Volume Equations and Biomass Prediction of Forest Trees of Nepal

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Introduction

Traditional forest mensuration is based on the combined use of measurements and models. Tree models describe the relationships between tree dimensions, and stand models the relationships between stand characteristics. Models may be expressed as equations, tables or diagrams.

Some tree characteristics, such as diameter and height, are easily measurable. Others, such as volume and biomass, are more conveniently predicted by a model, from diameter and height. Those characteristics which are obtained from models are the most important ones; diameter and height are only auxiliary measurements. Diameter and height can be measured with reasonable accuracy. The accuracy of volume and biomass estimation therefore mainly depends on the models. Without good tree models there is no accurate forest inventory.

The Forest Survey and Statistics Division is continuously carrying out forest inventories, which include diameter and height measurements, in sample plots established in different forest strata. The volumes of the trees are obtained from "Tree Volume Tables for Nepal". This publication includes volume tables for twenty important tree species and two species groups (miscellaneous species in the Terai and miscellaneous species in the hills). For each species, there is a table which gives the stem volume to 4 inches (about 10 cm) top diameter and another table for 8 inches (20 cm) top diameter. The tables were prepared in the Forest Resource Survey project in the 1960s as a joint effort of HMG of Nepal and USAID.

The tables have been very valuable for forest inventory during the past decades. However, they no longer meet all the needs of the inventory. The first drawback is that the tables express tree dimensions in inches, feet and cubic feet, although the inventory results are required in the metric system. Secondly, the volume models are not given as equations. An equation would be a much more practical form than a table when computers are used in the calculations. Thirdly, the present tables only give the timber volume. Because firewood, fodder and small-size construction wood are now as important as timber, it is necessary for the forest inventory to estimate the amount of biomass in small stems, branches and leaves.

The Forest Survey and Statistics Division has recognized the shortcomings of the tree models and has begun a long-term programme to improve the situation. This study is the first step of the process. It converts the volume tables into equations and into the metric system, and provides rough estimators for the biomass of stem, branches and foliage.

Study material

The study was based on the same material as "Tree Volume Tables for Nepal" (Table 1). The data were taken from 5220 trees of 21 species and two species groups (trees of *Schima wallichii* were not used in the 1960s). The trees were measured for the following characteristics:

- diameter at breast height (d)
- total height (h)
- total volume with bark (v)
- total volume without bark
- timber volume to 4 inches (10 cm) top diameter with bark
- timber volume to 4 inches (10 cm) top diameter without bark
- timber volume to 8 inches (20 cm) top diameter with bark
- timber volume to 8 inches (20 cm) top diameter without bark

The diameter, height and total volume were measured for each tree. The timber volume was determined, if the stem gave at least one log with the specified top diameter (4 or 8 inches).

The diameter at breast height was measured with a diameter tape and the total height with an Abney level. The volume computations were based on stem diameters at several heights. The lowermost diameters were measured with a tape measure and the others with a pentaprism caliper. The heights of the measurement points were obtained with an Abney level. The measurements were taken at eight-foot intervals, except the lowermost portion, where the interval was shorter. Additional diameters were also measured when there were irregularities in the stem. Typically there were 10 to 15 measurement points on each tree.

The bark of the bottom portion was measured with a bark gauge at each diameter measurement point. The bark thickness on other parts of the tree was measured on felled trees.

The data for each tree were plotted on graph paper. Stem volume was obtained by measuring the area represented by the graph with a planimeter and converting this to volume by appropriate multipliers. Volume without bark was obtained similarly by deducting the bark thickness from the outside diameter.

For the present study, the tree data from the 1960s were entered into the computer from the original sheets, carefully checked, and converted into the metric system.

Volume equations

The "Tree Volume Tables for Nepal" were originally computed from one of the following equations:

$$v_t = a + b\,(d^2h) \qquad (1)$$

$$v_t = a + b\,(d^2h) + c\,(d^2h)^2 \qquad (2)$$

where v_t = volume,
d = diameter at breast height,
h = height

a,b,c are parameters.

The functions were sometimes adjusted manually to get rational volumes. Especially for small trees the predictions of the unadjusted equations were not always sensible. This was because the ordinary least squares method used in the analysis gave too little weight to the small trees.

This study used the allometric equation which is commonly utilized for describing relations between tree dimensions:

$$v = a'\,d^b\,h^c \qquad (3)$$

where a', b and c are parameters. Since volume is proportional to the square of the diameter and directly proportional to the height, parameter b should be close to two and parameter c close to one.

The allometric equation (3) may be converted into the logarithmic form:

$$\ln(v) = a + b\ln(d) + c\ln(h) \qquad (4)$$

where a = ln(a') and ln means logarithm (here: logarithm to the base 2.71828). This form allows the estimation of parameters in linear regression analysis.

Taking logarithms of the predicted variable changes the distribution of residuals. The consequent bias is most easily corrected by adding the term $0.5\,s_f2$, half of the residual variation (squared standard error of estimate), to the equation (to parameter a). This correction was used in this study.

As Equation (4) is logarithmic, more weight is given to small trees compared with Equations (1) and (2).

The parameters of Equation (4) for different species are given in Table 2.

Validity of the equations

The degree of determination of the new equations is always higher and the relative standard error lower than in the corresponding tables of "Tree Volume Tables for Nepal". No bias can be found within the predictions (Fig. 1). The residuals are normally distributed and their variance remains constant over the range of variation in diameter and height (Figs. 2 and 3). The analysis of residuals therefore reveals that the volume function (Equation 4) was suitable.

When the original data were collected in the 1960s, attempts were made to get a representative selection by measuring trees from various stands in the Terai and hill areas, and on poor as well as good sites. The accuracy of the pentaprism caliper depends on the skill of the user. An effort was made to avoid possible bias in the measurement of upper diameters by regular checking and by using a few experienced surveyors to take all the measurements. A tree was omitted if its stem or the top was not visible, or if it was leaning.

