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Development of Standard Volume Equations for Malaysian Timber Trees I: Dark Red and Light Red Merantis

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ABSTRACT

Volume is important in updating and projecting inventories, determining harvest level or allowable cut, scheduling the harvest unit for logging, analyzing potential alternatives stand treatments and determining site-productivity. Inherent in the preparation of a forest management plan, an annual forest working plan and a forest harvesting plan is the availability of a volume table, which is usually derived from a functional relationship using a diameter and/or a log length or tree height. Four unweighted and five weighted volume equations were fitted by the method of least squares to volume data of each of the two species groups of Dipterocarp Merantis - Dark Red Meranti (DRM) and Light Red Meranti (LRM) obtained from the mixed tropical forest of Malaysia. Furnival's Index (FI) was used as the criterion for selecting the best fit regression equation of each species group under study. The equation weighted by $1/D^2H$ showed its superiority over other equations in both species groups. The standard volume equations selected are as follows:

DRM: $V = -0.5994 + 3.1947E\text{-}04D^2 + 0.0370H + 4.2054E\text{-}05D^2H$ (FI = 0.9474)

LRM: $V = 0.2059 + 1.6593E\text{-}04D^2 + 8.3346E\text{-}03H + 4.8974E\text{-}05D^2H$ (FI = 0.9434)

Where,

V is the commercial tree volume (m^3 overbark), D is the reference diameter or dbh (cm) and H is the total commercial log length (m) up to the first large branch below the crown base or up to the 30cm end diameter. The standard volume equations obtained from this study were compared with the existing volume equations by FAO (1973) and Canonizado and Buenaflor (1977).

Keywords: Dark Red Meranti, Furnival's Index, Light Red Meranti, standard volume equation, weighted least squares

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INTRODUCTION

The Malaysian flora, among the richest and most diverse in the world, is of great interest in view of the geographical position of the Peninsular – the southernmost land limit of the mainland of Asia. This rainforest is characterized by the dominance of the family Dipterocarpaceae, which forms the bulk of the commercially valuable timber trees in Malaysia and Southeast Asia. The forest covers the full range of timbers from Dipterocarps: Meranti to non-Meranti groups to non-Dipterocarps: Light Hardwoods (LHW) to Medium Hardwoods (MHW) to Heavy Hardwoods (HHW). Commercially, the Dipterocarp species is the most valuable timber in the timber markets – nationally and internationally, and it is usually of high price, though the non-Dipterocarp species is equally preferred commercially for specific end uses.

BACKGROUND AND SCOPE

Inherent to the preparation of a forest management plan or an annual forest working plan, or an annual harvesting plan is the development of volume tables for a species concerned. A number of researchers, such as Vincent and Sandrasegaran (1965), have compiled volume tables from the stem analysis data of felled trees for seven species and six species groups occurring in the rich lowland Dipterocarp forests. Similarly, Wan Razali *et al.* (1989) developed a volume table for the planted *Acacia mangium* in Peninsular Malaysia. However, most of these lowland forests, which have given way to agriculture development and the Permanent Reserve Forests (PRFs) for timber production, are now confined mainly to the hill forests between 300m to 750m altitude above sea level (asl). The volume tables for the lowland natural forests are thought to be not applicable or less applicable to hill forests due to the different growth structures and characteristics, as well as species composition of the hill forests. A bibliography search for the development of volume equations or volume tables of indigenous and exotic species in Malaysia reveals the following:

1. Sandrasegaran (1961) developed a commercial general volume table for ShorealeprosulaMiq (Meranti tembaga);
2. Vincent and Sandrasegaran (1965) compiled 13 commercial general volume tables from the stem analysis data of felled trees for 38 species and/or species groups;
3. Sandrasegaran developed a provisional local volume table for teak (*Tectonagrandis* linn. F.) (1966a) and *a local volume table for Tembusu (Fagraeafragrans* Ridl.) (1966b);
4. Sandrasegaran also constructed a local volume table for Yemani *(Gmelinaarborea*roxb) (1966c), fuel wood volume table for *Eucalyptus robusta (1966d),* a local volume table for *Eucalyptus saligna* Sm. grown in Malaya (1967a), a local volume table for *Eucalyptus grandis* (1967b), a general volume table for *Pinuscaribea*mor. (1968), a general volume table for *Tectonagrandis* Linn. f. (Teak) grown in

North-West Malaya (1969), a standard volume table for *Pinusmerkusii* Jungh & de vriese grown in the Forest Research Institute plantations in Malaya (1970), and a general volume table for *Rhizophoraapiculata* BI. (syn. *Rhizophoraconjugata* Linn.) (Bakau minyak) in Matang Mangroves, Taiping, West Malaysia (1972);

