Development of tree volume equations for common timber species in the tropical rain forest area of Nigeria

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Abstract

Volume equations were developed for common timber species in Nigeria's tropical rain forests. Data consisted of merchantable volume, stump diameter, diameter at breast height and merchantable height for 77 timber species. Number of observations per species ranged from 5 to 142, and diameter at breast height ranged from 20.0 to 230.0 cm. Schumacher–Hall's volume function was fitted to the data of each of the 33 well-sampled species ($n \geq 30$), using weighted least squares. The coefficients from these species-specific equations were used as input variables for species grouping. Species grouping was obtained using a two-stage approach of cluster analysis followed by discriminant analyses. First, cluster analysis was used to group the 33 well-sampled species into five clusters, and then discriminant analysis was used to assign each of the remaining 44 species (with $n < 30$) into one of the five clusters. The species groups obtained did not follow any particular taxonomic pattern, as there were species of the same genus that fell into different clusters. The Schumacher–Hall's volume function was fitted to the data for each species group. The resulting equations possessed desirable statistical properties and model behaviours, and can be used to estimate merchantable volume for common timber species in the tropical rain forest areas of Nigeria.

Keywords: Volume equations; Tropical forests; Timber species; Merchantable volume; Weighted regression; Species grouping

1. Introduction

The tropical rain forest is one of the major vegetation types of the globe (Richards, 1996; Whitmore, 1998), occupying a total area of 1818.43 million hectares and representing 47% of the total land area occupied by all forest types of the world (FAO, 2003). According to Turner (2001), the tropical rain forest is the most diverse of all terrestrial ecosystems, containing more plant and animal species than any other biome. In Nigeria alone, over 4600 plant species have been identified (Sarumi et al., 1996). In spite of this diversity, most species are locally endemic or rare and patchily distributed (Richards, 1996). Thus, the overall timber value per unit area is generally low, thereby necessitating logging over large areas to meet the ever-increasing demand. The FAO (1999) estimated that tropical countries are losing 127,300 km^2 of forest annually. In view of the great value of the tropical rain forest and the grave consequences of unregulated logging activities and over-exploitation, adopting sustainable management principles has become imperative.

Sustainable forest management requires estimates of growing stock. Such information guides forest managers in timber valuation as well as in allocation of forest areas for harvest. For timber production, an estimate of growing stock is often expressed in terms of timber volume, which can be estimated from easily measurable tree dimensions. The most common procedure is to use volume equations based on relationships between volume and variables such as diameter and height. 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. In Nigeria, much work has been done in this regard for plantation species, most of which are exotic (e.g. Okojie and Nokoe, 1976; Abayomi, 1983; Osho, 1983; Akindele, 1987, 2003; Onyekwelu and Akindele, 1995).

The pronounced heterogeneity in species composition and structure even within small areas constitutes a major challenge in development of volume functions for natural tropical

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forests. This challenge can be addressed in any of the following ways:

1. using data for each species separately to develop equations for individual species;
2. combining data for all species and developing a single set of equations for all species combined; or
3. classifying species into groups and combining data for all species within each group to develop equations for the group—the number of equations will depend on the number of groups into which species are classified.

As desirable as it is for each species to have its own separate set of equations, existing conditions in the tropical forests and the nature of their data constitute serious setbacks. In particular, many species lack sufficient data for reliable estimation of model parameters. On the other hand, pooling together the entire data set of all species for the purpose of fitting volume functions will result in a very large error variance. Consequently, the best approach is to aggregate species into several groups in order to reduce the number of functions required to a more manageable number, and to avoid the requirement for specific equations for species with few data (Vanclay, 1991).