Systematic errors in the original measurements appear as bias in the old as well as the new equations. The bias of the "Tree volume tables for Nepal" was tested in the 1960s by comparisons with felled trees. On 221 sal trees in three regions of the Terai the volume tables underestimated actual volume by 2.9 %. The estimated volumes of semal, asna and botdhainro, were also lower than the measured volumes, whereas for karma and bhurkul the tables gave slight overestimates. The differences were considered so small that no corrections to the volume tables were made.

Local volume tables

In the field it would be more practical to predict stem volume from diameter only, instead of diameter and height. This requirement calls for another set of volume equations where stem diameter is the only predictor. However, because the diameter-height relationship varies considerably according to stand density, growing site and geographical location, it is not possible to prepare general volume models of this type.

Because volume models with tree diameter as the only predictor are valid only locally, these models and tables must be prepared separately for a given locality, stand or purpose, using the more general equations published in this document. The method of preparing local volume tables needs height measurements from different diameter classes. They are converted into a dbh-height curve. Using the height indicated by the curve, the volume of a particular diameter class can be computed with the equations of this study.

Timber volume

The volume of timber (stem volume without tree top) was not modelled directly but with the help of a ratio which shows the proportion of the tree top (v_1 in Fig. 4) of the total stem volume (v). In the same way, the difference in timber volume between 10 cm and 20 cm top diameters (v_2 in Fig. 4) was modelled using the ratio between v_2 and the total timber volume v_t. The use of ratios, which vary between zero and one, instead of a direct prediction of the volume components, ensures that the predictions for different volume components are always realistic and that their sum equals the total stem volume.

The equations for the ratios were as follows (see Fig. 4):

$$\ln(v_1/v) = a + b\ln(d) \qquad (5)$$

$$\ln(v_2/v_t) = a + b\ln(d) \qquad (6)$$

This was the best function found. Height as the second predictor did not significantly improve the model.

According to the equations (Table 3), the proportion of tree top (beyond 10 cm) decreases sharply with increasing diameter. When the tree diameter is 50 cm, the top volume is only one percent of the total stem volume (Fig. 5). The shape of the functions for the ratio v_2 to v_t is basically the same (Table 4).

Bark volume

The bark volume was modelled as the proportion of bark in the stem volume. An equation similar to Equations (5) and (6) was again found to give the best fit:

$$\ln(p_b) = a + b\ln(d) \qquad (7)$$

where pb is the proportion of bark. Three separate bark equations were computed for each species (Tables 5, 6, and 7); one for the total tree length, another for the timber portion, and a third for the large-sized timber portion (see Fig. 4).

The degree of determination for the bark equations (Tables 5, 6 and 7) is considerably lower than for the volume equations (Table 2), for example. This does not mean that the predictions are inaccurate. The low degree of determination is due to the small range in the proportion of bark. This is especially true with big trees, from which the last equations (Table 7) were computed.

The proportion of bark decreases with increase in diameter (Fig. 6). There are big differences between tree species in the amount of bark (Fig. 6). For example, sal (*Shorea robusta*) and asna (*Terminalia tomentosa*) have about twice as much bark as blue pine (*Pinus wallichiana*) and oak (*Quercus* spp.).

Biomass

There are not enough data to compute biomass equations for Nepalese tree species. There are, however, other ways to predict biomass. This chapter briefly describes the method adopted by the Forest Survey and Statistics Division (see eg Pukkala and Rajbandhari 1990).

In the method adopted, stem biomass is obtained by multiplying stem volume by the wood density (Table 1). The air-dry densities of several Nepalese tree species are given in the Master Plan for the Forestry Sector (Forest resources information status and development plan, Appendix Table 2.2) and in Indian sources (Chowdhury & Ghosh, 1958; Trotter, 1960; Anon., 1963; Rao & Purkayastha, 1972).

The Master Plan also gives branch to stem and foliage to stem biomass ratios for several species (Appendix Table 2.3 in the same document). The ratios are given separately for small trees (dbh less than 28 cm), medium-size trees (28-53 cm) and big trees (53 cm). These three ratios (denoted as s, m and b, referring to small, medium-size and big trees) are used to derive the biomass ratio (r) for the actual tree as follows:

	if d is:
r = s	< 10 cm
r = [(d-10)m + (40-d)s]/30	10–40 cm
r = [(d-40)b + (70-d)m]/30	40–70 cm
r = b	> 70 cm

The air dry biomass of branches and leaves is computed from the stem biomass using these ratios.

Computer program

The system developed in this study enables the computation of the following tree characteristics as a function of diameter and height:

- volume of the whole stem
- volume to 10 cm top diameter
- volume to 20 cm top diameter
- bark volume
- stem biomass
- branch biomass
- foliage biomass
- biomass of the whole tree

The volumes and biomasses are not presented here in the form of tables, because of the space that they take up. The tables are published in a separate report of the Forest Survey and Statistics Division (Sharma & Pukkala, 1990).

To facilitate the flexible use of the volume equations and the biomass estimation system, a computer program was written which predicts tree volumes and biomass, and generates volume and biomass tables. If a species does not have a particular parameter from research results, the program uses an average or typical value taken from more thoroughly investigated species.

The computer program runs on a micro computer. It is distributed from the Forest Survey and Statistics Division. Figures 7 and 8 show examples of how the results of one tree or the parameters of a particular species are displayed and printed by the program.

Discussion

The methodology now established to predict volume and biomass improves the inventory system of the Forest Survey and Statistics Division considerably, and also tree measurement in general. However, the method and the models still need development. The most obvious defect is that the biomass estimation is very inaccurate and imprecise for individual trees. This is mainly because density values and biomass ratios are lacking for many species, or they are based on studies conducted outside Nepal. It would also be preferable to express the biomass or the biomass ratios as continuous functions of diameter and height, and not by three fixed ratios only. Another shortcoming is the lack of small trees in the present tree data; the valid range of the models begins only from breast height diameters of 12-13 cm.

The Forest Survey and Statistics Division is planning to develop the tree models further in the future. The aim is to produce improved volume and biomass models for five new species each year.

The Division will also publish instructions for tree analysis and for the compilation of tree models. In this way it is hoped that different offices and projects will adopt the same methodology with the result that the quality of the models is sufficient, and their usage easy.