5. Sandrasegaran (1973) discussed the statistical properties of tree volume and the use of weighted regression in the development of overbark and underbark volume tables for *Gmelinaarborea* Roxb (Yamane) grown in Peninsular Malaysia;
6. FAO (1973a) prepared the volume equations for the mixed Dipterocarp forests of West Malaysia during the 1st National Forest Inventory;
7. FAO (1973b) prepared a compilation of volume tables for the mixed Dipterocarp forests of Sarawak;
8. Canonizado and Buenaflor (1977) developed tree volume functions for the SJSB dipterocarp;
9. Wan Razali M (1981) developed a general volume table for *Pinuscaribaea* var. *Hondurensis*;
10. Wan Razali W.M. *et al*. (1983) constructed double entry volume table equations for some RRIM 600 series clones of *Hevea Brasiliensis;*
11. Afzal-ata *et al.* (1985) developed a local volume table for plantation Kapur (*Dryobalanopsaromatica*gaertn. f.) at Sungai Puteh Forest Reserve (Federal Territory);
12. Wan Razali W.M. *et al.* (1989) developed a volume table for planted *Acacia mangium* in Peninsular Malaysia;
13. Awang Noor Abd. Ghani*et al.* (1999) developed a preliminary analysis in the construction of local volume tables for lowland and hill Dipterocarp forests of Pahang;
14. Suratman *et al.* (2004) developed prediction models for estimating the area, volume, and age of rubber (*Heveabrasiliensis*) plantations in Malaysia using lands at TM data;
15. Nur Hajar Zamah Shari *et al.* (2007) developed a volume equation for Ramin (*Gonystylusbancanus*) in Pekan Peat Swamp Forest, Pahang, Malaysia;
16. Awang Noor Abd. Ghani and Khamuruddin Mohd Noor (2009) developed local volume tables for inland forests, Negeri Terengganu; and
17. Nur Hajar Zamah Shari *et al.* (2010) also developed a local volume table for the second growth forests using standing tree measurements.

In principle, there are two basic types of volume equation: local volume equation and standard volume equation. The local volume equation is based on the single variable of interest, usually diameter at breast height (dbh). The term 'local' is used because such equation is generally restricted to the local areas. Meanwhile, the standard volume equation gives volume in terms of dbh and merchantable or total length (L) and the type of equation may be prepared for individual species or groups of species and specific localities. A volume table is usually constructed from a volume equation.

A volume table developed by the Pahang Tenggara Regional Master Plan was used to estimate commercial standing volumes of trees at Syarikat Jengka Sdn. Bhd. (SJSB) (Anon, n.d.): a timber concessionaire in Pahang, Malaysia, who managed approximately 120,000 ha of mixed tropical forests of which about 60,000 ha were hill Dipterocarp forests. For a given species and dbh class, an average log length (L) in meter and a net factor (F) - equivalent to a form factor - were determined in priori. By using a perfect cylinder formula, that is $\{(\pi D^2/40{,}000) \times L \times F\}$, where D=dbh in cm, the volume for each tree was tabulated for the various species and dbh classes. However, the use of this formula in most cases underestimated the commercial standing volume of trees. For example, SJSB underestimated commercial standing volumes between 10 - 40% and 10 - 60%, respectively for a 4 and 5 log lengths (1 log length = 5 meter) with dbh classes between 60 - 110cm. Similar observations were also noted by another timber concession in Pahang, i.e. Lesong Forest Products, who managed 54,000 hectares of the mixed tropical forests of which at least 75% of the areas were made up of hill Dipterocarp forests. Nonetheless, reasons for the underestimation of tree volume were not exactly known; these are more likely due to the use of a perfect cylinder formula and an average log length for a given dbh class, although a net factor was used for each species. However, the use of an average log length for a given dbh class in a local volume equation contributed to a less accurate estimation of volume. Furthermore, SJSB used one volume equation for all species. Hence, standard volume equations by species groups would be a logical remedial action to solve the problem of volume underestimation. Canonizado and Buenaflor (1977), under the SJSB-FDPM Cooperative Projects known as Integrated Studies on Forest Management and Operations, developed a set of volume equations for Dipterocarp and non-Dipterocarp hill forests. However, these volume equations were developed using the ordinary least square regression techniques and based on a small number of felled sample trees. For unknown reasons, the equations were not used by SJSB.

This study was initiated to correct the inadequacies of the volume equations derived by the Pahang Tenggara Regional Master Plan, and to have a larger sample size in addition to the use of unweighted and weighted least square regression techniques. Furthermore, Furnival's Index (Furnival, 1961) was used in selecting the most suitable volume regression model, as compared to the use of usual statistics such as coefficient of determination (R^2), and adjusted R^2(R^2_{adj}) and/or residual mean square error (RMSE). The development of the volume equations of tropical mixed forests demands a lot of time to attain a true representation of the population of interest (volume) and it is often set-back by the erratic occurrence of certain individual species or species groups, diameter and height classes, as well as the availability of up-to-date analytical and statistical techniques; all of which require a continuous updating.

