	5	0.01634
Papilionoideae	*Pterocarpus osun*	9	0.02941
Papilionoideae	*Pterocarpus soyauxii*	2	0.00654
Rhizophoraceae	*Anopyxis Klaineana*	1	0.00327
Rubiaceae	*Mitragyna stipulosa*	4	0.01144
Rubiaceae	*Nauclea diderrichii*	4	0.01307
Rubiaceae	*Pausinystalia macrocera*	1	0.00163
Rutaceae	*Zanthoxylum zanthoxyloides*	3	0.00817
Sapotaceae	*Baillonella toxisperma*	1	0.00163
Sterculiaceae	*Pterygota macrocarpa*	8	0.02451
Sterculiaceae	*Sterculia oblonga*	1	0.00163
Sterculiaceae	*Triplochiton scleroxylon*	5	0.01634
Ulmaceae	*Celtis zenkeri*	8	0.02451
Verbenaceae	*Vitex gradifolia*	1	0.00163
Bignoniaceae	*Spathodea campanulata*	1	0.00163

Source: Field work, Aigbe *et al*, 2014

Species Grouping

Initial 54 tree species with n ≥ 3 were aggregated into five clusters, the remaining 11 tree species (n ≤ 2) were subjectively assigned to other 5 clusters (Table 3). This means that, there was subjective adjustment to the clustering procedure. This subjective adjustment had been done by scientists in other regions of the world. For example, Zhao *et al*. (2004) used subjective adjustment procedure to cluster mixed hardwood species to model individual tree diameter growth and mortality in alluvial valley in the lower Mississippi in United States. Similarly, Phillips *et al.* (2002) subjectively adjusted the clustering process in grouping mixed stand species in modelling tree growth in the Berau region of East Kalimantan in Indonesia. The linear spread of the cluster is shown in figure 2.

The species groups in this study did not reflect any expected taxonomic or ecophysiological trends because species of the same family and genus fall into different group (Table 4). For instance, the two species in the genus Terminalia and Pterocarpus were not in the same cluster. Similarly, the species of Albizia present in the data were shared among two clusters. Contratry to this, all the Alstonia species were assigned to Cluster 4. Akindele (2005) reported similar pattern of species grouping that does not reflect any expected taxonomic or ecophysiological trends. Species grouping using analytical methods has been known to produce results that do not necessarily have ecological significance (Vanclay, 1991).

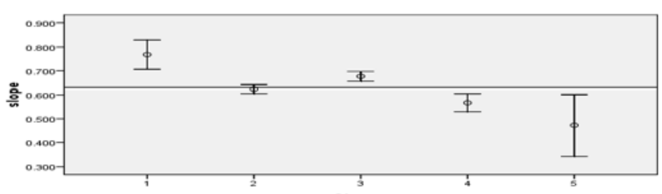

Fig. 2: Graphical display showing relative linear spread of the five clusters for the initial 54 species.

Table 3: Number of Species assigned to each Cluster

Cluster	Cluster Analysis	Total
1	13	16
2	9	12
3	9	12
4	16	18
5	7	10
Total	54	68

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Table 4: Result of grouping the 68 tree species into 5clusters

