

# TREE VOLUME TABLES FOR SMALL EUCALYPT ROUNDWOOD IN BANGLADESH

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## INTRODUCTION

For more than a decade species of Eucalyptus have been introduced and tested intensively by the Bangladesh Forest Research Institute in an attempt to find fast-growing species adapted to local conditions. The need for this research arose from the chronic shortage of fuelwood, posts, poles and other small roundwood in Bangladesh, a situation which is becoming rapidly worse with time.

Three species of Eucalyptus, of those so far adequately tested, have given good to spectacular growth under a range of local conditions, and seem likely to go a long way towards closing the gap between supply and demand in the future of small roundwood.

The three species are Eucalyptus camaldulensis, E. brassiana and E. tereticornis. E. camaldulensis is now being planted fairly widely. In view of the areas now being planted to these eucalypts and the necessity now to make predictions on the volume of wood being produced, volume tables were required. In this publication are presented comprehensive general volume tables for the species separately, and, for all three combined.

## COLLECTION OF DATA

Data were collected from felled trees about five-years old from two sites. Charkai and Charaljani.

Trees were felled leaving a 10 cm high stump (to allow coppicing for a further rotation) and diameters over- and under-bark were determined at 0.1 m, 0.5 m, 1 m, 1.3 m and 2 m from the ground, then at every one meter interval thereafter up the stem to the tip. The length and over- and under-bark diameter at one meter intervals were also measured on major branches. Total height from ground to tip was measured on the fallen tree. These data were sent to the Unit of Tropical Silviculture, Commonwealth Forestry Institute, Oxford, England, for computer compilation and fitting of regressions.

COMPILATION OF DATA

Total stem volumes were computed by sectional method, summing the volumes for each one-meter long billet.

In addition to the primary variables of Volume (V), Diameter at breast height (D) and total Height (H), various functions and ratios of these variables ( $D^2$ ,  $1/D$ ,  $1/D^2$ ,  $\text{Log}(V)$ ,  $\text{Log}(D)$ ,  $DH$ ,  $D^2H$ ,  $V/D^2H$ ,  $1/DH$ ,  $1/D^2H$ ,  $H/D^2$ ,  $H/D$  and  $\text{Log}(H)$ ) were derived to provide additional variables for testing in regression analyses.

COMPUTATION OF VOLUME FUNCTIONS

Fifteen regression models were tried for best fit with the different variables as follows:

1.  $V = a + bD$
2.  $V = a + bD + cD^2$
3.  $V = a + bD^2$
4.  $V = a + bD^2H$
5.  $V = a + bD^2 + cH + bD^2H$
6.  $V = a + bD^2 + cDH + bD^2H$
7.  $\ln(V) = a + b \ln(D)$
8.  $\ln(V) = a + b \ln(D) + c \ln(H)$
9.  $V/D^2 = a + b/D^2 + c/D$
10.  $V/D^2 = a + b/D$
11.  $V/D^2H = a + b/D^2H$
12.  $V/D^2H = a + b/D^2 + cH/D^2 + dH$
13.  $V/D^2H = a + b/D^2H = c/H + d/D^2$
14.  $V/D^2 = b/D^2 + cH/D + dH$
15.  $V/D^2H = a + b/D^2H + c/H + d/D$

Where V, D and H are as described above, a is the regression constant and b, c and d are regression coefficients. The logarithmic functions are to the base e (natural logarithms).

The regression models of best fit were chosen by reference to various parameters describing the regression, including the lowest furnival index and highest multiple correlation coefficient. In all cases, regression model No. 8 was best.

Volume functions were computed for:

- i) Each species separately for each of the two sites, Charkai and Charaljani.
- ii) All three species, E. camaldulensis, E. brassiana and E. tereticornis combined for each site.
- iii) Each species for combined sites, and
- iv) All species and sites combined.

These analyses gave rise to twelve separate functions. On inspection some of these fuctuions appeared to differ very little.

As an aid in deciding how many should be used, a small sub-sample of a range of diameters and heights was taken from the original data. For each of the twelve functions Table 1 shows the predicted volume for each diameter/height couplet in the sub-sample.

Using the figures from Table 1 a further table was drawn up listing, for each species/site combination, the average percentage difference that would be obtained by using one of the combined functions rather than that for the particular species/site combination (Table 2).