MATERIALS AND METHODS

Field Measurements

Data for the development of volume equations in this study were obtained through felling and measuring of trees from 29 sample locations in the production forests of SJSB. A sample location was a randomly chosen yarding setup of 20-30 hectares within a forest compartment of 100-120 hectares ear-marked for timber tree felling. Two types of working crew were provided by SJSB for this study; one was the tree felling crew and the other was the tree measuring crew who worked independently of each other. The measuring crew measured all the felled trees ≥ 50cm dbh (1.3m above ground or just above the end of taper if a tree was heavily buttressed) in each sample location after felling crew felled all commercial trees. Felling crew worked ahead of the measuring crew and the former was informed that all the felled trees would be commercially extracted as usual but was not told that all the felled trees would be measured for developing volume equations. As such, the felling crew was asked to cut all the trees as commercially done, and then cut the log at the end of the merchantable bole before the logs were extracted. These instructions were necessary so that the volume equations developed would reflect the actual commercial tree volumes extracted from the forests. However, the felling crew was directed not to section the logs as they normally did if a log was too long to be hauled or extracted. The sectioning of the logs would only be done after all the necessary measurements were completed by the measuring crew.

Trees felled and measured for the development of volume equations were distributed as equally as practicable throughout the sample locations. A total of 2707 trees of various species were measured from 29 locations in 7 logging compartments. These trees comprise the following:

Dipterocarp (Meranti)	=	914 trees
Dipterocarp (Non-Meranti)	=	809 trees
Non-Dipterocarp (LHW, MHW & HHW)	=	984 trees
Total	=	2707 trees

Commercially, the family Dipterocarpaceae (or commonly called Dipterocarps) comprises tree species belonging to Dark Red Meranti (DRM), Light Red Meranti (LRM), Yellow Meranti (YM) and White Meranti (WM). All individual species of DRM, LRM, YM and WM belong to the genus *Shorea*. The other Dipterocarpaceae family belongs to the non-Meranti group or the genus Non-*Shorea*. The rest of the families belong to non-Dipterocarpaceae (or commonly called Non-Dipterocarps) and commercially consist of Light Hardwood (LHW), Medium Hardwood (MHW) and Heavy Hardwood (HHW).

This paper, however, deals only with the development of volume equations for Dipterocarp Meranti comprising DRM and LRM. All the felled trees were not necessarily measured due to either relatively inaccessible areas or were on steep slopes or terrains that could risk the measuring crew. Each measured tree was identified to the species level possible.

The following measurements were taken on each sample tree after it was felled:

1. Diameter outside bark (D_{ob}) at dbh (1.3m above the ground or just above the end of taper, if a tree was heavily buttressed);
2. Diameter outside bark (D_{ob}) at a "reference point", if the reference point was lower than 1.3m high from the ground. The reference point was usually the point at which felling crew cut the tree;
3. Diameter outside bark (D_{ob}) at the end of the commercial log/ merchantable log/ clear bole log where felling crew made another cut. This end was usually at the first large branch below the base of the crown or at 30 cm diameter, whichever came first;
4. Diameter outside bark (D_{ob}) at the mid-point of the commercial log length;
5. Commercial log length from points in (2) and (3) above;
6. Diameter outside bark (D_{ob}) at the beginning point of "top" log, if any;
7. Diameter outside bark (D_{ob}) at the mid-point of the top log, if any;
8. Top log length from the point immediately after the knot of the first branch to 30 cm diameter if the cut in (3) above was at the first large branch below the crown base, and provided that the top log was not broken or damaged or both due to felling;
9. The average diameter (if any) of the rot or hole at the end points in (2) and (3) above to indicate the extent of decay or butt- or end-rot occurrences; and
10. The extent of felling damage to the top log, recorded as either broken or split or both.

All diameters were measured to the nearest 0.1cm and length to the nearest 0.1m. A full illustration of the field measurements of a felled tree is shown in Fig.1.

Species Grouping

Although all trees ≥ 50 cm dbh in all the sample locations were felled – not all were measured for reasons indicated earlier – it was not possible to provide sufficient depth and range of data necessary to compile volume equation for individual species mainly due to erratic occurrence of certain species and limited diameter and height classes. It was decided to construct volume equations by "species groups" as sufficient numbers of the sample trees in each species group were available.

How would one group the species? Would several volume equations necessary to segregate a species group, for example, by forest types and site or geographical regions? Since data for this project came from hill Dipterocarp forests (a forest type) and commercial volume was a parameter of interest, it was then decided to group the species by commercial classification currently used by Forestry Department Peninsular Malaysia (FDPM), taking into consideration the physical and biological factors of trees. This classification is shown in Table 1.