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Afzelia africana	*Amphimas pterocarpoides*	*Albizia gumifera*	*Alstonia boonei*	*Allanblackia floribunda*
Albizia ferruginea	*Carapa procera*	*Albizia zygia*	*Alstonia congensis*	*Ceiba pentandra*
Anopyxis Klaineana	*Celtis zenkeri*	*Drypetes preussii*	*Antiaris welwitschii*	*Daniellia ogea*
Anthocleista djalonensis	*Claoxylon hexandrum*	*Futumia elastic*	*Bombax buonopozense*	*Entandrophragma cylindricum*
Baillonella toxisperma	*Detarium macrocarpum*	*Lophira alata*	*Brachystegia eurycoma*	*Pausinystalia macrocera*
Berlinia grandiflora	*Diospyros crassiflora*	*Mamea Africana*	*Cylicodiscus gabunensis*	*Petersianthus macrocarpus*
Canarium schweinfurthii	*Drypetes gossweileri*	*Nauclea diderrichii*	*Distemonathus benthamianus*	*Piptadeniastrum africanum*
Coelocaryon preussii	*Irvingia gabonensis*	*Poga oleosa*	*Khaya ivorensis*	*pycnathus angolensis*
Erythrophleum sauveolens	*Mitragyna stipulosa*	*Pterocarpus osun*	*Klainedoxa gabonensis*	*Sterculia oblonga*
Ficus mucuso	*Pterygota macrocarpa*	*Spathodea campanulata*	*Lovoa trichilioides*	*Terminalia ivorensis*
Gossweilerodendron balsamiferum	*Triplochiton scleroxylon*	*Terminalia superba*	*Monodora myristica*	
Homalium spp.	*Zanthoxylum Zanthoxyloides*	*Xylopia aethiopica*	*Oxystigma manni*	
Milicia excelsa			*Parkia bicolor*	
Ricinodendron africanum			*Pterocarpus sauyaxii*	
Tetrapleura tetraptera			*Staudtia stipitata*	
Uapaca heudelotii			*Strombosia pustulata*	
			Treculia obovoidea	

			Vitex grandifolia	

The Volume Equations

Volume Equations for Individual Species

The volume equations developed for individual tree species are presented in Table 5. The table shows the regression parameters (α, β), adjusted coefficient of determination (R^2_{adj}), the weighted standard error of estimate (SEE) and F ratio. Number of observation per species is a contending factor when developing species specific volume equations. Equations can be re-calibrated to improve their precision as more data become available for these species because many of the species had few observations which could have adversely affected their parameter estimates. . The problem of many tropical tree species having insufficient data for modelling has long been recognised by several authors including Vanclay, (1991, 1994), Atta-Boateng and Moser (1998), Clark and Clark (1999), Gourlet-Fleury and Houllier (2000), Huth and Ditzer (2001), Phillips, *et al*. (2002) and Akindele and LeMay (2006). This is why species grouping is normally adopted as a way of accommodating those species with few observations.

Table 5: Species specific volume equations

Model Form: $\mathbf{V} = \alpha + \beta D^2 H + \varepsilon_i$

Species	α	β	R^2_{adj}	SEE	F ratio
Afzelia Africana	-0.678	0.718	0.983	0.975	517.3
Albizia ferruginea	-3.052	0.753	0.994	3.080	1186.2
Albizia gumifera	-0.067	0.679	0.961	0.328	50.5
Albizia zygia	-0.067	0.661	0.971	0.313	811.9
Allanblackia floribunda	0.232	0.462	0.877	0.446	65.2
Alstonia boonei	1.235	0.570	0.716	2.812	11.1
Alstonia congensis	0.339	0.551	0.994	0.953	827.2
Amphimas pterocarpoides	0.340	0.620	0.960	2.691	216.8
Anthocleista djalonensis	-0.588	0.743	0.974	0.747	223.5
Antiaris welwitschii	-0.033	0.650	0.952	0.135	80.5
Berlinia grandiflora	-0.125	0.713	0.972	0.503	657.0
Bombax buonopozense	4.971	0.513	0.926	3.686	88.7
Brachystegia eurycoma	3.925	0.509	0.895	6.593	284.7
Carapa procera	-0.110	0.625	0.979	0.426	605.2
Ceiba pentandra	8.578	0.496	0.971	2.745	101.1
Celtis zenkeri	-0.310	0.652	0.972	1.236	478.7
Coelocaryon preussii	-1.338	0.712	0.989	1.404	354.6