On inspection of the percentage differences in Table 2 it was decided that only four sets of volume tables would be sufficient to include most of the lowest values in Table 2 (marked by asterisks), namely

- i) One for each of the three species, and
- ii) A combined table for all three species with the recommendation that for each species/site combination the appropriate table to use is:

CHARKAI

<u>E. brassiana</u>	:	Combined species table
<u>E. tereticornis</u>	:	<u>E. tereticornis</u> table
<u>E. camaldulensis</u>	:	<u>E. camaldulensis</u> table

**TABLE 1 BANGLADESH EUCALYPTUS SPECIES - COMPARISON OF TWELVE SEPARATE FUNCTIONS USING A SMALL SUB-SAMPLE OF SEVENTEEN SETS OF DIAMETER AND HEIGHT**

D(CMS)	H(M)	E.BR.		E.TE.		E.CA.		ALL		E.BR.		E.TE.		E.CA.		ALL		
		CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI	CHARKAI
3.0	6.0	0.0029	0.0031	0.0029	0.0030	0.0029	0.0030	0.0029	0.0030	0.0029	0.0029	0.0028	0.0030	0.0029	0.0029	0.0029	0.0029	0.0029
5.0	6.0	0.0069	0.0070	0.0075	0.0072	0.0075	0.0072	0.0069	0.0072	0.0069	0.0065	0.0067	0.0071	0.0074	0.0074	0.0072	0.0069	0.0072
7.0	6.0	0.0128	0.0120	0.0138	0.0130	0.0138	0.0130	0.0128	0.0130	0.0125	0.0111	0.0118	0.0125	0.0118	0.0125	0.0125	0.0125	0.0129
4.0	9.0	0.0070	0.0074	0.0070	0.0071	0.0070	0.0071	0.0070	0.0071	0.0074	0.0074	0.0071	0.0073	0.0071	0.0070	0.0070	0.0071	0.0071
6.0	9.0	0.0137	0.0143	0.0146	0.0144	0.0146	0.0144	0.0137	0.0144	0.0140	0.0140	0.0140	0.0144	0.0139	0.0146	0.0146	0.0144	0.0144
8.0	9.0	0.0232	0.0227	0.0246	0.0237	0.0246	0.0237	0.0232	0.0237	0.0220	0.0220	0.0240	0.0240	0.0225	0.0245	0.0245	0.0237	0.0237
10.0	9.0	0.0354	0.0325	0.0369	0.0350	0.0369	0.0350	0.0354	0.0350	0.0313	0.0313	0.0361	0.0361	0.0327	0.0366	0.0366	0.0351	0.0351
6.0	12.0	0.0179	0.0193	0.0186	0.0187	0.0186	0.0187	0.0179	0.0187	0.0196	0.0196	0.0182	0.0182	0.0188	0.0186	0.0186	0.0188	0.0188
8.0	12.0	0.0300	0.0307	0.0313	0.0309	0.0313	0.0309	0.0300	0.0309	0.0308	0.0308	0.0304	0.0304	0.0304	0.0313	0.0313	0.0310	0.0310
10.0	12.0	0.0456	0.0439	0.0470	0.0456	0.0470	0.0456	0.0456	0.0456	0.0438	0.0438	0.0458	0.0458	0.0442	0.0469	0.0469	0.0458	0.0458
12.0	12.0	0.0646	0.0589	0.0654	0.0626	0.0654	0.0626	0.0646	0.0626	0.0584	0.0584	0.0644	0.0644	0.0600	0.0652	0.0652	0.0630	0.0630
10.0	15.0	0.0557	0.0555	0.0566	0.0559	0.0566	0.0559	0.0557	0.0559	0.0569	0.0569	0.0556	0.0556	0.0558	0.0568	0.0568	0.0564	0.0564
12.0	15.0	0.0788	0.0744	0.0789	0.0768	0.0789	0.0768	0.0788	0.0768	0.0759	0.0759	0.0781	0.0781	0.0758	0.0789	0.0789	0.0776	0.0776
14.0	15.0	0.1061	0.0954	0.1044	0.1006	0.1044	0.1006	0.1061	0.1006	0.0968	0.0968	0.1045	0.1045	0.0981	0.1042	0.1042	0.1016	0.1016
12.0	18.0	0.0930	0.0901	0.0918	0.0908	0.0918	0.0908	0.0930	0.0908	0.0940	0.0940	0.0918	0.0918	0.0917	0.0923	0.0923	0.0920	0.0920
14.0	18.0	0.1252	0.1155	0.1215	0.1188	0.1215	0.1188	0.1252	0.1188	0.1198	0.1198	0.1228	0.1228	0.1187	0.1219	0.1219	0.1204	0.1204
16.0	18.0	0.1624	0.1432	0.1549	0.1500	0.1549	0.1500	0.1624	0.1500	0.1479	0.1479	0.1583	0.1583	0.1484	0.1552	0.1552	0.1521	0.1521
Totals		0.8820	0.8266	0.8785	0.8547	0.8785	0.8547	0.8820	0.8547	0.8397	0.8397	0.8775	0.8775	0.8401	0.8787	0.8787	0.8628	0.8628