FAO (1973) concluded that tree forms within the mixed Dipterocarp forests did not show any marked affinity to species groups and could be a feature of environmental factors such as stand density. The FAO conclusion led to the derivation of one volume equation[1] to be applied to all individual species. However, my personal experiences have shown that there was a marked difference in tree form within a mixed Dipterocarp forest, and the above observation by FAO, though statistically verified, was mainly due to the small number of sample trees collected, especially for trees

[1] The equation derived was classified by diameter at reference point of <76cm and >76cm. For each diameter class, an equation was obtained for each commercial log length class. Equation in each commercial log length class for trees >76cm diameter was in a simple linear form having diameter (D) only as an independent variable.

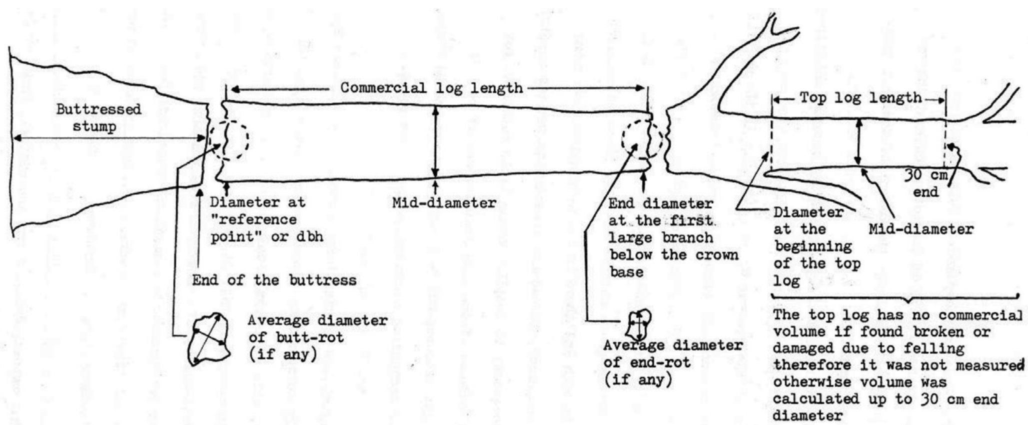

Fig. 1: Illustration of field measurements on a felled sample tree

TABLE 1
Commercial species groups used in this study

Dipterocarp Species Group	Species*
Dark Red Meranti	*Shoreacurtisii, S. platyclados, S. pauciflora, and S. singkawang.*
Light Red Meranti	*Shoreaacuminata, S. dasyphylla, S. hemsleyana, S. leprosula, S. lepidota, S. johorensis, S. ovalis, S. parvifolia, S.platycarpa, S. teysmanniana, and S. palembanica.*

Vernacular name and its symbol, vernacular synonyms, timber and trade names and storey class can be found in Wyatt Smith, J. (1979). Pocket Check List of Timber Trees.* Malayan Forest records No. 17, Forest Department Peninsular Malaysia, Kuala Lumpur**.**

with diameters >76cm, whereby a minimum of 21 trees with 3 or less commercial logs in bole (i.e. height <17.5m) to a maximum of only 51 trees with 4 commercial logs in bole (i.e. height 17.5m – 22.5m) were measured.

These observations and experiences strengthened the decision to derive one volume equation for each species group within a forest type - hill Dipterocarp forest.

Volume Calculation

The parameters on each sample tree for DRM and LRM are summarized in Tables 2a to 2b, respectively. The total overbark volume for the commercial log of each tree was the sum of two log section volumes, namely; from the dbh or reference point to the end of commercial log length and from the first large branch to the 30cm diameter limit - if the length of the latter log section was commercially extractable, otherwise, there was no volume for this log section. The volume of each log section was calculated using the Newton's formula, vis-à-vis:

$$V = \{[A_l + 4A_m + A_s] / 6\} \times L$$

Where

V = Volume overbark (ob), m^3

A_l = cross-sectional area (ob) at the bigger end of the log section (m^2),

A_m = cross-sectional area (ob) at the mid-point of the log section (m^2),

A_s = cross-sectional area (ob) at the smaller end (m^2), and

L = length of each log section (m).

Regression of Volume Equations

Although many methods of volume equation development are available (Chapman & Meyer, 1949; Hummel 1955), the method of least squares is the generally acceptable procedure. The popularity of the method is primarily due to its objectivity, the statistical provision for test of significance and the defining of confidence limits.