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Cylicodiscus gabunensis	1.947	0.513	0.901	5.133	55.4
Daniellia ogea	0.722	0.523	0.732	1.334	11.9
Diospyros crassiflora	-0.040	0.635	0.982	0.712	615.4
Distemonathus ben-thamianus	0.342	0.543	0.849	0.960	34.65
Entandrophragma cylindricum	3.401	0.483	0.986	3.241	342.1
Erythrophleum sauveolens	-2.783	0.780	0.979	4.424	94.2
Ficus mucuso	-0.310	0.816	0.984	0.226	364.0
Futumia elastic	-0.078	0.710	0.954	0.608	249.5
Gossweilerodendron balsamiferum	-0.866	0.956	0.997	0.180	746.6
Homalium spp.	-0.574	0.732	0.867	0.999	27.0
Irvingia gabonensis	0.082	0.626	0.994	0.441	3349.5
Khaya ivorensis	0.386	0.574	0.994	0.571	1252.8
Klainedoxa gabonen-sis	0.116	0.649	0.978	0.999	315.1
Lovoa trichilioides	0.650	0.544	0.866	2.561	13.9
Mamea Africana	-0.421	0.677	0.990	0.804	1610.1
Milicia excels	-1.641	0.719	0.984	1.299	365.6
Mitragyna stipulosa	-0.035	0.612	0.976	0.749	243.0
Monodora myristica	0.017	0.563	0.920	0.091	81.2
Nauclea diderrichii	-0.365	0.674	0.998	0.950	2847.2
Oxystigma manni	1.132	0.504	0.978	2.126	401.9
Parkia bicolor	0.099	0.639	0.986	0.689	777.7
Piptadeniastrum afri-canum	8.907	0.274	0.607	8.310	28.9
Poga oleosa	-0.002	0.659	0.972	0.614	277.9
Pterocarpus osun	-0.469	0.687	0.980	1.322	847.4
Pterocarpus sauyaxii	0.479	0.550	0.998	0.926	258.4
Pterygota macrocarpa	0.020	0.614	0.975	0.510	557.2
pycnathus angolensis	1.484	0.521	0.881	2.343	424.5
Ricinodendron afri-canum	-1.495	0.742	0.987	2.179	1315.4
Staudtia stipitata	0.006	0.562	0.869	0.867	1.433
Terminalia ivorensis	1.130	0.548	0.958	1.638	185.6
Terminalia superba	-0.063	0.667	0.972	0.965	381.8
Tetrapleura tetraptera	-0.496	0.873	0.978	0.229	134.9
Treculia obovoidea	-0.175	0.641	0.968	0.185	120.5
Triplochiton scleroxy-lon	0.934	0.604	0.953	1.352	183.2
Uapaca heudelotii	-0.338	0.729	0.997	0.275	5263.5

Source: Field work, 2014

Volume Equations for All Species combined

The volume equation for all species combined is presented in Table 6. Combining all the data will suppress the variability among different species. However, its major weakness is the implicit assumption that trees of various species have the same form. This is certainly not true in the tropical rain forest area. The equation can be used in situations where the objective to obtain rough estimates of tree volumes for tree species in the tropical rain forest area of Nigeria.

Table 6: Volume Equations for all tree species combined

Model form	α	β	R^2	R^2_{adj}	SEE	F ratio
$lnV = \alpha + \beta(lnD^2H) +$	-0.499	1.003	0.985	0.985	0.1708	39055

$lnV = Natural\ logarithm\ of\ volume$, *D = Dbh, H = Total stem height,* $\varepsilon_i = error\ estimate$ *and* α, β **as regression parameters**

Volume Equations for the Species Groups

The coefficients of the volume equations for the species groups using double variable D^2H predictors are presented in Table 7. Generalized logarithmic function was adjudged the best for predicting the volume of trees in all clusters because it performed better based on the criteria used in assessing the equations. Results in Table 7 indicate that the intercepts of the equations for all the clusters were negative. As noted by Avery and Burkhart (1994) negative intercepts are expected for merchantable tree size. In this study, D^2H predictor variable was found to be appropriate in reducing heteroscedasticity, which was effective in stabilising error variance. Similar results have been given by several authors including Snowdon (1985), Philip (1994) and Akindele (2005). Volume equation for species grouping is a useful management tool for sustainable management because its application in volume estimation reduces variance error and ensures its reliability for planning purpose.