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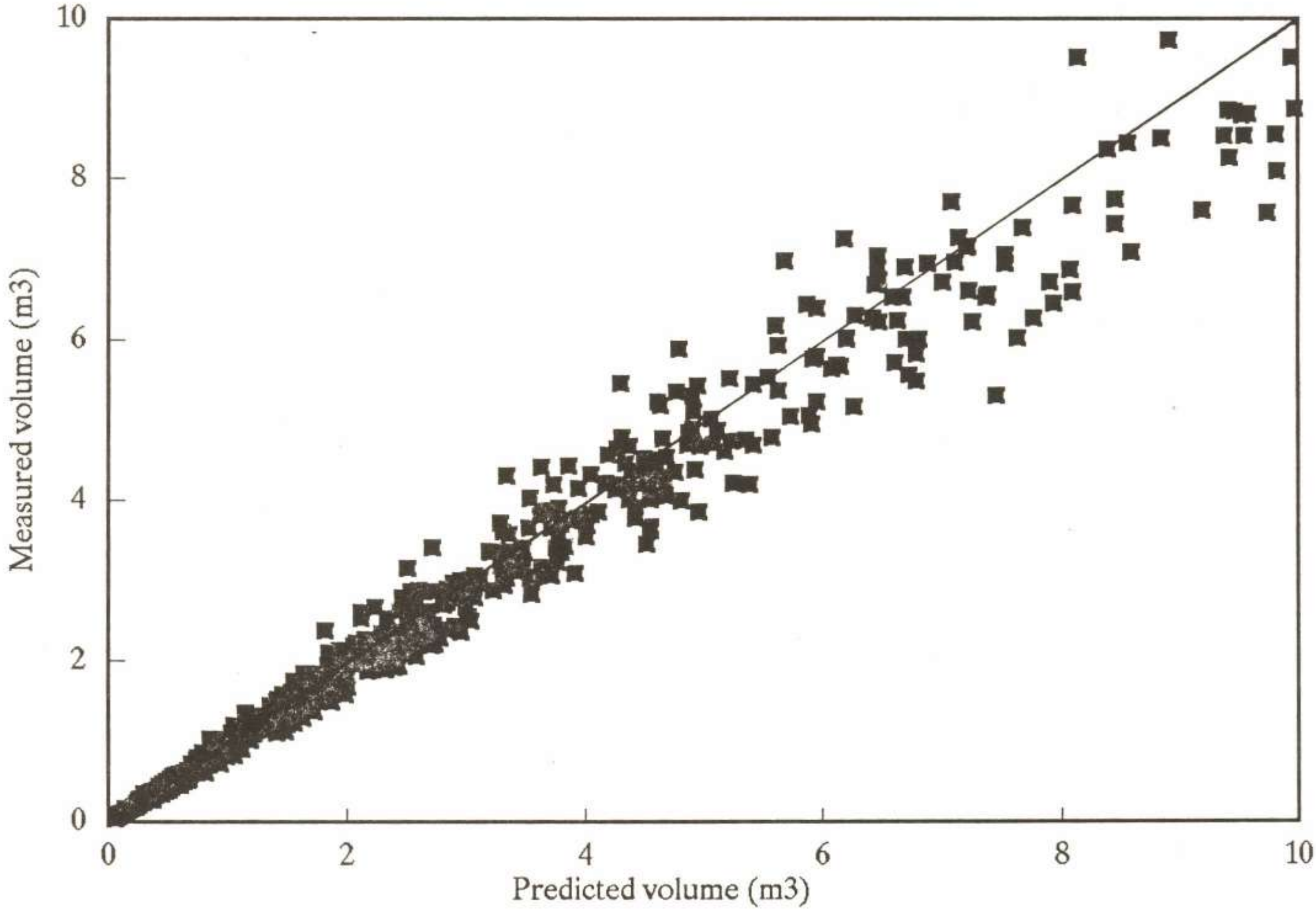
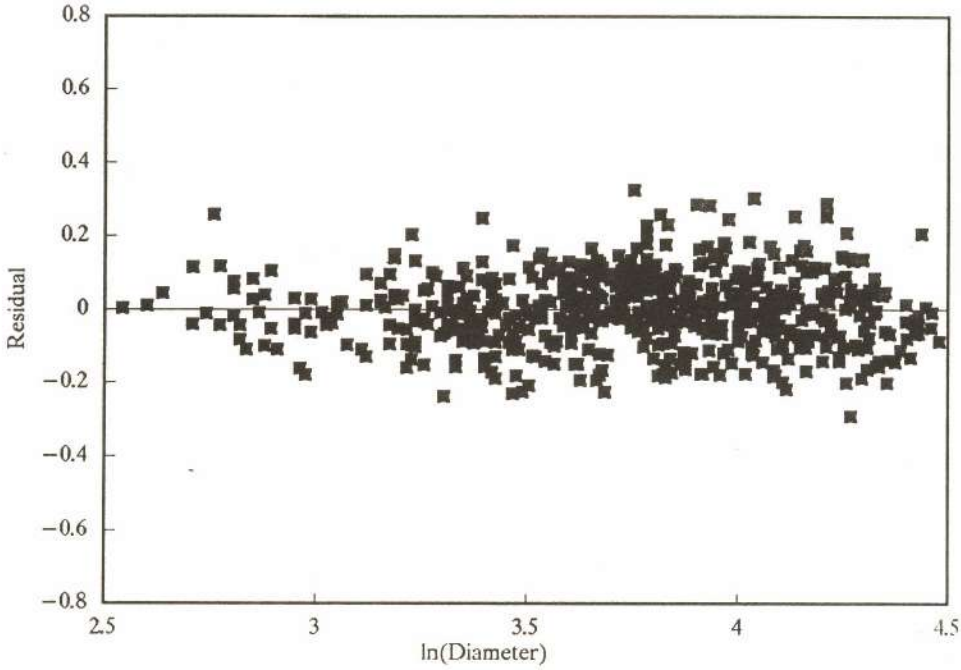


Fig. 1 – Example of the correlation between the measured stem volume and the prediction calculated with a model



