TREE TRUNK VOLUME OF *Shorea* SPECIES CASE STUDY IN DARMAGA AND HAURBENTES RESEARCH FOREST IN WEST JAVA, INDONESIA

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ABSTRACT

Activities of forest management require a well planned, systematic and well directed handling, so that achieving maximal and beneficial results in terms of economic, ecological and social prospects. In relevant to data on trunk volume of available tree stands are required to set up a plan intended to produce sustainable timber. The research was conducted in the Darmaga and Haurbentes research forests of the Forest and Nature Conservation Research and Development Center located in West Java. The trunk volume model as conceived was based on the Smalian's formula employed to particular tree species (i.e. *Shorea balangeran; S. guisso; S. leprosula; S. mecistopteryx; S. ovalis; S. palembanica; S. pinanga; S. selanica; S. seminis* and *S. stenoptera).* This model could estimate the trunk volume with non-destructive sampling. In this way, therefore, the trunk volume can be estimated from the tree diameter on a single variable.

Keywords: forest management, trunk volume, plantation forest, *Shorea* spp.

I. INTRODUCTION

A. Background

Man-made forests with a long live timber tree species on degraded land are more valuable than with fast growing tree species for carbon sequestration. Additionally, sustainable management of such forests might decrease human harvesting pressure on primary tropical rain forests through supplying timber from plantation forests. However, there is less information available about quantifying timber volume from man-made forest in the humid tropics.

A trunk volume of a tree is generally calculated from 30 cm above land surface or buttress to the height of crown base. The height of crown base depends on tree species and environment. In some species with self-pruning, their trunk free from branches is high, such as meranti *(Shorea* spp.) species. Several species have low of crown base, this maybe due to their branches are difficult to self-pruning or because of attacked pest. Tree growth in wide space generally has lower crown base than those of trees growing in narrow space. Another affecting factor to trunk volume is trunk shape. The trunk shape variation depends on tree species and crown shape. Trees in dense forests with sort live-crown are usually having more cylindrical trunk shape rather than those of trees with deep crown in open area. Trunk shape is also affected by silvicultural treatment. Thinning tends to cause the trunk shape with more conical because of the increment of live crown ratio. On the other hand, pruning of branches tends to produce trunk with more cylindrical

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due to reduction of live crown ratio (Daniel *et al.*, 1979).

Reliable information on tree and forest volume is vital for managing a forest in order to decide cutting cycle which can guarantee sustained yield principles. Bole volume of most tropical rain forest trees in Indonesia is highly correlated with diameter at breast height and height to the crown-base (Suhendang, 1993).

A method for estimating trunk volume of a tree that close to the realistic condition is a modification of Smalian's formula. The Smalian's formula is applied to calculate each section of trunk. The trunk volume is the total volume of each trunk section. Parameters needed to calculate the trunk volume section are length of trunk section, diameter of trunk base and top of trunk section.

B. Objective

The purpose of this research is to determine equations to estimate timber volume from trunk diameter in West Java, the humid tropics. The equations will help to have reliable management plan for establishing industrial plantations.

II. CONDITION OF THE STUDY SITE

This study was conducted in two locations i.e. the Darmaga and Haurbentes Research Forests managed by the Forest and Nature Conservation Research and Development Center (Figure 1).

Table 1. Site description of research forest area

	Research forests	
	Darmaga	Haurbentes
Location	Situ Gede Village, Darmaga Subdistrict, Bogor District, West Java	Ngasuh Village, Jasinga Subdistrict, Bogor District, West Java
Latitude	6° 33' 8"-6°33' 35" S	6° 32' S
Longitude	106° 105" 19" E	108° 26' E
Altitude (m asl.)	244	200-250
Climate type *	A (wet)	A (wet)
Annual rainfall (mm/yr)	3,940	4,276
Soil classification	Latosol	Red Yellow Podsolik, Regosol, Acid Brown Forest Soil
Establishment year	1956	1940
Area (ha)	58	100
Total of plots	136	164
Number of measured plots	3	9
Number of measured trees	63	144