Table 7: Regression statistics for the volume equation for each cluster

Model Form: $\ln V = \alpha + \beta \ln(D^2H) + \varepsilon_i$

Cluster	α	β	R^2_{adj}	SEE	F ratio
1	-0.543	1.038	0.990	0.147	10597.54*
2	-0.515	1.010	0.981	0.188	5400.03*
3	-0.478	1.009	0.974	0.175	4392.96*
4	-0.493	0.996	0.989	0.155	15105.87*
5	-0.478	0.984	0.975	0.181	4494.66*

V= Total volume, H = Total stem height, D = Diameter at breast height. * means significant at $p \le 0.05$

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The residual plots for these equations are presented in Figures 3a - e. The plots indicate good fits and confirmed the effectiveness of weighted least squares in stabilising error variance. The residual plots investigate the homogeneity of variance and thus conformity of the regression equations to the assumption of regression analysis.

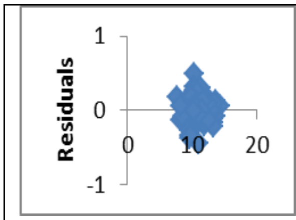

Figure 3a: Residual plot for cluster 1 using lnD²H predictor

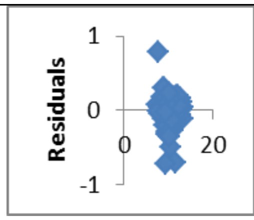

Figure 3b: Residual plot for cluster 2 using lnD²H predictor

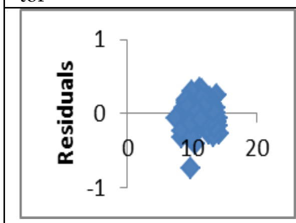

Figure 3d: Residual plot for cluster 4 using lnD²H predictor

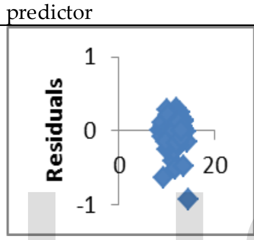

Figure 3e: Residual plot for cluster 5 using lnD²H predictor

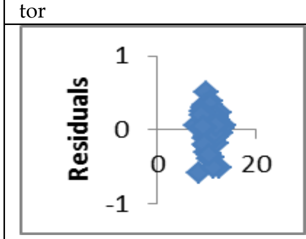

Figure 3c: Residual plot for cluster 3 using lnD²H predictor

Conclusion

The limiting factor in developing volume equation for tropical rainforests is dearth of data which impairs the development of reliable species-specific volume equations. This problem can be surmounted by aggregating the species into groups and then developing appropriate equations for each species group. In this study, volume equations were initially fitted into individuals' tree species with frequency of $n \geq 3$ and the coefficients use as a basis for aggregating species into 5 clusters. The species with frequency of $n \leq 2$ were subjectively added to the 5 clusters. Some species in the same genus fell into different clusters, which shows that statistical grouping of the species did not follow taxonomic or ecological pattern. The generalised logarithmic volume function performed better than other forms of volume functions.

References

[1] Abayomi, J.A., (1983): Volume tables for Nauclea diderrichii in Omo forest reserve, Nigeria. *Nigerian J. Forest.* 13 (1–2), 46–52.

[2] Adekunle V.A.J (2007): Non – Linear Regression Models for Timber Volume Estimation in Natural Forest Ecosystem, Southwest Nigeria. *Research Journal of Forestry 1 (2): 40–54.*

[3] Adekunle V.A.J., Akindele S.O. and Fuwape J.A. (2004): Structure and yield models of tropical lowland rainforest ecosystem of southwest Nigeria, Food, Agriculture and Environment 2 (2) 395-399.