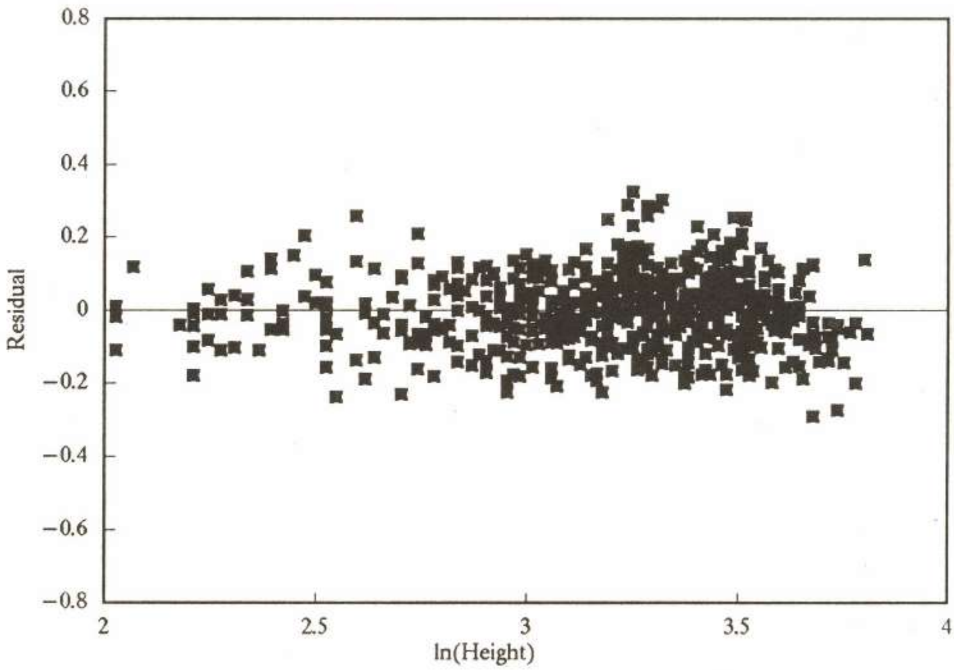
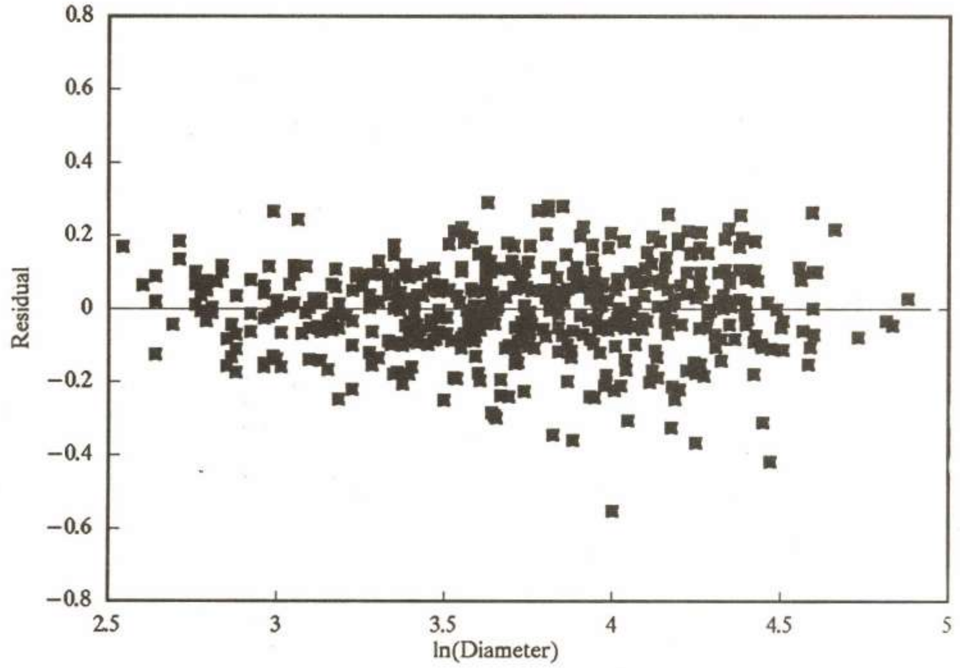


Fig. 2 – Distribution of residuals (logarithm of true volume minus logarithm of predicted volume) of the volume equations of chir pine (*Pinus roxburghii*)



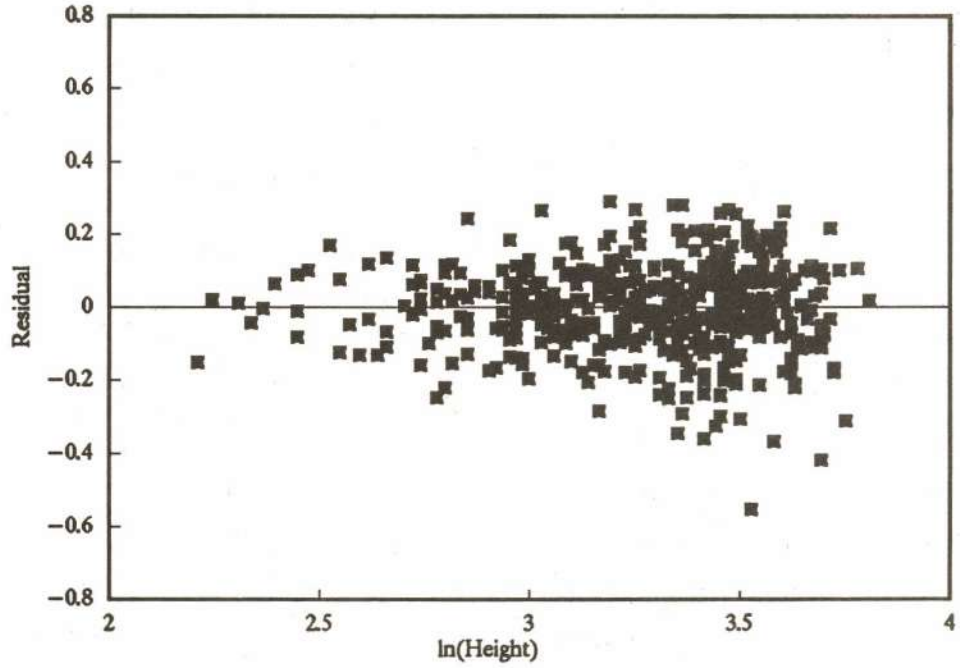


Fig. 3 – Distribution of residuals of the volume equations of asna (*Terminalia tomentosa*)