Remarks: * Schmidt and Ferguson (1951)
asl: above sea level

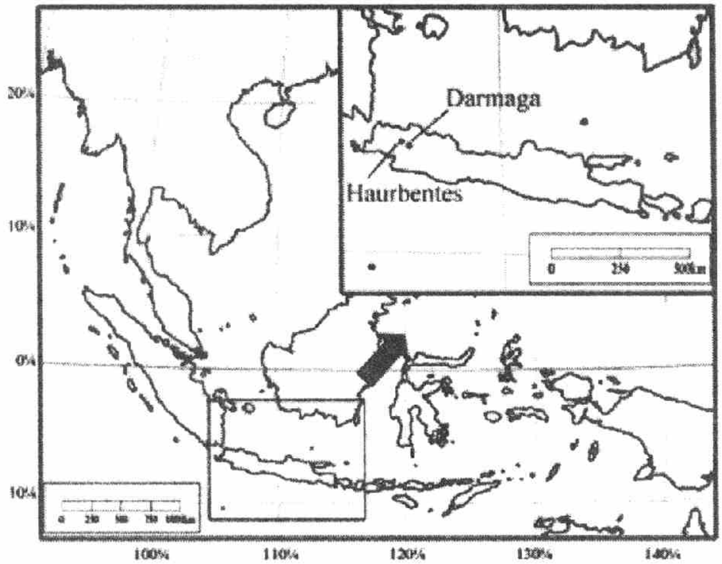

Figure 1. The location of Darmaga and Haurbentes Research Forest in West Java Province

III. METHODOLOGY

A. Sampled Trees

To estimate trunk volume of sampled trees in the research forests, field investigation and measurement were conducted from August to late September 2004 in Darmaga and Haurbentes Research Forests. The sampled trees were selected systematically from the defined sample plots either in one or two sample sites. Each diameter classes were sampled proportionally. The measured tree species were as follows; *Shorea balangeran; Shorea guisso; Shorea leprosula; Shorea mecistopteryx; Shorea ovalis; Shorea palembanica; Shorea pinanga; Shorea selanica; Shorea seminis* and *Shorea stenoptera* (Table 2).

Table 2. List of tree species, research plot location and number of sampled trees

Species	Location	Number of sample trees
Shorea balangeran	Plot 44, Dramaga	20
Shorea guisso	Plot 102, Dramaga	17
	Plot 71, Haurbentes	4
Shorea leprosula	Plot 102, Dramaga	10
	Plot 35, Haurbentes	13
Shorea mecistopteryx	Plot 27, Haurbentes	18
Shorea ovalis	Plot 59, Haurbentes	20
Shorea palembanica	Plot 21, Haurbentes	19
Shorea pinanga	Plot 5, Haurbentes	20
Shorea selanica	Plot 13, Dramaga	16
	Plot 50, Haurbentes	8
Shorea seminis	Plot 34, Haurbentes	21
Shorea stenoptera	Plot 13, Haurbentes	21

B. Data Collection and Processing

Measurement on each sampled trees and calculation of its bole volume were conducted as follows:

1. Trunk diameter at breast height (DBH) defined as diameter at 1.30 m above ground or 20 cm above buttress if the height of the buttress more than 1.30 m were measured and recorded. The thickness of bark was also measured and recorded. Base trunk diameters, diameter of trunk at just above buttress or 30 cm above ground if no buttress were also measured and recorded.
2. Height at crown base (lowest alive branch) and height of buttress were measured by using a height meter (Vertex 3, Haglof Co. Ltd.) and then recorded.
3. Above DBH, trunk diameters were measured and recorded with 2-7 m intervals until height at crown base by Bitterlich Tele Relascop. The height of measured points was also recorded.
4. Volume of each section was calculated from measured diameters and length by the Smalian's formula (Laar and Akca, 1997; Wood and Wiant, 1993). Trunk volume with bark (Vib) and without bark (Vob) were calculated by summing up volume of each section of the tree trunk.
5. The relationship between tree trunk volume and diameter for each species was analyzed by using quadratic polynomial regression model quadrate:

$$V = a + bD + cD^2 \qquad (1)$$

where: V = Vib or Vob (m^3)
D = DBH (cm)
a, b and c = coefficients

IV. RESULTS AND DISCUSSION

A. Diameter at Breast Height (DBH)

DBH of sample trees ranged between 16.9 cm (as the smallest) for *S. ovalis* species and 133.0 cm (as the largest) for *S. stenoptera*. For all of the sampled trees, the smallest average DBH (i.e. 37.5 cm) was recorded in *S. balangeran* with the DBH ranging about 22.1-58.1 cm and revealing the standard deviation at 10.1 cm. Meanwhile, the largest average DBH (i.e. 69.6 cm) occurred in *S. stenoptera* species with the DBH ranging about 23.0-133.0 cm at 33.9 cm standard deviation. The higher variation in DBH for particular species was greater standard deviation. Trees with wide DBH were generally older than those with small DBH. The summarized data for the DBH of the overall 10 tree species are disclosed in Table 3.

Table 3. Summarized data of the DBH for each tree species

Species	DBH (cm)			
	Min.	Max.	Ave.	St.dev.
S. balangeran	22.1	58.1	37.5	10.1
S. guisso	24.1	67.8	44.7	12.0
S. leprosula	20.4	123.5	69.4	25.8
S. mecistopteryx	22.0	74.6	43.1	16.3
S. ovalis	16.9	64.4	38.1	13.7
S. palembanica	20.4	75.2	44.8	19.1
S. pinanga	22.8	86.2	44.2	18.2
S. selanica	29.4	91.8	58.2	21.2
S. seminis	18.8	60.5	39.8	11.9
S. stenoptera	23.0	133.0	69.6	33.9

B. Correlation Between Tree Trunk Volume and Diameter

The correlation between tree trunk volume (Vib or Vob, m^3 $tree^{-1}$) and diameter (m) of all species observed were represented by quadratic regression models. Early stage growth of most observed species was slow and then increased with the addition of tree growth at which to some particular extent the growth increment reached maximum and finally their growth increment decreased gradually. Equation models for Vib for each species and its coefficient of determination were presented in Table 4. It can be seen that most of the volume equation show the coefficient of determination larger than 0.90. It means that more than 0.90 of the total variation in the volume is explained by the model, except for *S. guisso* (R^2 = 0.89).

Table 4. Tree volume equation for Vib and coefficient of determination for each species

Species	Equations for volume with bark (Vib)	R^2	P
S. balangeran	$Vib = -0.43 + 15.07D - 14.49D^2$	0.01	$P < 0.001$
S. guisso	$Vib = -0.83 + 17.14D - 9.76D^2$	0.89	$P < 0.001$
S. leprosula	$Vib = -0.14 + 12.98D - 1.43D^2$	0.92	$P < 0.001$
S. mecistopteryx	$Vib = -0.24 + 14.61D - 8.85D^2$	0.98	$P < 0.001$
S. ovalis	$Vib = -0.13 + 10.84D - 2.33D^2$	0.95	$P < 0.001$
S. palembanica	$Vib = 0.18 + 4.26D + 5.22D^2$	0.97	$P < 0.001$
S. pinanga	$Vib = 0.09 + 7.84D - 0.27D^2$	0.94	$P < 0.001$
S. selanica	$Vib = -0.66 + 17.39D - 4.30D^2$	0.96	$P < 0.001$
S. seminis	$Vib = -0.18 + 10.15D - 7.21D^2$	0.95	$P < 0.001$
S. stenoptera	$Vib = 0.60 + 8.59D + 0.13D^2$	0.97	$P < 0.001$

Equation models for Vob for each species and their coefficient of determination are presented in Table 5. Those are similar to Vib, and most of the volume equation show the coefficient of determination larger than 0.90 except for *S. guisso* (R^2 = 0.89).