[4] Adekunle V.A.J and Olagoke A.O (2008): Diversity and biovolume of tree species in natural forest ecosystem in the bitumen-producing area of Ondo State, Nigeria: A baseline study, Biodiversity and Conservation 17 2735-2755.

[5] Agbor C.O (2003). An ecological basis for the management of Afi Mountain Wildlife Santuary, Cross River State. Unpublished PhD thesis, Department of Wildlife and Fisheries Management, University of Ibadan.Pp 119-210.

[6] Aigbe H. I., Akindele S.O and Onyekwelu J.C. (2013): Volume equations for Oban tropical Forest Reserve, Cross River State, Nigeria. *Nigeria Journal of Forestry 43 (1) 53 – 67.*

[7] Aigbe H. I., Akindele S.O and Onyekwelu J.C. (2014): Tree species diversity and density pattern in Afi River Forest Reserve, Nigeria. *International Journal of Scientific & Technology Research 3 (10) 178 – 185.*

[8] Akindele S. O. (2005): Volume Functions for Common Timber Species of Nigeria's Tropical Rain Forests. A Technical Document submitted to International Tropical Timber Organization (ITTO).

[9] Akindele, S.O. and LeMay, V.M. (2006): Development of Tree Volume Equations for Common Timber Species in the Tropical rain Forest Area of Nigeria. *Forest. Ecology and Management*. 226, 41-48.

[10] Akinsanmi, F.A (1999): Updating Environmental Information in Nigeria. Invited Lead paper presented at the 26th Annual Conference of the Forestry Association of Nigeria held in Maiduguri, Borno. November 7 – 12, 1999. 15p.

[11] Alamu L.O and Agbeja B.O (2011): Deforestation and endangered indigenous tree species in South-West Nigeria. *International Journal of Biodiversity and Conservation.* Vol. 3(7), Pp. 291-297.

[12] Alder D. and Abayomi J.O. (1994): Assessment of data requirements for sustained yield calculations, unpublished report prepared for the Nigeria Tropical Action Programme, FORMECU, Federal Department of Forestry, Ibadan, Nigeria, p. 28.

[13] Atta-Boateng, J. and Moser, Jr. J. W. (1998): A method for classifying commercial tree species of an uneven-aged mixed species tropical forest for growth and yield model construction. *Forest Ecology and Management* 104: 89-99.

[14] Avery, T.E. and Burkhart, H.E. (2002): *Forest Management*, 5th ed. McGraw-Hill Higher Education, New York, USA, p. 456.

[15] Balogun, O.Y., (2003): *Senior Secondary School Atlas*, 2nd edition, p: 19. Longman Publishers, Lagos.

[16] Campbell, D. G., Daly, D. C., Prance, G. T. and Maciel, U. N. (1986). Quantitative ecological inventory of Terra firma and the Varzea tropical forest on the Rio Xingu, Brazilian Amazon. *Brittanica*, 38, 369–393.

[17] Clark, D. A. and Clark D. B. (1999): Assessing the growth of tropical rain forest trees: issues for forest modelling and management. *Ecological Applications* 9(3): 981-997.

[18] Clark D. B., Palmer M. W. and Clark D. A. (1999): Edaphic factors and the landscape-scale distributions of Tropical Rainforest Trees. *Ecology* 80: 2662-2675.

[19] Clutter, J. L., J. C. Fortson, L. V. Pienaar, G. H. Brister and R. L. Bailey (1983). *Timber Management: A Quantitative Approach*. John Wiley and Sons, New York. 333pp.

[20] Edminster, C.B., R. T. Beeson and G. E. Metcalf (1980): Volume tables and point-sampling factors for ponderosa pine in the Front Range of Colorado. U. S. Forest Service, Rocky Mountains Forest and Range Experimental Station, *Research Paper RM-218*. 14p.

[21] FAO (2009): *The State of the World's Forests 2009*. Food and Agriculture Organization of the United Nations, Rome.

[22] FAO (2010): *Global Forest Resources Assessment 2010*. Food and Agriculture Organization of the United Nations, Rome. FAO forestry paper. 163p.