However, the need to weigh volume equations in most circumstances in order to induce or to equalize homogeneity of variance in volume along the regression line has been discussed by Wright (1964) and Cunia (1964); this being the pre-requisite before valid test of significance can be applied to the regression equation. The inclusion of weighted or transformed models into the analysis poses problems in testing the goodness-of-fit to statistically select the most appropriate model. Regression in which the same dependent variable has been subjected to different transformations or weightings cannot be compared directly for goodness-of-fit using the R^2 or even adjusted R^2. The regression may be biased by a transformation or weighting of the dependent variable, volume in this case.

A more suitable index for comparing a such regression equation is that of Furnival (1961); the expression of Furnival's Index is given as follows:

$$FI = [f'(V)]^{-1} s$$

The geometric mean of the derivative of the dependent variable (V) of the unweighted regression is 1.0. The geometric mean of

TABLE 2a
A summary of parameters per tree (unless specified) of DRM

Parameter	No	Min	Max	Mean	Std. Deviation
Trees measured	408	-	-	-	-
Diameter at reference point (cm)	-	50.0	177.3	86.3	21.3
Total commercial log length (m)	-	7.9	35.1	21.8	6.1
Trees with broken or damaged top/ crown after first large branch[1]	340	-	-	-	-
Trees with internal rot (hole) at the base of reference point and its diameter (cm)[2]	25	18.0	76.9	35.1	15.0
Trees with internal rot (hole) at the end point of commercial log and its diameter (cm)[3]	0	-	-	-	-
Trees with reference point higher than the dbh (1.3m)[3]	332	-	-	-	-

[Note: If the internal rot (hole) at the base of reference point extended all the way to the end of the commercial log, which could easily be seen if there was, the volume of the defective wood was calculated for each commercial log as half the sum of the bigger end cross-sectional area and the cross-sectional area of the smaller end multiplied by the length of the rot, which was equal to the length of the commercial log, L. This defective volume was deducted from the commercial log volume. However, in this study, no trees of any species groups had the internal rot extended all the way from the base of the reference point to the end of the commercial log].

TABLE 2b
A summary of parameters per tree (unless specified) of LRM

Parameter	No	Min	Max	Mean	Std. Deviation
Trees measured	331	-	-	-	-
Diameter at reference point (cm)	-	52.1	138.2	80.5	17.7
Total commercial log length (m)	-	9.7	37.1	24.3	5.3
Trees with broken or damaged top/ crown after first large branch[4]	242	-	-	-	-
Trees with internal rot (hole) at the base of reference point and its diameter (cm)[5]	7	17.5	45.8	30.8	10.2
Trees with internal rot (hole) at the end point of commercial log and its diameter (cm)[3]	-	-	-	28.4	-
Trees with reference point higher than the dbh (1.3m)[6]	292	-	-	-	-

the derivatives of the dependent variable Log_eV, V/D^2, and V/D^2H of the weighted equations are V, D^2 and D^2H, respectively. The equation with the smallest Furnival's Index indicates the best fit regression equation for a particular species group in this study.

With the above observation, 9 of the most commonly used regression equations or models were fitted to the raw data of trees in each species group and analyzed accordingly. The most commonly used regression models are as follows:

UNWEIGHTED EQUATIONS

1. $V = \beta_0 + \beta_1 D^2H + \varepsilon$
2. $V = \beta_0 + \beta_1 D^2 + \beta_2 H + \beta_3 D^2H + \varepsilon$
3. $V = \beta_0 + \beta_1 D^2 + \beta_2 DH + \beta_3 D^2H + \varepsilon$
4. $Log_e V = \beta_0 + \beta_1 Log_e D + \beta_2 Log_e H + \varepsilon$

WEIGHTED EQUATIONS

5. $V/D^2H = \beta_0 + \beta_1(1/D^2H) + \varepsilon$.... Equation [1] weighted by D^2H
6. $V/D^2 = \beta_0 + \beta_1 [1/D^2) + \beta_2 (H/D^2) + \beta_3 H + \varepsilon$ .... Equation [2] weighted by D^2
7. $V/D^2H = \beta_0 + \beta_1 (1/D^2H) + \beta_2 (1/H) + \beta_3 (1/D^2) + \varepsilon$.... Equation [2] weighted by D^2H
8. $V/D^2 = \beta_0 + \beta_1 (1/D^2) + \beta_2 (H/D) + \beta_3 H + \varepsilon$.... Equation [3] weighted by D^2
9. $V/D^2H = \beta_0 + \beta_1(1/D^2H) + \beta_2(1/H) + \beta_3(1/D) + \varepsilon$.... Equation [3] weighted by D^2H

Where

V = dependent variable (commercial tree volume, m^3),

D = dbh or reference diameter (cm),

H = commercial log length (m),

β_i= regression coefficients, and

ε = error term.