Table 5. Tree volume equation for Vob and coefficient of determination for each species

Species	Equations for volume without bark (Vob)	R^2	P
S. balangeran	$Vob = -0.43 + 14.11D - 13.31D^2$	0.01	$P < 0.001$
S. guisso	$Vob = -0.80 + 16.32D - 8.94D^2$	0.89	$P < 0.001$
S. leprosula	$Vob = -0.14 + 12.19D - 1.16D^2$	0.93	$P < 0.001$
S. mecistopteryx	$Vob = -0.24 + 13.27D - 7.21D^2$	0.98	$P < 0.001$
S. ovalis	$Vob = -0.13 + 9.96D - 1.27D^2$	0.94	$P < 0.001$
S. palembanica	$Vob = 0.15 + 4.06D + 5.04D^2$	0.97	$P < 0.001$
S. pinanga	$Vob = 0.09 + 7.35D + 0.05D^2$	0.94	$P < 0.001$
S. selanica	$Vob = -0.66 + 16.68D - 4.03D^2$	0.96	$P < 0.001$
S. seminis	$Vob = -0.18 + 9.91D - 7.19D^2$	0.95	$P < 0.001$
S. stenoptera	$Vob = 0.55 + 8.10D + 0.26D^2$	0.97	$P < 0.001$

C. Tree Volume with Bark (Vib) and without Bark (Vob)

The Vib of sample trees ranged from 0.15 m^3 $tree^{-1}$ (the smallest) in the species of *S. ovalis* to 17.40 m^3 $tree^{-1}$ (the largest) in *S. stenoptera.* The Vob of sample trees ranged from 0.14 m^3 $tree^{-1}$ (the smallest) found the species of *S. ovalis* to 16.83 m^3 $tree^{-1}$ (the largest) found in *S. stenoptera.* For all the sampled trees, the smallest mean Vob is 1.25 m^3 $tree^{-1}$, found in the species of S. seminis. The Vob of *S. seminis* ranged between 0.25-2.48 m^3 $tree^{-1}$ and its standard deviation was 0.71. The largest mean Vob was 6.03 m^3 $tree^{-1}$ and found in the species of *S. leprosula.* The Vob of *S. leprosula* ranged between 0.26-15.77 m^3 $tree^{-1}$, its standard deviation was 3.96. The difference between Vib from Vob of each species was generally less than 0.5 m^3 $tree^{-1}$ except for *S. leprosula* and *S. stenoptera* which can reach their maximum DBH more than 110 cm (Table 3). It means that bark thickness is not important to increased Vib. On the other hand, bark contains high macro and micro nutrients, which are beneficial for plant growth and soil fertility improvement. Therefore, it is better to leave the bark in the field after tree cutting to reduce degradation of soil fertility after forest exploitation.

Table 6. Statistics data for Vib and Vob of each species

Species	Vib (m^3 $tree^{-1}$)				Vob (m^3 $tree^{-1}$)			
	Min.	Max.	Ave.	St.dev.	Min.	Max.	Ave.	St.dev.
S. balangeran	0.29	3.12	1.42	0.82	0.26	2.93	1.31	0.77
S. guisso	0.29	5.25	2.26	1.46	0.27	5.07	2.16	1.42
S. leprosula	0.28	16.37	6.35	4.12	0.26	15.77	6.03	3.96
S. mecistopteryx	0.41	5.13	2.26	1.51	0.36	4.89	2.09	1.43
S. ovalis	0.15	3.93	1.55	1.11	0.14	3.73	1.45	1.06
S. palembanica	0.32	4.54	1.65	1.42	0.30	4.37	1.56	1.36
S. pinanga	0.43	5.84	1.85	1.47	0.39	5.67	1.76	1.42
S. selanica	1.26	11.10	5.09	3.55	1.19	10.64	4.87	3.43
S. seminis	0.26	2.57	1.29	0.73	0.25	2.48	1.25	0.71
S. stenoptera	0.39	17.40	5.79	4.71	0.35	16.83	5.52	4.56