[23] FAO, (2011): State of the World's Forests, 2011, FAO Rome, 164 pp.

[24] FORMECU, (1999): Forest Resources Study of Nigeria. Overview revised national report prepared for forestry management evaluation and coordinating unit. Volume one. 108p.

[25] FRA, (2010): Global Forest Resources Assessment 2010, Main report. FAO Forestry Paper, 163, FAO Rome, 340 pp.

[26] FRIN (2000): Nigeria Country Report on the Forest Revenue system and financial support for sustainable forest management. 50pp.

[27] Gitay, H. and I. R. Noble (1997). What are functional types and how should we seek them? Pages 3-19. In: T. M. Smith, H. H. Shugart and F. I. Woodward (Editors). *Plant functional types*. Cambridge University Press, Cambridge, UK.

[28] Gourlet-Fleury, S. and F. Houllier (2000): Modelling diameter increment in a lowland evergreen rain-forest in French Guiana. *Forest Ecology and Management* 131: 269- 289.

[29] Gourlet-Fleury, S., Blanc L., Picard N., Sist P., Dick J., Nasi R., Swaine M.D. and Forni., E (2005): Grouping species for predicting mixed tropical forest dynamics: Looking for a strategy. *Ann. Forest Science.* 62: 785-796.

[30] Heaney, A. and Proctor, J. (1990). Preliminary studies on forest structure and floristics on Volcan Barva, Costa Rica. *J. Trop. Ecol.*, 6, 307–320.

[31] Ho, C. C., Newbery, D. M. C., & Poore, M. E. D. (1987): Forest composition and inferred dynamics in Jengka forest reserve, Malaysia. *J. Trop. Ecol. 3*, 25-26. http://dx.doi.org/10.1017/S0266467400001103.

[32] Hubbell, S. P. and Foster, R. B. (1983): Diversity of canopy trees in neotropical forest and implication for conservation. In: Sutton, S.L., Whitmore, T.C. & Chadwick, A.C. (eds.) Tropical rainforest: ecology and management, pp. 24-41. Blackwell Scientific, Oxford

[33] Huth, A. and Ditzer T. (2001): Long-term impacts of logging in a tropical rain-forest – a simulation study. *Forest Ecology and Management* 142: 33-51.

[34] Ihenyen J., Mensah J.K., and Okoegwale E.E (2010); Tree/Shrubs Species Diversity of Ehor Forest Reserve In Uhunmwode Local Government Area of Edo State, Nigeria. *Researcher*: 2(2): P 37-49.

[35] ITTO. (2011): Status of tropical forest mangemenent. Technical series 38. P.420.

[36] IUCN (2010). *Plants under pressure – a global assessment. The first report of the IUCN Sampled Red List Index for Plants*. Royal Botanic Gardens, Kew, UK, Natural History Museum, London, and International Union for Conservation of Nature.

[37] Jaffré, T. and Veillon, J. M. (1990). Etude floristique et structurale de deux forêts denses humides sur roches ultrabasiques en Nouvelle-Calédonie. *Bull. Natl. Hist. Nat., Paris*, 12, 243–273.

[38] Kochummen, K. M., J. V. LaFrankie and N. Manokaran (1990): Floristic composition of
Pasoh Forest Reserve, a lowland rain forest in Peninsular Malaysia. *Journal of Tropical Forest Science* 3: 1-13.

[39] Kohler, P., T. Ditzer and A. Huth (2000). Concepts for the aggregation of tropical tree species into functional types and the application to Sabah's lowland rain forests. *Journal of Tropical Ecology* 16: 591-602.

[40] Lieberman, M. and D. Lieberman (1994): Patterns of density and dispersion of forest trees. Pages 106-119. In: L. A. McDade, K. S. Bawa, H. A. Hespenheide and G. S. Hartshorn (Editors). *La Selva: ecology and natural history of a neotropical rain forest*. University of Chicago Press, Chicago, Illinois, USA.