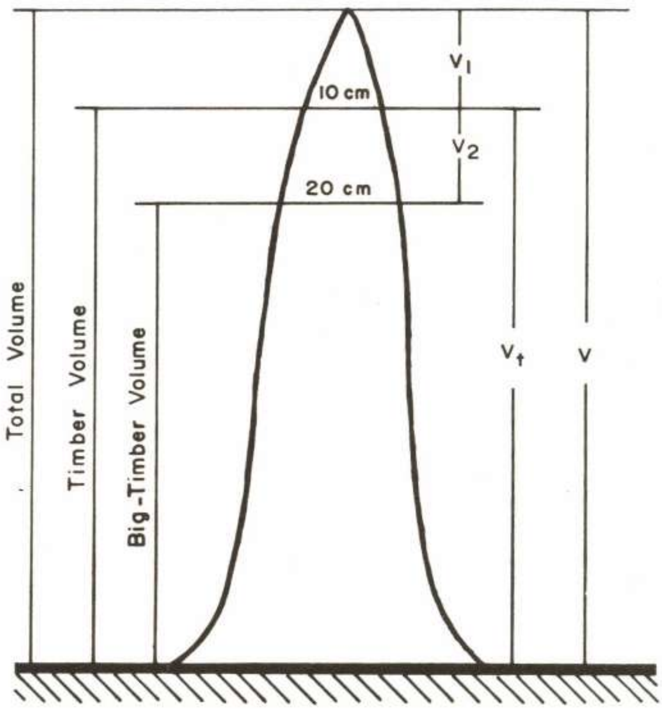


Fig. 4 – Symbols of stem components as used in the equations

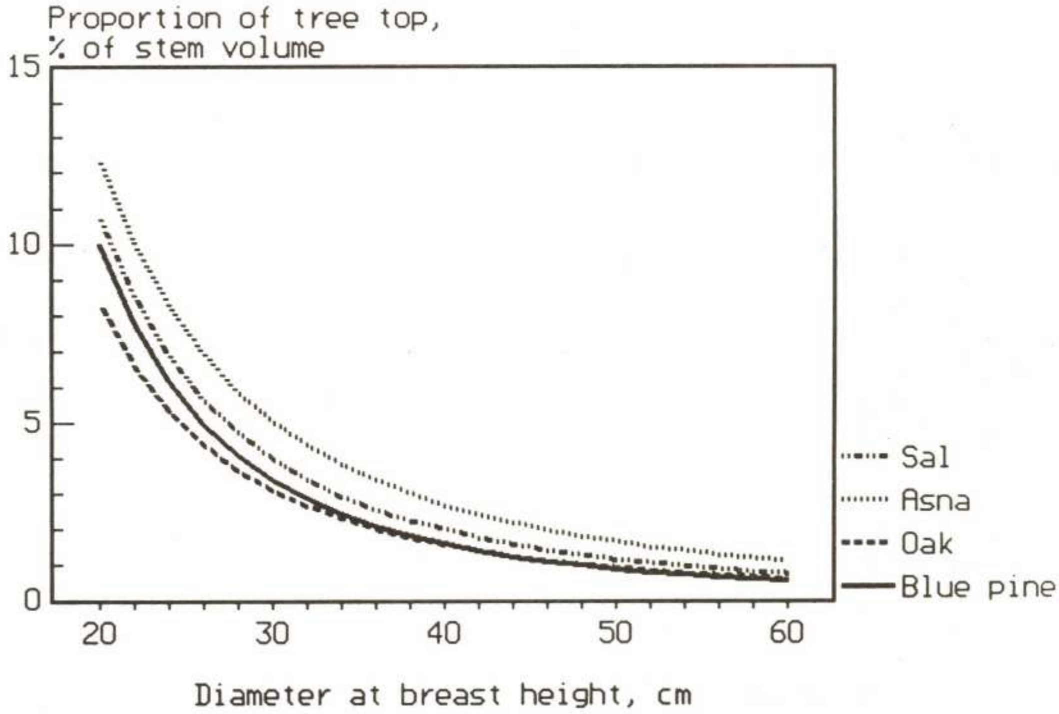


Fig. 5 – Example of the dependence of the proportion of tree top (v_1 in Fig. 4) on the diameter at breast height