**TABLE 2 AVERAGE PERCENTAGE DIFFERENCE THAT WOULD BE OBTAINED BY USING ONE OF THE COMBINED FUNCTIONS RATHER THAN THAT FOR THE PARTICULAR SPECIES/SITE COMBINATION**

Species/site combination	CHARKAI		CHARALJANI			
	<u>E. brassiana</u>	<u>E. tereticornis</u>	<u>E. camaldulensis</u>	<u>E. brassiana</u>	<u>E. tereticornis</u>	<u>E. camaldulensis</u>
All species and sites combined	- 2.2*	+ 4.4	- 1.8	+ 2.8	- 2.4*	- 0.8*
Species combined for both sites	- 4.8	+ 2.6*	0.0*	0.0*	- 3.3	- 0.6*
Species combined at each site	- 3.1	+ 3.4	- 2.7	+ 3.6	- 1.6*	- 1.6

\*lowest values

CHARALJANI


- E. brassiana : E. brassiana table
- E. tereticornis : Combined species table
- E. camaldulensis : Either E. camaldulensis or combined species table

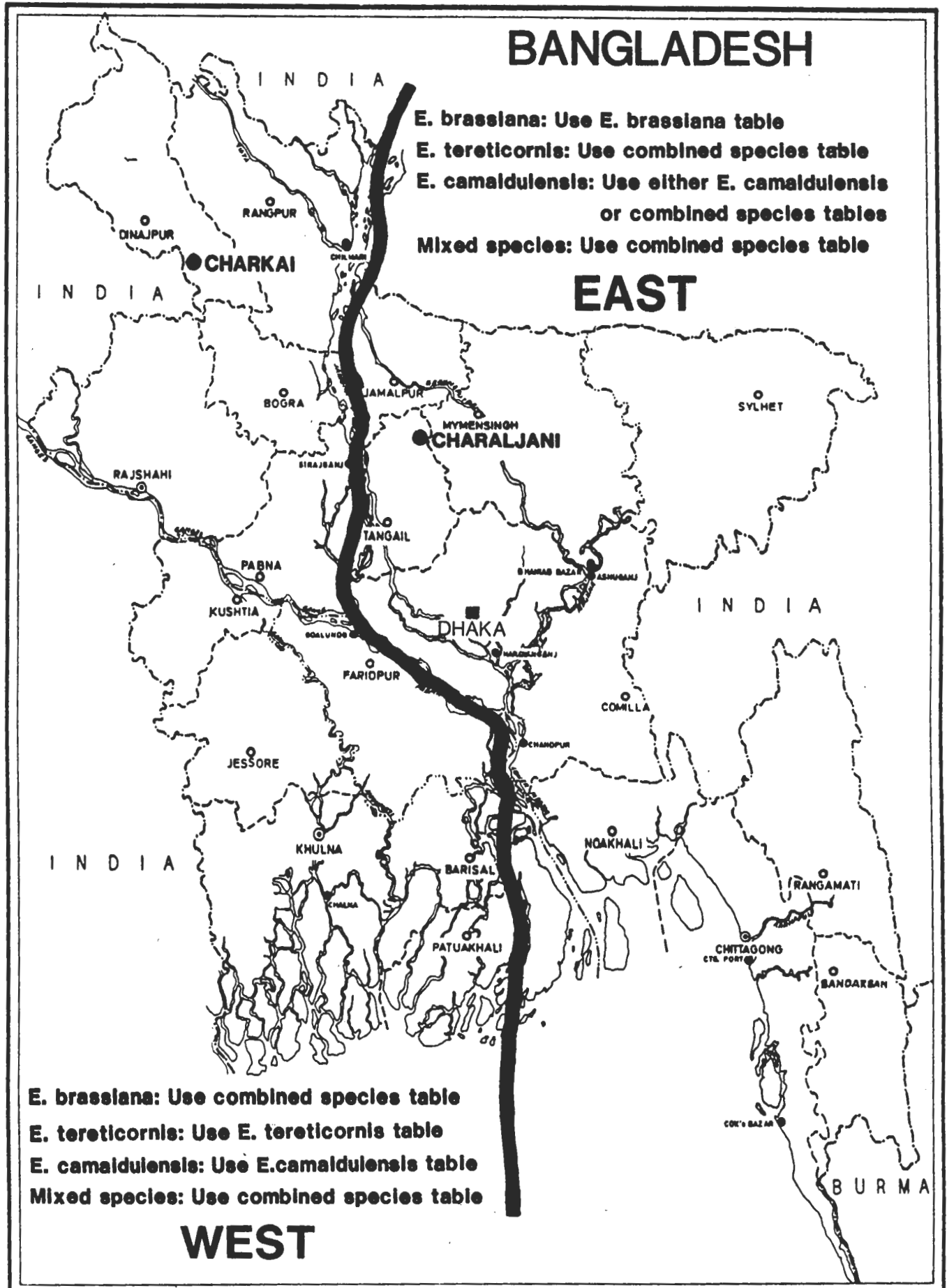
For the time being, these two sites, Charkai and Charaljani, can be considered "poor" and "good" sites respectively and taken to be broadly representative of growth and stemform of Eucalyptus in western and eastern parts of Bangladesh. Therefore the appropriate volume table to use is indicated by the map (Fig. 1).