Several methods have been proposed for grouping tropical forest species. In biodiversity applications, tree species are classified at the level of family or genus (e.g. Keay, 1989). This method is not suitable for growth and yield studies due to variation in growth pattern and form of tree species within the same family or genus (Phillips et al., 2002). Avery and Burkhart (2002) suggested that where it is not feasible to construct separate equations for each species, those of similar taper and shape might be grouped together. Unfortunately, information on tree form and taper is still lacking for most native tree species in the tropical rain forest. Species grouping has also been based on ecophysiological criteria such as light or shade tolerance attributes of the species (Swaine and Whitmore, 1988; Whitmore, 1989; Chai and LeMay, 1993), gap requirements for regeneration (Shugart, 1997) or potential canopy layer (Richards, 1936; Poker, 1995; Condit et al., 1996). The major setback to the use of this method for tree species in Nigeria is that ecophysiological information on many species is not available and, therefore, using this method would leave many species unclassified. Another criterion that has been used to group tropical species is their commercial value as determined by their utility potentials and prevailing market values (e.g. Sutter, 1979). As pointed out by Akindele et al. (2001), commercial values of tropical timber species change with time. Species, such as *Mansonia altissima*, were previously regarded as being of low value in Nigeria up to the 1980s. At present, this species is in very high demand in Nigeria, and has become one of the leading commercial species.

The most common procedure for grouping tree species in growth and yield studies is the use of cluster analysis or other classification procedures (Vanclay, 1991; Phillips et al., 2002; Picard and Franc, 2003; Zhao et al., 2004). Clustering of species is normally based on the predictor variables to used in the model (Atta-Boateng and Moser, 1998; Favrichon, 1998; Finegan et al., 1999; Gourlet-Fleury and Houllier, 2000; Huth and Ditzer, 2001), aggregation errors, or the Euclidean distance between species parameters (Picard and Franc, 2003). This method of species grouping ensures that species are classified according to the functions that drive the model rather than on ecophysiological attributes, which may not even result in improved model precision and for which there is limited knowledge.

The objectives of this study were to aggregate native timber species of tropical Nigerian forests into groups and develop tree volume equations for each group of species. It is hoped that the equations will serve as efficient tools for obtaining reliable estimates of growing stock in the tropical rain forest ecosystem.

2. Methodology

2.1. The data

The data used for this study were mainly data collected during Nigeria's Forest Resources Study funded by the African Development Bank and the Federal Government of Nigeria. Additional data from an inventory project funded by the African Academy of Sciences were also included. The data were individual tree diameter (overbark) at breast height (1.3 m above ground; dbh), merchantable height, and merchantable volume. Because of the form of many of these species, merchantable height was defined as the base of live crown (i.e., height to the first live branch). Using other upper stem diameter measurements and Newton's formula (Husch et al., 2003), merchantable volume was calculated for each tree. Altogether, the data consist of 2391 observations representing 77 species, with the number of observations (n) per species ranging from 5 to 142. Only two species had $n \geq 100$, eleven others had n ranging from 50 to 99, and 20 others had n ranging from 30 to 49. Therefore, only 33 of the 77 species had $n \geq 30$.

2.2. Fitting volume equations for individual species

To obtain the coefficients to be used as the basis for grouping tree species, volume equations for each of the 33 well-sampled species and for the 44 less-sampled species were fitted. Even though the same equation form may not be ideal for all species due to differences in their characteristics, a single equation form for all species was adopted to be able to use these coefficients as the basis for grouping.

Tree stem volume is a function of diameter, height, and form as in the expression:

$$V = f(D, H, F) \tag{1}$$

where V = volume, total or merchantable; D = dbh; H = total, merchantable, or height to some specific limit; and F = measure of form such as the Girard form class or absolute form quotient (Husch et al., 2003). Most volume equations use D (for local volume equations) and sometimes D and H (for standard volume equations) as independent variables, since measures of form are often more difficult and expensive to obtain. Since volume is linearly related to tree basal area, the relationship between tree volume and dbh is curvilinear. Also, the error variance for volume functions generally increases with tree size. A common procedure used to eliminate heterogeneity of variance is to carry out a logarithmic transformation. This procedure has its own limitation as it produces negatively biased estimates of tree volume (van Laar and Akca, 1997). Though methods of correcting the bias have been proposed (e.g., Baskerville, 1972; Yandle and Wiant, 1981; Lee, 1982), a weighted least squares fit of volume equations is more straight forward, and was used in this study.