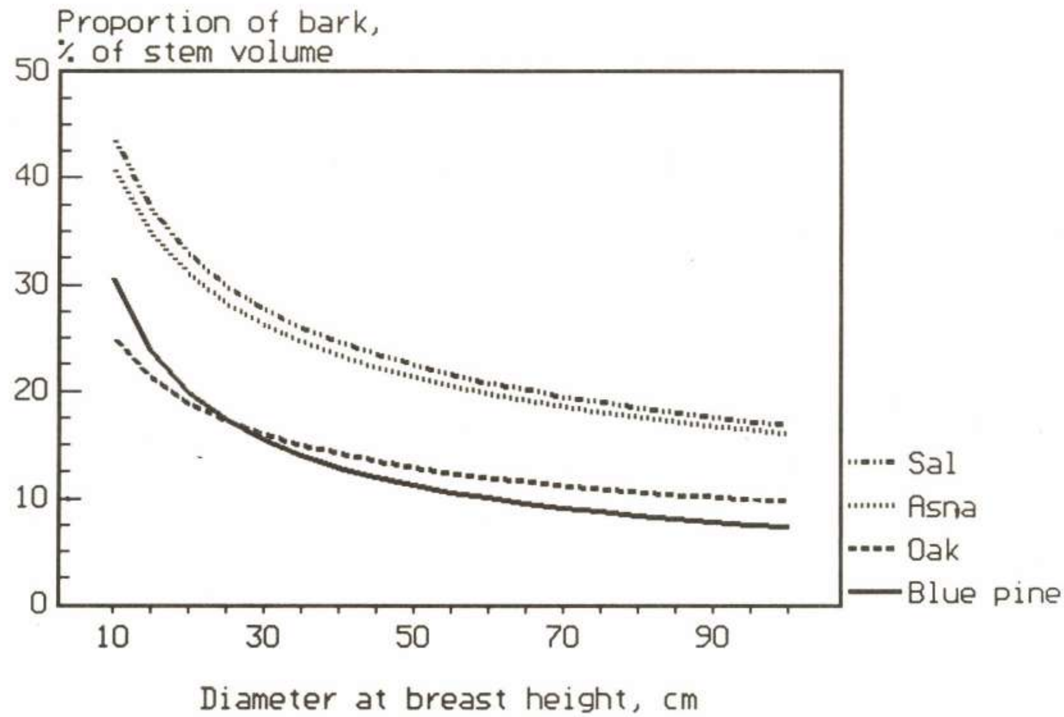


Fig. 6 – Examples of the dependence of the proportion of bark on the diameter at breast height

Species: *Shorea robusta*	
Diameter	50.0 cm
Height	35.0 m
Volume	2.86 m^3 (with bark)
Volume to 10 cm	2.19 m^3 (without bark)
Volume to 20 cm	2.08 m^3 (without bark)
Bark volume	0.64 m^3
Stem mass	2.5 tonnes (air dry)
Branch mass	870 kg (air dry)
Foliage mass	168 kg (air dry)
Total tree mass	3.6 tonnes (air dry)

Figure 7 – An example of the output of the calculation program

Species: *Shorea robusta*

ln (v) = -2.4554 + 1.9026 ln (d) + 0.8352 ln (h)

ln (top/v) = 5.2026 + -2.4788 ln (d)

ln [v(10-20 cm)/v(timber)] = 8.1560 + -2.8365 ln (d)

ln (bark/v) = 0.1372 + -0.4182 ln (d)

ln [bark(timber) / v(timber)] = 0.1448 + -0.4202 ln (d)

Density (air dry wood): 880 kg/m^3

Branch to stem & foliage to stem ratios

Diam. < 28 cm	0.3000	0.0620
Diam 28-53 cm	0.3410	0.0670
Diam > 53 cm	0.3570	0.0670

Figure 8 – An example of the parameters as displayed by the calculation program

Table 1 – Number of trees and the minimum, mean and maximum diameter of the studied species. The minimum and maximum diameter show the range over which the models are valid. The last column indicates the air-dry density of wood as assumed when converting stem volume to biomass.

		No. of trees	Diameter (cm)			Density
			Minimum	Mean	Maximum	kg/m^3
Abies pindrow	Fir	148	13.0	36.9	77.2	480
Acacia catechu	Khair	270	13.2	28.6	53.3	960
Adina cordifolia	Karma	229	13.2	48.3	121.4	670
Albizia spp.	Siris	112	15.5	42.8	119.4	673
Alnus nepalensis	Utis	163	12.7	33.5	83.6	390
Anogeissus latifolia	Banjhi	123	14.5	37.3	82.6	880
Bombax malabaricum	Semal	221	14.5	54.5	137.4	368
Cedrela toona	Toon	139	13.0	36.4	91.2	480
Dalbergia sissoo	Sissoo	266	14.0	41.4	78.0	780
Eugenia jambolana	Jamun	142	14.5	44.1	108.7	770
Hymenodictyon excelsum	Bhurkul	125	13.5	43.4	95.5	513
Lagerstroemia parviflora	Botdhainro	192	13.2	37.3	80.0	850
Michelia champaca	Champ	113	16.3	56.3	136.4	497
Pinus roxburghii	Chirpine	612	12.7	46.6	100.3	650
Pinus wallichiana	Bluepine	340	13.0	43.3	92.7	400
Quercus spp.	Oak	152	13.0	52.7	113.0	860
Schima wallichii	Chilaune	47	18.3	43.5	77.5	689
Shorea robusta	Sal	895	12.7	44.5	144.5	880
Terminalia tomentosa	Asna	492	12.7	46.0	131.1	950
Trewia nudiflora	Gutel	98	15.7	38.2	70.1	352
Tsuga spp.	Hemlock	94	13.7	48.9	117.9	450
Miscellaneous in Terai		109	14.5	51.3	114.8	
Miscellaneous in Hills		138	14.7	34.3	94.0	

Table 2 – Parameters a, b and c of the volume equations $\ln(v) = a + b\ln(d) + c\ln(h)$, where v is the total stem volume with bark. n is the number of observations, R^2 degree of determination (%), s_f residual variation around the function and $s_e\%$ the relative standard error of estimate: $s_e\% = 100[\exp(0.5\ s_f^2)-1]^{0.5}$

	a	b	c	n	R^2	s_f	$s_e\%$
Abies pindrow	-2.4453	1.7220	1.0757	148	99.2	0.10	6.9
Acacia catechu	-2.3256	1.6476	1.0552	270	96.7	0.12	8.8
Adina cordifolia	-2.5626	1.8598	0.8783	229	98.1	0.14	9.8
Albizia spp.	-2.4284	1.7609	0.9662	112	98.8	0.12	8.6
Alnus nepalensis	-2.7761	1.9006	0.9428	163	97.8	0.13	9.0
Anogeissus latifolia	-2.2720	1.7499	0.9174	123	98.6	0.11	8.1
Bombax malabaricum	-2.3865	1.7414	1.0063	221	98.9	0.11	7.8
Cedrela toona	-2.1832	1.8679	0.7569	139	97.9	0.14	9.7
Dalbergia sissoo	-2.1959	1.6567	0.9899	266	97.6	0.12	8.5
Eugenia jambolana	-2.5693	1.8816	0.8498	142	98.3	0.12	8.5
Hymenodictyon excelsum	-2.5850	1.9437	0.7902	125	98.7	0.11	8.0
Lagerstroemia parviflora	-2.3411	1.7246	0.9702	192	97.5	0.14	9.9
Michelia champaca	-2.0152	1.8555	0.7630	113	98.1	0.14	9.9
Pinus roxburghii	-2.9770	1.9235	1.0019	612	99.2	0.10	7.1
Pinus wallichiana	-2.8195	1.7250	1.1623	340	98.9	0.12	8.1
Quercus spp.	-2.3600	1.9680	0.7469	152	98.6	0.14	9.6
Schima wallichii	-2.7385	1.8155	1.0072	47	98.3	0.12	8.5
Shorea robusta	-2.4554	1.9026	0.8352	895	98.3	0.13	8.9
Terminalia tomentosa	-2.4616	1.8497	0.8800	492	98.9	0.12	8.6
Trewia nudiflora	-2.4585	1.8043	0.9220	98	97.7	0.12	8.2
Tsuga spp.	-2.5293	1.7815	1.0369	94	99.5	0.08	5.8
Miscellaneous in Terai	-2.3993	1.7836	0.9546	109	98.3	0.16	11.5
Miscellaneous in Hills	-2.3204	1.8507	0.8223	138	97.7	0.14	10.0