RESULTS AND DISCUSSION

Tables 2a and 2b show various parameters measured and calculated for DRM and LRM, respectively. As mentioned earlier, the regression models and geometric means of each species group were analyzed. The results – regression coefficients, residual standard deviation from the fitted regression, the geometric mean and the FI – are shown in Tables 3a and 3b for the respective Meranti species groups.

The results showed the superiority of the weighted equation in the species group. The equation with the smallest FI was chosen as having the best fit to the data of each species group. These are as follows:

Dark Red Meranti

$V/D^2H = (4.2054E\text{-}05) - (0.5994(1/D^2H)) + (3.1947E\text{-}04(1/H)) + (0.0370(1/D^2))$ .... Equation [7]

Multiplying both sides by D^2H produces the final volume equation:

$V = - (0.5994) + (3.1947E\text{-}04D^2) + (0.0370H) + (4.2054E\text{-}05D^2H)$

Light Red Meranti

$V/D^2H = (4.8974E\text{-}05) + (0.2059(1/D^2H)) + (1.6593E\text{-}04(1/H)) + (8.3346E\text{-}03(1/D^2))$.... Equation [7]

TABLE 3a
Commercial volume equations for Dark Red Meranti (DRM) (*Best fit Standard volume equation)

Unweighted equations	Standard deviation	R^2	Geometric mean of =		Furnival's Index
1. $V = 0.5558 + 5.4636E\text{-}02D^2H$	1.2499	0.9562	1	1	1.2499
2. $V = -3.8178E\text{-}02 + 2.4194E\text{-}04D^2 + 1.1169E\text{-}02H + 4.5669E\text{-}05D^2H$	1.2088	0.9593	1	1	1.2088
3. $V = -0.6272 + 3.0308E\text{-}04D^2 + 8.3666E\text{-}04DH + 3.8626E\text{-}05D^2H$	1.2048	0.9596	1	1	1.2048
4. $\text{Log}_e V = -9.0841 + 1.9823\text{Log}_e D + 0.8063\text{Log}_e H$	0.1669	0.9110	V	8.5977	1.4357
Weighted equations					
5. $V/D^2H = 5.5369E\text{-}05 + 0.4348(1/D^2H)$	6.7333E-06	0.0707	D^2H	147844	0.9955
6. $V/D^2 = 2.9047E\text{-}04 - 0.4153(1/D^2) + 2.8170E\text{-}02(H/D^2) + 4.3424E\text{-}05H$	1.3953E-04	0.6860	D^2	7033.14	0.9814
7. $V/D^2H = 4.2054E\text{-}05 + 0.5994(1/D^2H) + 3.1947E\text{-}04(1/H) + 0.0370(1/D^2)$	6.4084E-06	0.1624	D^2H	147844	**0.9474***
8. $V/D^2 = 1.8759E\text{-}04 + 0.2771(1/D^2) - 1.2135E\text{-}04(H/D) + 4.8954E\text{-}05H$	1.3975E-04	0.6851	D^2	7033.14	0.9829
9. $V/D^2H = 4.6356E\text{-}05 + 4.4099E\text{-}02(1/D^2H) + 2.2247E\text{-}04(1/H) + 1.0053E\text{-}04(1/D)$	6.4308E-06	0.1565	D^2H	147844	0.9508

TABLE 3b
Commercial volume equations for Light Red Meranti (LRM) (*Best fit Standard volume equation)

Unweighted equations	Standard deviation	R^2	Geometric mean of =		Furnival's Index
1. $V = 0.6559 + 5.4174E\text{-}05D^2H$	1.2452	0.9447	1	1	1.2452
2. $V = 0.4124 + 1.9456E\text{-}04D^2 - 4.5242E\text{-}03H + 4.8406E\text{-}05D^2H$	1.2223	0.9470	1	1	1.2223
3. $V = -0.6640 + 1.6634E\text{-}04D^2 - 3.5342E\text{-}04DH + 5.1538E\text{-}05D^2H$	1.2217	0.9470	1	1	1.2217
4. $\text{Log}_e V = -8.8185 + 1.9102\text{Log}_e D + 0.8316\text{Log}_e H$	0.1327	0.9273	V	8.6073	1.1423
Weighted equations					
5. $V/D^2H = 5.4586E\text{-}05 + 0.5969(1/D^2H)$	6.5029E-06	0.1073	D^2H	146561	0.9531
6. $V/D^2 = 2.3282E\text{-}04 + 8.5472E\text{-}02(1/D^2) + 1.2158E\text{-}02(H/D^2) + 4.6376E\text{-}05H$	1.5466E-04	0.6803	D^2	6192.74	0.9578
7. $V/D^2H = 4.8974E\text{-}05 + 0.2059(1/D^2H) + 1.6593E\text{-}04(1/H) + 8.3346E\text{-}03(1/D^2)$	6.4372E-06	0.1306	D^2H	146561	0.9434*
8. $V/D^2 = 2.0917E\text{-}04 - 0.2244(1/D^2) + 1.6679E\text{-}04(H/D) + 4.6293E\text{-}05H$	1.5469E-04	0.6802	D^2	6192.74	0.9579
9. $V/D^2H = 4.9151E\text{-}05 + 0.3091(1/D^2H) + 1.4857E\text{-}04(1/H) + 9.5435E\text{-}05(1/D)$	6.4381E-06	0.1303	D^2H	146561	0.9436