After a series of model fitting trials, the generalized logarithmic model (Schumacher and Hall, 1933; Clutter et al., 1983), also known as Schumacher–Hall volume function was selected and fitted to individual species data. Expressing volume (V) as a function of dbh (D) and height (H), the model form is

$$V_i = \beta_0 + \beta_1 D_i^{\beta_2} H_i^{\beta_3} + \varepsilon_{i(2)} \tag{2}$$

where V = merchantable volume (m^3); D = dbh (cm); H = merchantable height (m); $\varepsilon_{i(2)}$ = residual and β_0, β_1, β_2 and β_3 are the model parameters. A nonlinear least squares fit of this model to each species indicated that the standard deviation of errors was proportional to D^2H. Therefore, the model was weighted by the reciprocal of D^2H. The weighted nonlinear model was

$$Y_i = \beta_4 X_{1i} + \beta_5 X_{2i}^{\beta_6} X_{3i}^{\beta_7} + \varepsilon_{i(3)} \tag{3}$$

where $Y_i = V_i/D_i^2H_i$, $X_{1i} = 1/D_i^2H_i$, $X_{2i} = D_i$, $X_{3i} = H_i$, β_4, β_5, β_6 and β_7 are model parameters, and $\varepsilon_{i(3)}$ is the weighted residual. The estimated coefficients of Eq. (3) were used to recover the estimated coefficients of Eq. (2) using: $\hat{\beta}_0 = \hat{\beta}_4$, $\hat{\beta}_1 = \hat{\beta}_5$, $\hat{\beta}_2 = \hat{\beta}_6 + 2$, and $\hat{\beta}_3 = \hat{\beta}_7 + 1$. The estimated coefficients for Eq. (3) were then used as the input variables for aggregating the species into groups.

2.3. *Species grouping*

A two-stage approach involving cluster and discriminant analyses was used to group species. In the first stage, cluster analysis was used to group the 33 well-sampled species ($n \geq 30$) into five clusters based on the estimated coefficients. The FASTCLUS procedure in SAS (Version 9.1) was used for the cluster analysis. This procedure utilizes the *k-means* clustering algorithm whose observations are assigned to clusters such that the means across clusters (for all variables) are as different from each other as possible, given a fixed number of k clusters. To evaluate the effectiveness of cluster analysis, Wilks' lambda (Dillon and Goldstein, 1984) was computed. This statistic is a multivariate measure of group differences over several variables, defined as

$$\Lambda = \prod_{j=1}^{M} (1 - \hat{\lambda}_{(j)}) = \frac{|S_{yy}^{-1} S_{yx} S_{xx}^{-1} S_{xy}|}{S_{yy}} \tag{4}$$

where $y = k - 1$ dummy variables representing the k (five) clusters, $x = p$ variables (four coefficients) used in clustering, Λ is a Wilks' lambda variable, $M = \min(k - 1, p)$ and $\hat{\lambda}_{(j)}$ denotes the squared canonical correlation. Values of lambda near zero denote high discrimination between groups.

The second stage involved the use of discriminant analysis (PROC DISCRIM of SAS, Version 9.1) to assign the 44 less-sampled species ($n < 30$) into the five clusters. According to Stockburger (1998), discriminant analysis is very useful for classifying a set of observations into predefined classes. Based on the 33 species already classified into five clusters, a set of linear functions of the input variables (i.e., the four coefficients for the volume equations) was obtained to maximally discriminate between the five clusters. These linear functions were then used to assign each of the 44 less-sampled species to a cluster. First, the generalized distance was calculated between the mean vector of the coefficients for a particular less-sampled species, and the average vector of coefficients (centroid, $\bar{x}_m$) of each of the five clusters using the well-sampled species, expressed as

$$D_m^2(x) = (x - \bar{x}_m)' \, \mathrm{COV}^{-1} (x - \bar{x}_m) \tag{5}$$

where $\bar{x}_m$ represents the centroid of one of the five clusters, x represents the mean vector of estimated coefficients for an unclassified species, and COV is the covariance matrix of the estimated coefficients over all 33 well-sampled species. Using these generalized distances, the probability of a species being in each cluster (i.e., posterior probability of membership) was calculated using

$$\Pr(m|x) = \frac{\exp(-0.5 D_m^2(x))}{\sum_{m=1}^{k} \exp(-0.5 D_m^2(x))} \tag{6}$$

An observation is classified into a group m if this results in the largest probability, $\Pr(m|x)$, corresponding also to the smallest distance, of $D_m^2(x)$.