[41] Mosango, M. (1991): Contribution 'A l'étude botanic biogéo 1' ecosystem Forêt en region equatorial (Ile Kongolo,Zaire). *Belg. J. Bot.* 124, 167–194.

[42] NEST (1991): Nigeria threatened environment. Nigeria Environmental Study/Action Team.
Ibadan. 288p

[43] Nsor M. E (2004). The geology of the Cross River Basin. Unpublished Msc thesis. Department of Soil Science, University of Calabar, Nigeria. Pp. 98.

[44] Omule, S. A. Y., V. E. Fletcher and K. R. Polsson (1987): Total and Merchantable Volume Equations for small coastal Douglas-fir.

ISSN 2229-5518
Forest Resources Development AgreementReport (FRR 010). B.C. Ministry of Forests and Lands, Victoria, British Columbia, Canada.16p.

[45] Onyekwelu, J.C., Mosandl, R. and Stimm, B (2008): Tree species diversity and soil status of primary and degraded tropical rainforest ecosystems in South-Western Nigeria. Journal of Tropical Forest Science, 20 (3): 193 – 204.

[46] Oyebo M., Bisong F. and Morakinyo (2010): A preliminary assessment of the context for REDD in Nigeria. Comissioned by the Federal Ministry of Environment and the Cross River State's Forestry Comission and UNDP. Pp.167.

[47] Philip, M.S. (1994): Measuring tree and forests. 2nd ed. CAB International, Wallingford, UK. 310pp.

[48] Phillips, P. D., I. Yasman, T. E. Brash and P. R. van Gardingen (2002): Grouping tree spp. for analysis of forest data in Kalimantan (Indonesian Borneo). *Forest Ecology and Mgt.* 157: 205-216.

[49] Schmitt, C.B., Burgess, N.D., Coad, L., Belokurov, A., Besançon, C., Boisrobert, L., Campbell, A., Fish, L., Gliddon, D., Humphries, K., Kapos, V., Loucks, C., Lysenko, I., Miles, L., Mills, C., Minnemeyer, S., Pistorius, T., Ravilious, C., Steininger, M. and Winkel, G. (2009). Global analysis of the protection status of the world's forests. *Biological Conservation*, 142(10), 2122-2130.

[50] Schumacher, F. X. and F. S. Hall (1933): Logarithmic expression of timber-tree volume. *Journal of Agricultural Research* 47 (9): 719-734.

[51] Sheykholeslami A., Kia Pasha, Kh. and Kia Lashaki A. (2011): A Study of Tree Distribution in Diameter Classes in Natural Forests of Iran (Case Study: Liresara Forest). *Annals of Biological Research*, 2011, 2 (5):283-290.

[52] Snowdon, P. (1985). Alternative sampling strategies and regression models for estimating
forest biomass. *Australian Forest Research* 15 (3): 353-366.

[53] Sidiyasa, K. (2001) Tree Diversity in the Rain Forest of Kalimantan, the Tropenbos Foundation, Wageningen, the Netherlands.

[54] Thorington R.W., S. Tannenbaum. A. Tarak and R. Rudran. (1982): Distribution of trees in Baro colorado Islands: A five hectare sample.‖ In *The Ecology of a Tropical Forest – Seasonal Rhythms and Long-term Changes* (eds Leigh Jr., E. G. Rand, A. S. and Windsor, D. M.), Smithsonian Institute Press, Washington DC.

[55] Vanclay, J.K., (1991): Aggregating tree species to develop diameter increment equations for tropical rainforests. *Forest Ecology Management.* 42: 143-168.

[56] Vanclay, J.K. (1994): *Modelling Forest Growth and Yield*. Applications to Mixed Tropical Forests, CAB International, Wallingford UK. 329pp

[57] Zhao, D., B. Borders and Wilson M. (2004): Individual-tree diameter growth and models for bottomland mixed-species hardwood stands in the lower Mississippi alluvial valley. *Forest Ecology and Management* 199: 307-322.