Multiplying both sides byD^2H produces the final volume equation:

$$V = (0.2059) + (1.6593E\text{-}04D^2) + (8.3346E\text{-}03H) + (4.8974E\text{-}05D^2H)$$

Comparison of Standard Volume Equations Developed Herewith with FAO 1973 and Canonizado and Buenaflor 1977 volume equations

The nature of the development of many other volume equations (e.g., FAO, 1973; Canonizado & Buenaflor, 1977), hence volume tables, for hill Dipterocarp forests makes it difficult to make a good comparison between them and the equations developed in this present study. Perhaps, some "arbitrary" comparisons can only be made between the three sets of volume table equations - FAO (1973), Canonizado and Buenaflor (1977) and the present study, whereby, some forms of regression analyses have been used, although different goodness-of-fit statistics have been used to select the best fitted equations.

The basis of comparison between the three sets of volume table equations for each species group is a range of reference diameter or dbh (mean ± standard deviation) and to use 4 and 5 log lengths (1 log length = 5 meter), which were the average for the species groups as found in the present study. The results of the comparison are shown in Table 4a and Table 4b.

TABLE 4a
A comparison of the gross volume estimates (m^3) for two species groups at various reference diameters, with 4 log length (1 log length = 5m)

Diam 5cm class	No. of 5m log	DRM			Difference (nearest 1%)		LRM			Difference (nearest 1%)	
		1973	1977	2012			1973	1977	2012		
		(3)	(4)	(5)	(5)-(3) %	(5)-(4) %	(3)	(4)	(5)	(5)-(3) %	(5)-(4) %
60	4	-	-	-	-	-	-	-	-	-	-
65	4	3.90	4.71	5.04	29%	7%	3.90	4.82	5.21	33%	8%
70	4	4.60	5.50	5.83	27%	6%	4.60	5.59	5.99	30%	7%
75	4	5.35	6.36	6.67	25%	5%	5.35	6.42	6.82	27%	6%
80	4	6.35	7.28	7.57	19%	4%	6.35	7.31	7.70	21%	5%
85	4	7.40	8.27	8.35	13%	1%	7.40	8.26	8.65	17%	5%
90	4	8.45	9.31	9.54	13%	3%	8.45	9.26	9.65	14%	4%
95	4	9.50	10.44	10.61	12%	2%	9.50	10.32	10.71	13%	4%
100	4	10.55	11.62	11.75	11%	1%	10.55	11.43	11.83	12%	4%
105	4	11.60	12.88	12.94	12%	0.5%	11.60	12.61	13.00	12%	3%
110	4	12.70	14.20	14.18	12%	-0.1%	12.70	13.84	14.23	12%	3%

Diameter for comparison is outside the mean ± standard deviation, as obtained in this study
(1973 = FAO; 1977 = Canonizado and Beunaflor; 2012 = this study).

TABLE 4b
A comparison of the gross volume estimates (m^3) for two species groups at various reference diameters, with 5 log length (1 log length = 5m)

Diam 5cm class	No. of 5m log	DRM			Difference (nearest 1%)		LRM			Difference (nearest 1%)	
		1973	1977	2012			1973	1977	2012		
		(3)	(4)	(5)	(5)-(3) %	(5)-(4) %	(3)	(4)	(5)	(5)-(3) %	(5)-(4) %
60	5	-	-	-	-	-	-	-	-	-	-
65	5	3.90	5.65	6.12	57%	8%	3.90	5.84	6.29	61%	8%
70	5	4.60	6.60	7.04	53%	7%	4.60	6.77	7.23	57%	7%
75	5	5.35	7.63	8.04	50%	5%	5.35	7.77	8.23	54%	6%
80	5	6.80	8.74	9.10	34%	4%	6.80	8.85	9.31	37%	5%
85	5	8.40	9.93	10.23	22%	3%	8.40	9.99	10.46	24%	5%
90	5	10.05	11.19	11.43	14%	2%	10.05	11.20	11.68	16%	4%
95	5	11.65	12.53	12.70	9%	1%	11.65	12.48	12.96	11%	4%
100	5	13.30	13.96	14.03	6%	0.5%	13.30	13.84	14.32	8%	3%
105	5	14.95	15.46	15.44	3%	0%	14.95	15.26	15.74	5%	3%
110	5	16.55	17.05	16.91	2%	-0.8%	16.55	16.75	17.24	4%	3%