2.4. *Fitting volume functions for the species groups*

Once all 77 species were classified into species groups, the tree volume functions were fitted for each group, using data for all species within the group. The regression statistics were computed using the PROC NLIN module of SAS (Version 9.1), using the weighted volume equation (Eq. (3)). To verify the assumption of equal variances for the weighted equations, residuals were plotted against the predicted volume. The coefficients for Eq. (2) were then recovered, and used to calculate an index of fit (I^2) and standard error of estimate (S.E.E.) for each species group as follows:

$$I^2 = 1 - \left[\frac{\sum_{i=1}^{n} (V_i - \hat{V})^2}{\sum_{i=1}^{n} (V_i - \bar{V})^2} \right] \tag{7}$$

$$\text{S.E.E.} = \sqrt{\frac{\sum_{i=1}^{n} (V_i - \hat{V})^2}{n - p}} \tag{8}$$

where V is the observed volume, $\hat{V}$ is the predicted volume, $\bar{V}$ is the mean volume (all volumes in m^3), n is the number of observations, and p is the number of estimated coefficients (four).

3. Results and discussion

In terms of their taxonomy, the 77 Nigerian topical timber species used in this study belong to 27 different families as indicated in Table 1. The Leguminosae family has the highest frequency in terms of both number of species and total number of observations. The tree species in this family are particularly valuable in the forest because they enrich the nitrogen content of soil. They include important tropical timber species such as *Afzelia africana*, *Albizia* species, *Brachystegia* species, *Daniellia ogea*, *Piptadeniastrum africanum* and *Pterocarpus* species. The number of observations per species (n) in the data set was generally low, with only two species having $n \geq 100$. 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).

The dbh's in the dataset set ranged from 20.0 to 230.0 cm, and merchantable height ranged from 1.5 to 42.5 m. There was more variation in the merchantable height. The base of live crown varies greatly between and within species, and is usually influenced by growing space, competition, site quality, tending practices, extent of self-pruning by individual trees, and other factors. Merchantable volume also varied widely, with the minimum and maximum being 0.03 and 55.44 m^3, respectively.

Table 1
Data distribution according to family

Family	No. of species	No. of observations
Anacardiaceae	2	36
Anisophylleaceae	1	17
Annonaceae	1	72
Apocynaceae	3	100
Bombacaceae	2	49
Boraginaceae	1	64
Burseraceae	1	12
Capparaceae	1	36
Chrysobalanaceae	1	20
Combretaceae	2	82
Dipterocarpaceae	1	20
Ebenaceae	1	29
Euphorbiaceae	1	34
Flacourtiaceae	1	23
Guttiferae	2	190
Irvingiaceae	2	27
Lecythidaceae	1	28
Leguminosae	22	615
Meliaceae	11	183
Moraceae	3	91
Myristicaceae	2	49
Olacaceae	1	113
Rubiaceae	3	53
Sapindaceae	1	20
Sapotaceae	1	62
Sterculiaceae	7	286
Ulmaceae	2	80
Total	77	2391

3.1. Species groups

Cluster and then discriminant analysis was used to separate the 77 species into five statistically distinct species groups (Table 2). The largest variation in volume, dbh, and merchantable height was in the Species Group 3, which had the highest number of trees (Table 3). For the discriminant analysis, Wilks' lambda was 0.0074, which is very close to