The same method was applied to calculate tree trunk volume of *S. ovalis, S. parvifolia and S. bracteolata* in North Barito Forest District, Central Kalimantan (Wahyono and Soemarna, 1985) and tree trunk volume of *S. parvifolia* and *S. leprosula* in Batanghari, Jambi (Wahyono and Soemarna, 1984). However, the model of regression equation used to construct the volume table was different. They used linear regression model ($\log V = a + b \log D$) which was calculated by least square method.

Each method can be applied to calculate tree trunk volume of *Shorea* spp. depends on the species measured. The quadratic regression models are appropriate to *Shorea* spp. in West Java plantation forest, whereas linear regression models are appropriate to *S. ovalis, S. parvifolia, S. bracteolata* in Central Kalimantan and S. *parvifolia and S. leprosula* in Jambi natural forest. The latest compilation of tree trunk volume equation for *Shorea* spp. and *Dipterocarpus* spp. in natural forest in Indonesia are presented in Table 7 (Rachmayanti, 2004).

Table 7. Equation for tree volume of some species in Indonesia natural forest

No.	Species	Equation for volume	D min.	D max.	Location
1	*Dipterocarpus* spp.	$V = 0.000142682 D^{2.514157281}$	20	140	Kalsel
2	*Shorea* spp.	$V = 0.00009273 D^{2.5747}$	20	100	Bengkulu
3	*Shorea* spp.	$V = 0.000239 D^{2.4329}$	20	120	Maluku
4	*Shorea* spp.	$V = 0.0000951 D^{2.56269}$	10	200	Sumsel
5	*Shorea* spp.	$V = 0.0001034 D^{2.62683}$	20	100	Sumut
6	*Shorea* spp.	$V = 0.0003205 D^{2.3218}$	20	118	Kalteng
7	*Shorea* spp.	$V = 0.000308353 D^{2.3035}$	20	120	Merangin, Jambi
8	*Shorea* spp.	$V = 0.0001648 D^{2.4864}$	20	150	Sintang, Kalbar
9	*Shorea* spp.	$V = 0.00051207 D^{2.1894}$	20	85	Riau
10	*Shorea* spp.	$V = 0.0001406 D^{2.4482}$	20	100	Kalbar
11	*Shorea* spp.	$V = 0.000293 D^{2.3454}$	20	110	Jambi
12	*Shorea* spp.	$V = 0.0002658 D^{2.2816}$	20	100	Kalbar
13	*Shorea* spp.	$V = 0.0003048 D^{2.2713}$	20	259	Riau
14	*Shorea* spp.	$V = 0.0001141 D^{2.52225}$	20	200	Sulteng
15	*Shorea* spp.	$V = 0.000316 D^{2.3}$	20	80	Jambi
16	*Shorea* spp.	$V = 0.0001322 D^{2.4777}$	20	219	Kalsel

V. CONCLUSION

The relationship between volume of wood portion with bark (Vib) as well as volume of wood without bark (Vob) and DBH of particular species, i.e. *S. balangeran; S. guisso; S. leprosula; S. mecistopteryx; S. ovalis; S. palembanica; S. pinanga; S. selanica; S. seminis* and *S. stenoptera* can be illustrated by quadratic polynomial regression models. Most of the models have coefficient of determination larger than 0.90 except for *S. guisso.* It means that more than 0.90 of total variation in wood volume is accounted by the models. By using quadratic regression model for each species, timber production per hectare of the observed 10 species can be estimated from DBH census in certain area. It can be further concluded that using DBH as a single tree variable for estimating trunk biomass volume for the particular tree species is remarkably feasible.

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