Table 3 – Parameters of the equations for the proportion of tree top (beyond 10 cm). The equation is: $\ln(v_1/v) = a + b\ln(d)$ where v_1 is the overbark volume of tree top and v is the total overbark stem volume.

	a	b	n	R^2	s_f	se%
Abies pindrow	5.4443	-2.6902	148	85.3	0.49	35.4
Acacia catechu	5.4401	-2.4910	270	78.3	0.39	27.8
Adina cordifolia	5.4681	-2.4398	227	76.6	0.57	41.9
Albizia spp.	4.4031	-2.2094	112	82.6	0.46	33.3
Alnus nepalensis	6.0190	-2.7271	163	78.6	0.51	37.3
Anogeissus latifolia	4.9502	-2.3353	123	85.5	0.41	29.9
Bombax malabaricum	4.5554	-2.3009	214	79.8	0.54	39.2
Cedrela toona	4.9705	-2.3436	137	81.8	0.45	32.8
Dalbergia sissoo	4.3580	-2.1559	266	72.8	0.45	32.8
Eugenia jambolana	5.1749	-2.3636	139	81.5	0.44	31.9
Hymenodictyon excelsum	5.5572	-2.4960	122	79.0	0.52	37.7
Lagerstroemia parviflora	5.3349	-2.4428	191	77.3	0.51	37.3
Michelia champaca	3.3499	-2.0161	111	74.3	0.51	37.1
Pinus roxburghii	6.2696	-2.8252	610	85.2	0.47	34.3
Pinus wallichiana	5.7216	-2.6788	340	84.8	0.50	36.2
Quercus spp.	4.8511	-2.4494	152	75.5	0.65	48.6
Schima wallichii	7.4617	-3.0676	47	86.5	0.44	31.7
Shorea robusta	5.2026	-2.4788	888	78.9	0.51	37.2
Terminalia tomentosa	4.5968	-2.2305	492	79.6	0.55	40.1
Trewia nudiflora	5.3475	-2.4774	98	69.5	0.54	39.9
Tsuga spp.	5.2774	-2.6483	94	89.5	0.41	29.9
Miscellaneous in Terai	4.8991	-2.3406	109	78.2	0.63	47.1
Miscellaneous in Hills	5.5323	-2.4815	138	79.8	0.50	36.1

Table 4 – Parameters for the equations which express the proportion of small-size timber (beyond 20 cm top diameter but thicker than 10 cm) of the total timber volume. The equation is: $\ln(v_2/v_t) = a + b\ln(d)$ where v_2 is the overbark volume of the top portion of timber (diameter 10-20 cm) and v_t is the total overbark timber volume.

	a	b	n	R^2	s_f	$s_e\%$
Abies pindrow	9.0316	-3.1527	102	62.8	0.51	48.7
Acacia catechu	8.3845	-2.8693	157	59.8	0.43	30.7
Adina cordifolia	7.6404	-2.6695	196	71.7	0.52	37.9
Albizia spp.	7.9419	-2.7343	96	85.0	0.45	32.2
Alnus nepalensis	7.8979	-2.7867	107	68.0	0.48	35.0
Anogeissus latifolia	7.7573	-2.6716	81	72.2	0.44	32.0
Bombax malabaricum	6.4019	-2.3873	192	75.0	0.52	37.9
Cedrela toona	7.3734	-2.5998	107	67.9	0.49	35.5
Dalbergia sissoo	6.8821	-2.4400	230	59.0	0.50	36.1
Eugenia jambolana	7.6807	-2.6648	122	74.2	0.51	37.0
Hymenodictyon excelsum	6.8250	-2.4603	102	69.2	0.48	35.1
Lagerstroemia parviflora	7.2637	-2.5282	145	71.0	0.43	31.0
Michelia champaca	6.7852	-2.4567	103	80.2	0.46	33.7
Pinus roxburghii	8.5662	-3.0486	529	74.6	0.53	39.1
Pinus wallichiana	8.1696	-2.8862	279	77.1	0.48	35.0
Quercus spp.	7.0779	-2.5739	132	71.8	0.55	40.1
Schima wallichii	8.5074	-2.8908	47	67.1	0.51	37.2
Shorea robusta	8.1560	-2.8365	758	74.1	0.51	37.1
Terminalia tomentosa	7.4095	-2.6093	400	79.4	0.48	35.2
Trewia nudiflora	7.4480	-2.6313	82	74.1	0.39	28.0
Tsuga spp.	7.5935	-2.7629	80	79.3	0.47	34.4
Miscellaneous in Terai	6.7548	-2.4589	88	80.4	0.45	32.6
Miscellaneous in Hills	7.0759	-2.5336	88	67.5	0.50	32.2

Table 5 – Parameters of the equations for bark proportion in the whole stem. The equation is: $\ln(p_b) = a + b\ln(d)$ where p_b is the bark proportion.