Table 2
Five species groups for 77 common timber species in Nigeria

Group 1	Group 2	Group 3	Group 4	Group 5
Antrocaryon klaineanum	*Albizia ferruginea*	***Afzelia africana***	***Alstonia boonei***	***Antiaris toxicaria***
Celtis zenkeri	*Funtumia africana*	***Albizia zygia***	*Amphimas pterocarpoides*	*Blighia sapida*
Chrysobalanus icaco	*Gossweilerodendron balsamiferum*	***Ceiba pentandra***	*Bombax buonopozense*	*Entandrophragma cylindricum*
Coelocaryon preussii	***Guarea cedrata***	***Cordia millenii***	*Brachystegia eurycoma*	***Eribroma oblonga***
Copaifera mildbraedii	*Guarea thompsonii*	*Cyclicodiscus gabunensis*	*Brachystegia kennedyi*	*Hannoa klaineana*
Daniellia ogea	*Holoptelea grandis*	***Detarium senegalense***	*Brachystegia nigerica*	***Hylodendron gabunense***
Dialium guineense	*Khaya grandifoliola*	*Distemonanthus benthamianus*	*Canarium schweinfurthii*	*Lannea welwitschii*
Erythrophleum suaveolens	*Nauclea diderrichii*	***Funtumia elastica***	***Carapa procera***	*Lovoa trichilioides*
Khaya ivorensis	*Nesogordonia papaverifera*	*Lophira alata*	*Diospyros mespiliformis*	*Milicia excelsa*
Pentaclethra macrophylla	*Pterocarpus santalinoides*	***Mansonia altissima***	*Irvingia gabonensis*	***Mitragyna ledermannii***
Symphonia globulifera	*Sterculia tragacantha*	***Pterocarpus osun***	***Manilkara obovata***	*Mitragyna stipulosa*
Trilepisium madagascariense	*Trichilia monadelpha*	***Pterygota macrocarpa***	*Petersianthus macrocarpus*	***Pentadesma butyracea***
	Trichilia retusa	***Ricinodendron heudelotii***	***Piptadeniastrum africanum***	*Tetrapleura tetraptera*
		Sterculia rhinopetala	*Poga oleosa*	
		Strombosia pustulata	***Pycnanthus angolensis***	
		Trichilia prieuriana	*Scottellia coriacea*	
		Triplochiton scleroxylon	*Staudtia stipitata*	
			Stemonocoleus micranthus	
			Terminalia ivorensis	
			Terminalia superba	
			Trichilia gilgiana	
			Xylopia aethiopica	

Bold face type indicates those with $n \geq 30$.

Table 3
Summary of tropical forest data used in the study

Species group	1	2	3	4	5
No. of species	12	13	17	22	13
No. of observations	444	161	184	625	347
Minimum dbh (cm)	20.0	20.0	20.0	20.0	20.0
Maximum dbh (cm)	158.0	75.6	200.0	230.0	120.0
Minimum merchantable height (m)	1.7	3.0	2.0	1.5	1.7
Maximum merchantable height (m)	37.2	31.7	41.1	36.7	42.5
Minimum merchantable volume (m^3)	0.0415	0.0980	0.0405	0.0330	0.0913
Mean merchantable volume (m^3)	0.8797	0.7916	2.0522	1.7374	1.4848
Maximum merchantable volume (m^3)	12.5908	7.2255	55.4398	48.2321	33.7231

Table 4
Coefficients of the weighted volume equation by species group[a]

Species group	$\hat{\beta}_4$	$\hat{\beta}_5$	$\hat{\beta}_6$	$\hat{\beta}_7$
1	0.0153 (0.0069)	0.000187 (0.000037)	−0.5277 (0.0406)	0.1963 (0.0435)
2	0.0555 (0.0149)	0.000027 (0.000012)	−0.0201 (0.0913)	0.2369 (0.0714)
3	0.0021 (0.0076)	0.000076 (9.715E−6)	−0.0355 (0.0246)	−0.0826 (0.0214)
4	−0.0363 (0.0083)	0.000130 (0.000018)	−0.1517 (0.0253)	−0.1187 (0.0270)
5	0.0582 (0.0109)	0.000025 (6.006E−6)	−0.0149 (0.0438)	0.2455 (0.0579)

$\hat{Y}_i = \hat{\beta}_4 X_{1i} + \hat{\beta}_5 X_{2i}^{\hat{\beta}_6} X_{3i}^{\hat{\beta}_7}$ where $Y_i = V_i/D_i^2 H_i$, $X_{1i} = 1/D_i^2 H_i$, $X_{2i} = D_i$, $X_{3i} = H_i$.