STAND TABLES

For the all-species-combined function a total of 954 trees was included, with diameter and height class distributions as shown in Table 3.

A total of 164 trees was used for the E. brassiana species function (Table 4). Another 279 trees were included for the E. tereticornis species function (Table 5) and 511 trees for the E. camaldulensis species function (Table 6). Since all the computer generated volume tables have the same format, in several tables some or many of the values shown will be well outside the range of the original data set.

Extrapolation in the volume tables much outside the range of height and diameter shown in the appropriate stand table should only be done with caution. These limits have been marked approximately on each table by a dotted line and a tick mark (  ) indicates which part of the table is within these limits.



**FIGURE 1 MAP SHOWING WHICH VOLUME TABLES TO USE IN THE EASTERN OR WESTERN PARTS OF THE COUNTRY**







TABLE 5 BANGLADESH EUCALYPTUS CAMALDULENSIS - STAND TABLE

DIAMETER	HEIGHT CLASSES														TOTAL
	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	GT20.3	0	
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.0	0	3	17	5	0	0	0	0	0	0	0	0	0	0	25
4.0	0	2	24	43	6	0	0	0	0	0	0	0	0	0	75
5.0	0	1	5	43	35	7	0	0	0	0	0	0	0	0	91
6.0	0	0	2	21	31	18	4	1	1	1	0	0	0	0	77
7.0	0	0	0	2	24	26	10	6	7	0	0	0	0	0	58
8.0	0	0	0	0	4	10	6	19	16	0	0	0	0	0	40
9.0	0	0	0	0	1	6	12	12	12	2	0	0	0	0	38
10.0	0	0	0	0	0	2	0	4	12	2	12	2	0	0	32
11.0	0	0	0	0	0	0	0	0	5	3	12	3	0	0	20
12.0	0	0	0	0	0	0	0	0	3	4	9	4	0	0	16
13.0	0	0	1	0	1	0	0	2	2	8	7	8	1	0	22
14.0	0	0	0	0	0	0	0	2	2	5	2	5	0	0	12
15.0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
16.0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1
17.0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1
18.0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
19.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT 21.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	6	49	114	102	69	47	48	46	26	4	0	0	0	511

TABLE 6 BANGLADESH EUCALYPTUS TERETICORNIS - STAND TABLE

DIAMETER	HEIGHT CLASSES														TOTAL	
	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.5	GT20.3	0		
2.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.0	0	7	9	2	0	0	0	0	0	0	0	0	0	0	0	18
4.0	0	0	19	12	4	0	0	0	0	0	0	0	0	0	0	35
5.0	0	0	12	20	11	0	0	0	0	0	0	0	0	0	0	43
6.0	0	0	3	12	15	6	2	0	0	0	0	0	0	0	0	38
7.0	0	0	0	4	16	18	4	1	0	0	0	0	0	0	0	39
8.0	0	0	0	2	8	15	2	0	0	0	0	0	0	0	0	34
9.0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	17
10.0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	18
11.0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	14
12.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11
13.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7
14.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
15.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
17.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
GT 21.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	0	7	43	52	55	46	35	19	15	6	1	0	0	0	279	

CONFIDENCE LIMITS

Confidence limits at the 95% level have been provided for the total volume over bark tables only; these limits do not apply to individual trees but to all trees of the particular diameter and height. These volume tables should not be used to determine volumes of individual trees in a stand. The mean height and diameter of the stand should be calculated first, then the means found in the table in order to derive the mean tree volume, which would be multiplied by the number of stems/ha to arrive at volume/ha.