	a	b	n	R^2	s_f	se%
Abies pindrow	-0.0552	-0.4804	148	42.6	0.24	17.2
Acacia catechu	0.0368	-0.4852	194	43.7	0.17	11.7
Adina cordifolia	-0.4428	-0.2575	153	41.6	0.13	9.4
Albizia spp.	0.3809	-0.5361	61	53.0	0.21	15.0
Alnus nepalensis	-1.3593	-0.2015	163	13.8	0.18	12.8
Anogeissus latifolia	-0.2512	-0.6053	123	76.8	0.14	10.1
Bombax malabaricum	1.0876	-0.6846	122	80.6	0.15	10.4
Cedrela toona	0.3300	-0.4853	83	67.2	0.15	10.6
Dalbergia sissoo	-0.0408	-0.4218	167	28.5	0.24	16.8
Eugenia jambolana	-0.1451	-0.3617	86	25.7	0.21	15.0
Hymenodictyon excelsum	0.4405	-0.4755	76	64.9	0.15	10.3
Lagerstroemia parviflora	0.6336	-0.6531	143	66.4	0.19	13.4
Michelia champaca	-0.1672	-0.4535	78	46.8	0.20	13.9
Pinus roxburghii	1.1876	-0.7029	612	57.3	0.24	17.3
Pinus wallichiana	0.2438	-0.6214	265	68.2	0.20	14.2
Quercus spp.	-0.4146	-0.4193	152	35.4	0.26	18.8
Schima wallichii	0.9782	-0.5657	47	46.1	0.22	15.7
Shorea robusta	0.1372	-0.4182	895	58.6	0.14	9.9
Terminalia tomentosa	0.0572	-0.4114	492	56.8	0.17	12.3
Trewia nudiflora	-0.4918	-0.4689	49	56.2	0.15	10.6
Tsuga spp.	-0.2186	-0.4796	94	64.9	0.16	11.4
Miscellaneous in Terai	0.1634	-0.5581	109	40.0	0.35	25.1
Miscellaneous in Hills	-0.3878	-0.3159	138	19.9	0.25	17.9

Table 6 – Parameters of equations for the bark proportion in timber (that part of the stem which is thicker than 10 cm in diameter). The equation is: $\ln(p_b) = a + b\ln(d)$ where p_b is the bark proportion.

	a	l	n	R^2	s_f	se%
Abies pindrow	-0.0615	-0.4786	148	42.6	0.24	17.2
Acacia catechu	0.2306	-0.5530	270	50.4	0.16	11.5
Adina cordifolia	-0.1764	-0.3302	227	39.4	0.17	12.3
Albizia spp.	0.7955	-0.6634	112	72.6	0.18	13.1
Alnus nepalensis	-1.4088	-0.2123	163	14.9	0.18	12.9
Anogeissus latifolia	-0.3033	-0.5919	123	77.8	0.14	9.7
Bombax malabaricum	1.1938	-0.7262	214	81.9	0.16	11.1
Cedrela toona	0.3475	-0.4968	137	62.8	0.16	11.1
Dalbergia sissoo	-0.1498	-0.3802	223	25.5	0.22	15.9
Eugenia jambolana	0.2571	-0.4715	138	43.5	0.21	14.9
Hymenodictyon excelsum	0.4562	-0.4890	122	63.3	0.15	10.5
Lagerstroemia parviflora	0.7698	-0.7061	191	55.6	0.24	17.4
Michelia champaca	0.0244	-0.5005	111	52.6	0.20	14.5
Pinus roxburghii	1.1763	-0.6997	610	57.3	0.24	17.2
Pinus wallichiana	0.4925	-0.6517	340	51.4	0.28	19.8
Quercus spp.	-0.4224	-0.4184	152	35.3	0.26	18.3
Schima wallichii	0.8683	-0.5659	47	46.1	0.22	15.7
Shorea robusta	0.1448	-0.4202	888	59.3	0.14	9.8
Terminalia tomentosa	0.0672	-0.4154	492	58.7	0.17	12.0
Trewia nudiflora	-0.8570	-0.3503	98	38.6	0.15	10.4
Tsuga spp.	-0.2181	-0.4797	94	65.0	0.16	11.4
Miscellaneous in Terai	0.1772	-0.5617	109	40.3	0.35	25.1
Miscellaneous in Hills	-0.3796	-0.3188	138	20.0	0.25	18.0

Table 7 – Proportion of bark in big-size timber (that part of the stem which is thicker than 20 cm in diameter). The equation is: $\ln(p_b) = a + b\ln(d)$ where p_b is the bark proportion.

	a	b	n	R^2	s_f	se%
Abies pindrow	-0.8747	-0.2661	102	7.5	0.25	17.9
Acacia catechu	-0.0687	-0.4719	158	24.1	0.16	11.1
Adina cordifolia	-0.1772	-0.3322	198	32.7	0.15	10.6
Albizia spp.	0.7744	-0.6586	96	65.0	0.19	13.2
Alnus nepalensis	-1.4061	-0.2124	107	7.7	0.19	13.2
Anogeissus latifolia	-0.5284	-0.5350	81	52.7	0.14	9.6
Bombax malabaricum	1.1557	-0.7155	199	72.8	0.16	11.6
Cedrela toona	0.5925	-0.5622	109	50.8	0.15	10.6
Dalbergia sissoo	0.4042	-0.5267	230	27.2	0.21	15.1
Eugenia jambolana	0.2314	-0.4654	124	36.1	0.21	14.8
Hymenodictyon excelsum	0.3869	-0.4728	105	50.9	0.14	10.1
Lagerstroemia parviflora	0.5828	-0.6588	146	29.9	0.27	19.3
Michelia champaca	0.2137	-0.5466	105	52.6	0.20	14.1
Pinus roxburghii	1.2535	-0.7194	531	43.1	0.25	17.7
Pinus wallichiana	1.6781	-0.9544	279	55.1	0.26	18.8
Quercus spp.	0.3842	-0.6149	132	39.1	0.26	18.8
Schima wallichii	1.0878	-0.6197	39	31.2	0.23	16.4
Shorea robusta	0.1672	-0.4271	764	42.0	0.15	10.8
Terminalia tomentosa	0.1515	-0.4299	400	32.6	0.23	16.0
Trewia nudiflora	-0.6019	-0.4163	81	28.7	0.16	11.1
Tsuga spp.	-0.3266	-0.4464	80	28.3	0.24	16.9
Miscellaneous in Terai	0.5510	-0.6544	88	32.7	0.35	24.9
Miscellaneous in Hills	0.4031	-0.5321	88	27.6	0.22	15.5