[a] Values in parentheses are the standard errors for the coefficients.

zero, indicating that the discrimination between the groups is very high ($p < 0.0001$), and that the five species groups are well separated. This suggests that cluster analysis was appropriate and effective for aggregating tropical timber species into groups. Zhao et al. (2004) also found cluster analysis suitable for grouping mixed species hardwood stands to model individual tree diameter growth and mortality in the lower Mississippi alluvial valley in the United States. Similarly, Phillips et al. (2002) found cluster and discriminant analyses to be appropriate for grouping mixed species stands for modeling growth in the Berau region of East Kalimantan (Indonesia Borneo). Unlike in their study where some subjectivity was introduced to ensure clustering was related to species characteristics, species groups in this study were obtained purely by analytical methods without any subjective adjustment. The result is that species groups in this study did not reflect any expected taxonomic or ecophysiological trends. For instance, the two species in the genus *Albizia* were not in the same species group. Similarly, the four species of *Trichilia* in the data were shared among three clusters. On the other hand, all the three species of *Brachystegia* were in Species Group 4. Other genera whose species fell within the same cluster are *Guarea*, *Mitragyna* and *Terminalia*. These three genera are represented by two species each. Species grouping using analytical methods has been known to produce results that do not necessarily have ecological significance (Vanclay, 1991). To reflect ecological significance, subjective adjustment of analytical results would be needed. Such adjustments can only be made where there is sufficient information about the ecological attributes of the species, and this information is generally not available for most of the species considered in this study.

3.2. The volume equations

The coefficients and associated standard errors for the weighted volume equations by species group are presented in Table 4. Residual plots for the volume equations generally indicate an even spread of residuals above and below the zero line, with no systematic trend (Fig. 1a–e). This suggests that weighted least squares are effective in stabilizing error variance, and the use of the reciprocal of D^2H as a weighting factor in this study appeared to be appropriate for reducing heteroscedasticity. Similar remarks have been made by several authors including Cunia (1964), Clutter et al. (1983), Snowdon (1985) and Philip (1994). The coefficients compare well with what has been reported elsewhere outside the tropical rain forest (e.g. Newnham, 1967).

The estimated coefficients for Eq. (3) were recovered and used to calculate the fit statistics (Table 5). The estimated exponent associated with dbh ($\hat{\beta}_2$) is close to 2 (except for Cluster 1), while that of merchantable height ($\hat{\beta}_3$) is close to 1, indicating a linear relationship with basal area and with height,

Table 5
Estimated parameters and fit statistics for the volume equation by species group

Species group	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	$\hat{\beta}_3$	I^2	S.E.E. (m^3)
1	0.0153	0.000187	1.4723	1.1963	0.8632	0.4347
2	0.0555	0.000027	1.9799	1.2369	0.9412	0.2089
3	0.0021	0.000076	1.9645	0.9174	0.9385	1.1714
4	−0.0363	0.000130	1.8483	0.8813	0.9587	0.8428
5	0.0582	0.000025	1.9851	1.2455	0.9143	0.8248

I^2 = index-of-fit; S.E.E. = estimated standard error of estimate (in original units of volume).

as expected. The index of fit, which is analogous to coefficient of multiple determination (R^2), ranged between 0.86 and 0.96. This suggests that a very large proportion of the variation in tree volume is explained by dbh and merchantable height for each species group. The equations were not conditioned to pass through the origin since the dependent variable was merchantable, rather than total tree volume. As noted by Avery and Burkhart (2002), for merchantable volume prediction, negative intercepts are expected. In this study, however, most of the intercepts are close to zero, with only Species Group 4 having a negative estimated intercept.