THE VOLUME FUNCTIONS

The four volume functions selected are as follows:

All species combined:

$$\ln V = -9.4209 + 1.7480 \cdot \ln D + 0.9310 \cdot \ln H$$

where

V is total volume over bark in cu. m.

D is diameter at breast height in cm.

H is total height in m.

\* means the product of

and all logarithms are to the base e.

A total of 954 trees was used; the regression accounted for 98.4% of the variation (R-squared value of 0.984).

Eucalyptus brassiana:

$$\ln V = -9.5783 + 1.6783 \cdot \ln D + 1.0483 \cdot \ln H$$

based on 164 trees with an R-squared of 0.985.

Eucalyptus tereticornis:

$$\ln V = -9.4264 + 1.6850 \cdot \ln D + 0.9840 \cdot \ln H$$

based on 279 trees with an R-squared of 0.981.

Eucalyptus camaldulensis:

$$\ln V = -9.3520 + 1.8055 \cdot \ln D + 0.8590 \cdot \ln H$$

based on 511 trees with an R-squared of 0.986

CONVERSION FACTORS

Conversion factors (F) were computed to be applied to total volume overbark for deriving total volume underbark and volume to various top-end-diameter limits. All the conversion factors apply to all species and sites since very little difference was found between the various combinations. A table of conversion factors has been included (Table 7). All factors are predicted from diameter (D).

Underbark/overbark

$$F = 0.6416 + 0.019286*D - 0.0006263*D*D$$

to a maximum diameter of 15 cm, after which a constant factor of 0.790 is used.

5 cm top diameter

$$F = 0.9723 (1.0 - e^{**(-0.6557*D)})^{**24.203}$$

where

e is the base of natural logarithms = 2.7183

\*\* means raised to the power of

\* means the product of.

This is a nonlinear function which is asymptotic, reaching a maximum value of 0.9723.

10 cm top diameter

$$F = 0.9151 (1.0 - e^{**(-0.4043*D)})^{**72.101}$$

15 cm diameter

$$F = -1.6656 + 0.1618*D - 0.002452*D*D$$

This was based on very few trees (<30) most of which were E. camaldulensis.

VOLUME TABLES

There are eight tables in each set - total, 5 cm, 10 cm and 15 cm volumes both over- and underbark (overbark first, followed by underbark). Four sets are given, in the following order: general volume tables (all species), E. brassiana, E. camaldulensis and, finally, E. tereticornis. A guide for using tables such as these was presented in Choudhury and Davidson (1984).

TABLE 7 BANGLADESH EUCALYPTUS SPECIES - CONVERSION FACTORS

DIAMETER	ub/ob	5cm	10cm	15cm
3.0	0.694			
4.0	0.709	0.157		
5.0	0.722	0.384		
6.0	0.735	0.603		
7.0	0.746	0.759		
8.0	0.756	0.856	0.051	
9.0	0.764	0.910	0.134	
10.0	0.772	0.939	0.255	
11.0	0.778	0.955	0.391	
12.0	0.783	0.963	0.520	
13.0	0.786	0.968	0.628	0.023
14.0	0.789	0.970	0.712	0.119
15.0	0.790	0.971	0.774	0.210
16.0	0.790	0.972	0.818	0.295
17.0	0.790	0.972	0.849	0.376
18.0	0.790	0.972	0.871	0.452
19.0	0.790	0.972	0.885	0.523
20.0	0.790	0.972	0.895	0.590
21.0	0.790	0.972	0.902	0.651
22.0	0.790	0.972	0.906	0.707
23.0	0.790	0.972	0.909	0.759
24.0	0.790	0.972	0.911	0.805
25.0	0.790	0.972	0.912	0.847

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REFERENCE

CHOUDHURY, J.H. and DAVIDSON, J. (eds) (1984) Tree Volume Tables for Four Species Grown in Plantations in Bangladesh. Bangladesh Forest Research Institute, Inventory Division, Bulletin No. 2. 150pp.