Diameter for comparison is outside the mean ± standard deviation, as obtained in this study
(1973 = FAO; 1977 = Canonizado and Beunaflor; 2012 = this study)

From Tables 4a and 4b, all the species groups generally showed higher volume estimates (>1.0m^3) than the volume estimates of FAO (1973), but fairly close to the volume estimates obtained by Canonizado and Buenaflor (1977). In comparison, the following generalizations can be made:

1. The volume equations in this study consistently gave higher estimates - up to 33% for diameter classes between 60 - 110cm at 4 log length and up to 61% for diameter classes 60 - 110cm at 5 log length compared with FAO (1973);
2. The volume equations in this study consistently gave higher estimates - up to 8% for diameter classes between 60 - 110cm at 4 and 5 log length compared with Canonizado and Buenaflor (1977);
3. For DRM and LRM at 4 and 5 log length with tree diameter >100cm, the difference in volume estimates between the equation developed herewith and that of FAO (1973) was up to 2m^3/tree; and
4. For DRM and LRM, at 4 and 5 log length with tree diameter >75cm, the difference in the volume estimates between equation developed herewith and that of Canonizadoand Buenaflor (1977) was up to 0.5m^3/tree.

Notes on the Occurrence of Butt- and End-rots and Log Damage Due to Felling

The extent of the butt- and end-rots occurrences in commercial tree boles was small. Approximately 6% and 2% of the commercial tree boles of DRM and LRM respectively showed some forms of butt-rots. No trees, except 1 out of 331 LRM trees measured, showed any sign of end-rot in the commercial tree boles. No trees in any species groups studied had the rot extended all the way (i.e. from the base of the reference point to the cut point) at the first large branch below the crown base.

The percentage of trees having a reference diameter higher than dbh was high in all species groups - 81.4% in DRM and 88.2% in LRM. This showed that the Meranti trees in hill Dipterocarp forests in this area were heavily buttressed and the height of the buttressed stumps, which were left inside the forest, exceeded 1.3m.

It was noted that the incidence of the top log damage or breakage, after the first large branch due to felling, was higher in DRM (83.3%), followed by LRM (73.1%), indicating that the recovery of volume of logs after the first large branch ranged from a low of 17% of all the trees measured in DRM to a high of 27% in LRM. The recovery of sound commercial log boles, especially after this first branch, was low due to problem of breakage during felling, hence, additional handling of this portion of the logs would be required to recover the commercially available wood fibres for other purposes, such as for chips. The availability of wood fibres from branches and other parts of the stem, such as damaged top logs and high stumps left in the forest could be very substantial and thus the economics of harvesting such wood fibres should be carefully considered.

CONCLUSION

The volume equations for DRM and LRM developed in this study can be expected to give satisfactory estimates for the aggregate standing volume of a group of tree species. The problem of underestimating log volumes, for examples, by as much as 40% for a 4 log length (about 20 meters total log length) and 60% for a 5 log length (about 25 meters total log length) would have been addressed by the development of these new volume equations; more so as the volume equations were developed by species groups rather than one equation fits all, the number of sample trees measured were 739 trees for both DRM and LRM, while the range of diameters and log lengths measured were 50 - 177cm and 8 - 37m, respectively. Lastly, a more superior method of the weighted least squares to equalize the homogeneity of variance in volume, along the regression lines and validated by the Furnival's Index as statistical measure of goodness-of-fit, was used.

These equations are also expected to give accurate and satisfactory estimates of the standing volume of mixed hill Dipterocarp forests in the nearby region, but as with all volume equations a test of applicability is necessary if used outside the range of the original data and/or other conditions. With the advent of computer and given these volume equations, volume tables for DRM and LRM can easily be computed for a required range of diameters and heights for daily and routine uses of practicing foresters.

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FOOTNOTES

[2] Indicates that trees have no utilizable volume after this branch and also indicates the incidence of log damage due to felling.

[3] The length of the rot into the log was not measured unless the hole extended all the way to this end point, whereby its length was equal to the length of commercial log. This information was provided to the SJSB management as to indicate the extent of occurrence of the butt- or end-rot. Species were mainly S. pa*uciflora and S. curtesii*.

[4] Indicates the number of trees having buttress higher than dbh.

[5] Indicates that trees have no utilizable volume after this branch and also indicates the incidence of log damage due to felling.

[6] The length of the rot into the log was not measured unless the hole extended all the way to this end point, whereby its length was equal to the length of commercial log. This information was provided to the SJSB management as to indicate the extent of occurrence of the butt- or end-rot. Species were mainly S. le*prosula, S. ovalis, S. parvifolia and S. lepidota.*

[7] Indicates the number of trees having buttress higher than dbh.