A good measure of the overall predictive value of the regression equation is the standard error of estimate (S.E.E.). It is a common measure of goodness of fit in nonlinear regression (Glantz and Slinker, 2001) with low values indicating better fit. In this study, the S.E.E. values ranged from 0.2089 m^3 for Species Group 2 to 1.1714 m^3 for Species Group 3. These two groups had the lowest and the highest mean merchantable

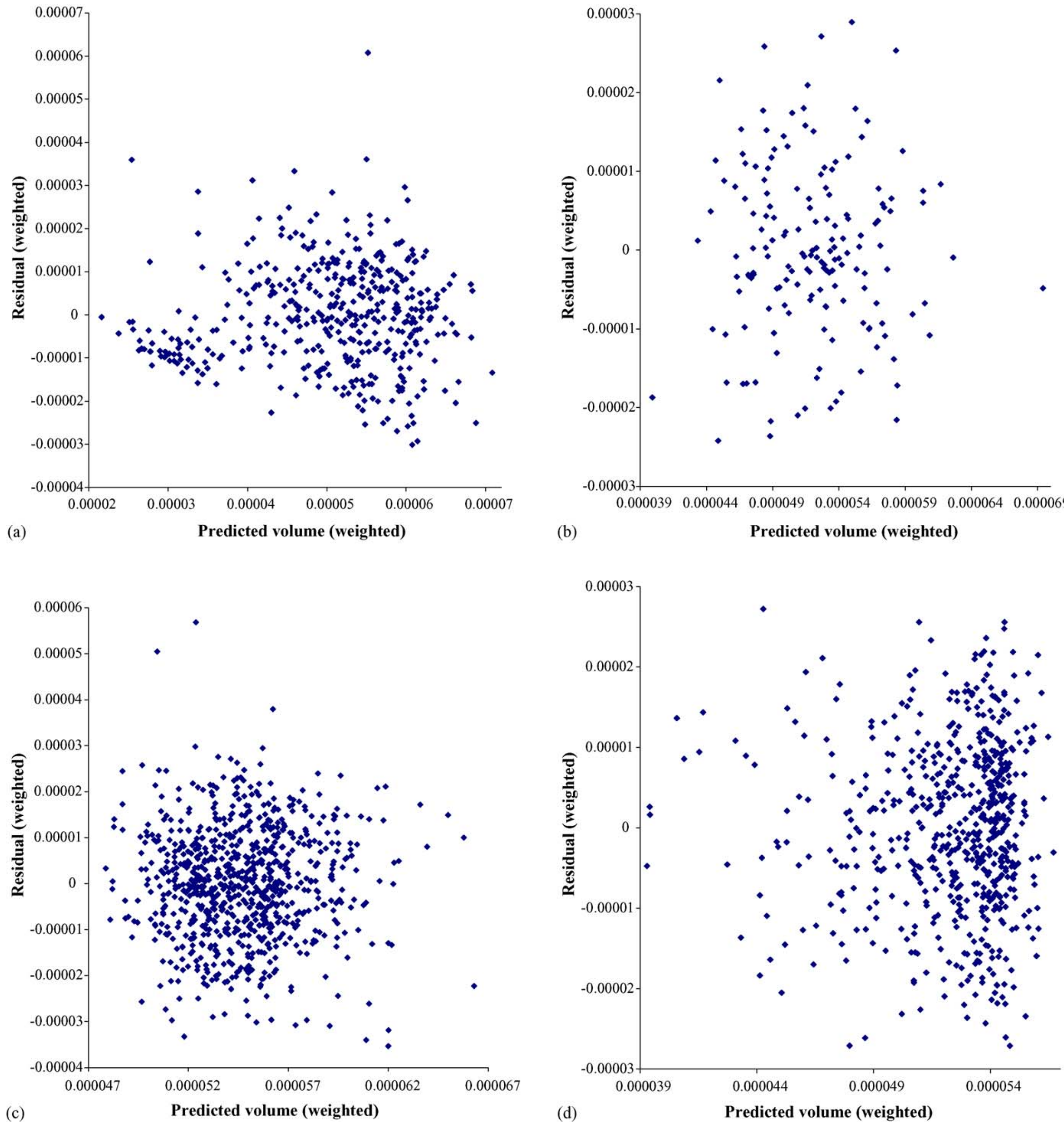

Fig. 1. Residual plots for: (a) Species Group 1; (b) Species Group 2; (c) Species Group 3; (d) Species Group 4; and (e) Species Group 5.

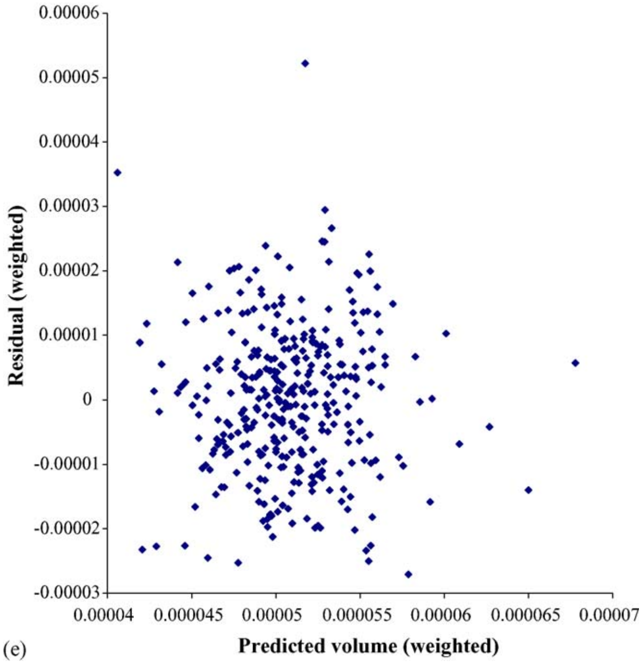

Fig. 1. (*Continued*).

volume, respectively (Table 3). The standard errors were calculated based on Eq. (2), and therefore represents volume in m^3 (not weighted volume). These values suggest good fits since they are generally low within the context of the field data.

4. Conclusion

The paucity of data for many tropical timber species impairs development of reliable species-specific volume equations. Results of this study show that this problem can be mitigated by aggregating species into groups and then developing appropriate equations for each species group. Species grouping involved initially fitting a volume equation for each species in the dataset. Then, cluster analysis of estimated coefficients for more frequent species ($n \geq 30$) to form groups, and discriminant analysis to assign the less frequent species ($n < 30$) into those groups. This two-stage approach was found suitable for grouping the tropical timber species Nigeria's lowland rain forest area. The fact that many species in the same genus fell into different clusters shows that statistical grouping of the species did not follow taxonomic or ecological pattern. Any attempt to impose specific ecological pattern into the clustering process will involve some subjectivity. The species groups produced in this study are considered adequate in the context of the data available, although further work is required to incorporate measures of tree form into the clustering process. Consequently, the grouping in this study should not be considered as final. There would be the need to repeat the analysis as more data become available, until the resulting groupings show greater stability.

The generalized logarithmic volume function (also termed Schumacher's volume function) performed better than other forms of volume functions. To stabilize the error variance, the reciprocal of D^2H was found to be the appropriate weighting factor for the two-variable volume function. The same model form was used in this study for the species-specific equations in order to have a common basis for aggregating them into groups. Where there is a particular interest in species-specific volume equations, the testing of other model forms should be considered in order to see if there will be any improvement on the equations presented in this study. In addition, as more data become available, there would be the need to re-calibrate the volume equations of those species with few observations, and re-group them. The tree volume equations for the species groups appear to be more precise due to relatively large number of observations and should therefore be used instead of the species-specific equations for which sample size was small. It should however be noted that the increase in precision associated with species grouping has implication of increase in bias for individual species volume estimation.

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